CASE STUDIES – A TOOL FOR LEARNING

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Abstract: *The Canadian Engineering Accreditation Board requires broadly-based undergraduate programs that develop technical awareness, motivation, confidence, teamwork and life-long learning. These objectives can be reached in both undergraduate and postgraduate courses using projects based on case studies. The projects use published data and records of performance that students can reproduce using modern design tools and numerical analysis. The paper includes examples of projects in the subject area of geotechnical engineering. Case studies are becoming increasingly valuable as employers and licensing authorities move toward a combination of broadly-based undergraduate education and more specialized postgraduate or in-practice training.*

Keywords: Problem-based learning, project-based learning, case study projects, teamwork, confidence.

1. EDUCATION, LICENSING AND TRAINING

The Canadian Engineering Accreditation Board (CEAB) requires undergraduate programs to provide a broad approach to the nature and scope of professional engineering [20]. It directs close attention to *what is being learned* and less attention to *what is being taught*. Compared with earlier programs, graduates from recent programs have a better awareness of the ways engineers rationalize problems on behalf of their clients and produce solutions. This is good.

The CEAB requires modern programs to provide:

1. ability to integrate and apply fundamentals of mathematics and science with technical skills,
2. improved skills in critical thinking, problem solving, and communication
3. competence in applying technology for effective analysis, design, and communication,
4. opportunities to participate in effective teams
5. motivation for self-responsibility, life-long learning, and self-development

All of these are important and valuable objectives in a modern integrated program of fundamental mathematics, science, and engineering [5].

Of necessity, the shift in emphasis toward increased professionalism in four-year undergraduate programs

means teaching fewer of the technical skills that employers want for specialization in many branches of engineering practice. This has been recognized internationally through the so-called Washington and Bologna Accords, which suggest a three-stage approach for licensing professional engineers. These are (1) a fairly broad initial approach like that required by the CEAB, which involves *engineering education* in first-degree programs, (2) more specialized *training* in subsequent postgraduate programs (or equivalent), and (3) *directed experience* in practice [12]. With this framework, it will be imperative to produce four-year undergraduate programs that students can reasonably expect to complete in four years.

Employers are concerned that Canada's apparently slow adoption of the three-stage approach will reduce their abilities to compete for international projects. Accreditation, education, training, specialization, and licensing are dealt with more fully in an accompanying paper by J.Graham and M.Alfaro to this conference.

Employers know that graduates from current engineering programs generally understand fundamental engineering science quite well and are computer literate. However, they are less competent – or confident – which is perhaps more important – 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 following sections examine ways of developing better technical, learning, and professional skills.

2. PROBLEM-BASED LEARNING

Medical education commonly uses an approach known as *Problem-Based Learning* (PBL). Because of its early adoption in McMaster University in Hamilton ON, it is sometimes known as the McMaster Model, even though in its modern form, it seems to have originated in the Harvard School of Business.

Instead of the standard building-block structure that feeds lots of content to students, PBL adopts a system in which students are actively involved in the learning process. Graduates of PBL programs have a good

understanding of professional behaviour, including access to available resources and keeping up-to-date with current literature. The model requires increased expenditure of resources and time, both by the students and by the institution.

While problem-based learning is now widely used in medicine, it may not always produce the desired levels of content-specific knowledge or problem-solving skills in other disciplines [7]. In medicine, licensing depends on postgraduate programs that follow traditional undergraduate programs in basic sciences. In contrast, licensing in engineering is based on accredited undergraduate programs in which topics need to be learned in a defined order [10]. Engineering programs must also include the broadly based professional skills – as opposed to technical skills – that were outlined earlier.

3. PROJECT-BASED LEARNING IN ENGINEERING

Physicians and engineers solve problems differently. Physicians tend to deal individually with problems that can be solved relatively quickly, often with the help of supporting technologists or professionals. In contrast, most problems in engineering are multi-disciplinary and relate to fundamental theories and techniques. ‘Projects’ as they are most often called, involve teams of professionals with a wide range of specializations. They require days or months of work by teams of engineers, rather than the minutes or hours that physicians (mostly) spend solving patients’ problems [10].

This difference between the two professions means that *problem-based learning*, which is common in medicine, has been replaced in engineering by *project-based learning*, which emphasizes the breadth and team-working aspects of engineering professionalism. Project-based learning is more directed toward the *application* of previously acquired knowledge, whereas problem-based learning is directed toward *acquisition* of knowledge. They both are multidisciplinary and both rely on self-direction, time management, collaboration, and avoidance of duplication. Projects generally require groups of students to work with teachers who act as advisers and consultants rather than formal instructors [4].

A hybrid approach appears preferable in engineering. ‘Mixed-mode’ programs require a combination of traditionally taught courses and courses with project-based components that increase in extent, complexity, and student autonomy in later years. Blending these two approaches appears to be the best way to satisfy industry's needs for independent self-learning without sacrificing knowledge of engineering fundamentals. Blended programs have been welcomed by students, accreditation organizations, and industry.

4. PROJECT-BASED LEARNING IN GEOTECHNICAL COURSES

Many academics already use projects 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. Following sections describe our experiences in teaching geotechnical engineering.

4.1 Introductory soils testing

The laboratory component of our introductory course Geotechnical Materials and Analysis does not simply teach technicians’ skills. While it does include (largely) hands-on experience in classification, oedometer, direct shear, and undrained triaxial tests, its emphasis is different. The tests are performed in the context of small simplified design projects that need the test results. Students perform the tests under supervision, analyse the test data, and then use the results in simple analyses taught in accompanying lectures

For example, results of Atterberg and hydrometer tests are incorporated into recommendations about the suitability of samples for the core of an earth dam. Oedometer tests provide information that are used in simple 1-D calculations of settlements of an oil tank. ‘Quick’ undrained (U-U) tests provide shear strengths that are used in ‘ $\phi_u = 0$ ’ analysis of a cut slope in clay. Instruction in laboratory procedures is given through a combination of notes and guidance by the professor, teaching assistants, and the laboratory technician.

4.2 Geotechnical Design

Our subsequent senior-level course uses analytical tools learned in the previous course and applies 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 previously-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 information, and consolidation and strength data at each of the piers for a site with rather variable soil and bedrock conditions. In the first phase of the project, they are simply asked to

prepare a site evaluation report on the soil, rock, and groundwater conditions, and how these will affect construction decisions. In parallel with later lectures, further parts of the project 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 environment, students take control of the technical content of what they need to learn. They also learn to manage their time and resources to meet the required completion date. The role of 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 our courses, most 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.

4.3 Case study projects

Students often comment that they have been taught design skills but lack confidence and judgment in their application. Readiness for practice can be improved considerably by extending *project-based learning* toward the approach 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 projects. It becomes the principal topic for the remainder of this paper.

Geotechnical publications like the Canadian Geotechnical Journal report many successful, and perhaps more importantly, unsuccessful projects in considerable detail. Using these reports, case study projects can ask teams of students to verify the original design values and compare them with the performance measured after construction. The projects involve reassessing the assumptions made by the original designers and recalculating the analyses made during the original design.

A report that can be used for a case studies project will 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 will allow 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.

Students can, in several weeks and in parallel with 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.

5. EXAMPLES OF CASE STUDY PROJECTS

The three following projects are examples of the many we use in elective undergraduate courses and postgraduate courses. The examples are from geotechnical engineering, but the process can be readily adapted for other subject areas. 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 describe the projects and indicate our students' ability to produce results close to those in the original publications. Other projects used by our colleagues at the University of Manitoba study sand or wick drains used 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 following examples.

Table 1. Typical instructions for a case study project.

You have been given a cross-section of an 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.

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 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).

5.1 Stability of the Shellmouth Dam Test Fill

Rivard and Lu [11] described a series of dikes and other structures on Lake Agassiz clay, which is moderately-to-highly plastic, postglacial, swelling clay [3]. Fissures (and often slickensides) are frequent in the clay, especially in lower layers above water-laid or basal till.

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 [11] 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

Fig.1. Cross-section of Shellmouth Dam test fill.

Peak strength $c' = 12.4 \text{ kPa}$ $\phi' = 25.8^\circ$;
post-peak strength $c' = 0$, $\phi' = 25.8^\circ$.

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 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. Students 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

Fig.2. Stability analysis of Shellmouth Dam test fill.**Table 2.** Comparison of original Rivard and Lu [11] calculations with recent student case studies project, Bishop’s method.

	Rivard and Lu [11]	Student values
Peak strengths	1.29	1.31
Post-peak strengths	1.08	1.12

values. Typically their 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.

5.2 Failure of Transcona Grain Elevator, 1913

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 Skaffeld [1] showed the foundation clay was overconsolidated near the ground surface and almost normally consolidated near the bottom of the deposit. Plate loading tests and smaller

Fig.3. Transcona grain elevator after failure, 1913.

Fig.4. Cross section redrawn from Blatz and Skaffeld [1].

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 Skaffeld 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 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 Skaffeld [1] showed that the maximum pore water pressure is 260kPa at an 'elevation' of 2.0m in the figure, 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 were fed into SLOPE-W in the way suggested by Krahn [6], a defined failure surface analysis produced a safety factor of 1.08. This compares

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

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

Fig.7. Simulated vertical displacements (settlements).

reasonably with the 0.95 produced by Blatz and Skaffeld [1] using effective stresses, and 1.01 from a total stress bearing capacity solution.

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

5.3 La Grande 4 (LG4) Dam, Québec

The LG4 rockfill dam in northern Québec (Figure 8) has maximum height 125m, length 3800m and volume of $19 \times 10^6 \text{ m}^3$. 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) has been used as a case study project on seepage analysis and slope stability. Postgraduate students are given hydraulic conductivities from the original publications and asked to calculate:

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

Table 3 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 becomes much too large. This makes a considerable difference to seepage quantities, pore water pressures, and

therefore to the factor of safety. It is not possible to take unsaturated flow into account using sketched flow nets.

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 from the original values by +5.8, +4.3, and -16.5 percent respectively.

Plane strain analysis of the cross section does not take account of the steep bedrock in the valley. This important geological constraint provides a valuable topic for

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

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

Table 3. Comparison of published and student's values.

Parameter	Paré et al. [8][9]	Student 1	Student 2
Seepage, $\text{m}^3/\text{day}/\text{m}$	-	1.69	1.69
PWP at PO-1, kPa	200.7	201.3	200.8
Safety factor	-	1.87	1.87

Fig.10. Total heads - metres.

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

discussion between students and advisor on the topic of 2-D *versus* 3-D numerical modeling.

6. CONCLUDING COMMENTS

It is important that university programs concentrate on professional engineering and not on teaching simple technologies. Our paper outlines a learning approach that improves students' motivation and confidence.

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) formulating a client's problem, b) appreciating the range of technical, social, environmental, financial, and scheduling issues that will control the project, and c) working toward a timely, effective, and economic solution that is appropriate to the risk involved. Particularly important in providing this understanding are an awareness of other people's points 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.

Many components of the process of design – as distinct from technical skills – can be learned in teams working on published case studies.

Students study a published report 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, perform a new set of calculations, and compare the results with the original calculations and field measurements. In the process, students 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 has been positive. Although students are often intimidated when they begin a project, they rapidly 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 a different name, namely *case studies projects*.

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