Dunmore Bridge Case Study: An introduction to Geotechnical Engineering via Finite Element Analysis

A.J. Abbo & S.G. Fityus
School of Engineering, University of Newcastle, Callaghan, Australia

S. Mackenzie
Coffey Geotechnics, Warabrook, Australia

ABSTRACT: This paper describes the development of a case study based upon the preliminary design of a working platform to support a 1200T crane during the replacement of bridge spans on the historic Dunmore Bridge (Woodville, NSW, Australia). The case study was developed to enrich the teaching of finite element methods to undergraduate students by exposing students to practical aspects of finite element modelling and the use of commercial finite element software. The nature of the project permitted geotechnical engineering topics to be incorporated into the case study and introduced students to CPT testing and interpretation, importance of working platforms and realistic soil profiles.

The Dunmore Bridge project was selected for the case study as it has many interesting aspects that are topical, interesting and motivational to the students. Historic records of the bridge construction are available and being a local bridge, the site can readily be visited by students. As the upgrade of the Dunmore Bridge is scheduled to occur within the next 18 months the project is topical and will be covered by the local media. The project is being recorded using time-lapse photography which will provide an additional multi-media resource for use in refinement of the case study. Feedback from students on the case study and how it helped motivate student learning was obtained via an anonymous online discussion forum.

Finite element, geotechnical engineering, engineering education, case study

1 INTRODUCTION

The use of real world examples has been identified by engineering students as a key attribute of a good engineering lecturer (Collins, 2009). Case studies play an important role in engineering education by exposing students to real world examples (Raju and Sankar, 1999) and to situations and challenges that would not typically be encountered in classroom activities (Akili, 2007). In doing so, they provide relevance through the context of a real project, motivation for students to engage, interaction to enhance learning, integration of existing knowledge and the development of communication skills (Akili, 2007). They also provide a means for the development of key skills and attributes such as teamwork, communication and problem solving (Davis and Wilcock 2003). Case studies also improve the motivation and engagement of students in learning (Mustoe and Croft 1999).

In the teaching of geotechnical engineering, the use of case studies provides the means by which students can be exposed to the complexities of practical examples beyond the artificial world of infinite half spaces and homogenous and isotropic soil, typically used to drill undergraduate students in the fundamentals of soil behaviour. Indeed, the development of case studies in conjunction with adjunct faculty members or practicing geotechnical engineers (Akili 2005) provides a means to bring the skills and perspective of engineering practice into the classroom and expose students to more of the practice of geotechnical engineering.

The use of real world examples, or at least more realistic problems, is becoming important in the teaching of finite element methods. Traditional finite element courses focus on the theory behind the methods which are often reinforced with computer programming to implement and apply the methods to simple problems. Indeed, this is the approach taken in many elementary text books of the methods (e.g. Smith and Griffiths, 2004). Such approaches, as recently advocated by Kosasih (2010) who used computer programming to compliment the use of commercial software packages, are still valuable, providing students with insight into finite element techniques. However, finite element courses, and their teaching, are being transformed by the availability of high powered commercial finite element software with easy to use graphical interfaces. The use of programming to develop a depth of understanding of finite element methods is being replaced with courses that teach the application of software with emphasis on finite element modeling.

Real world examples, or at least realistic examples, may also be introduced within a course through project or problem based learning methodologies. The use of problem based learning methodologies has also been adopted in the teaching of finite element methods. Zhuge and Mills (2009) redesigned a finite element course to utilize problem based learning methodologies in the context of structural engineering projects. Miner (2000) utilized a realistic project for the design of a bracket on an aircraft to educate mechanical engineering students.

In this paper we describe the development of a geotechnical engineering case study within an undergraduate course on finite element methods. In the context of the finite element course the primary objective of introducing a case study is to improve motivation of students and to better engage students in learning. The case study is intended to compliment the soil mechanics and geotechnical engineering strands of their degree by requiring students to employ knowledge from prior courses, gain an appreciation of the practice of geotechnical engineering and to prepare students for the capstone geotechnical engineering course. Motivated by Zhuge and Mills (2009), who restructured a similar course at the University of South Australia through the use of structural engineering examples, a case study has been developed based upon a geotechnical engineering project.

2 BACKGROUND

In the third year of the Civil engineering degree at the University of Newcastle students are required to undertake a course on finite element methods. The course focuses on the fundamentals of the finite element method including shape functions, numerical integration, linear algebra, formulation of elements (truss, beam and continuum), solution of large systems of equations and how these are used within the framework of displacement based finite element techniques. While students are not required to perform any computer programming, the course is presented in the context of how the methods are implemented in order to illustrate to students the power of the finite element method.

Feedback from students on the finite element course, through various student surveys, has generally indicated some students struggle with the mathematics and formulations that form the basis of lectures. Suggestions offered by students in the survey, on how the course could be improved, often included better use of examples, such as:

> *"The course content can be very dry, providing more real life examples and case studies throughout would be appreciated."*

Other feedback from students, via surveys and casual conversations with the lecturer, reveals a perception that much of the course it of little relevance to some civil engineers, particularly to those students already planning a career outside of the design office. A consequence of this is that there appears to be an increasing focus by many students on learning how to answer assessment items, rather than gaining a deep understanding and appreciation of finite elements. Particularly alarming were comments by one student who wrote in an evaluation of the course:

> *"I would suggest more relevant examples based on the assignment content"..."Working through examples that are relevant to assessment items would be more appropriate to the learning process. ..."*

This student has little motivation other than to pass the course and, as a result, has committed to superficial learning to achieve this. To motivate an increasing number of such students with similar perceptions, there is a need to challenge and motivate students, and to better engage students in higher levels of learning.

The courses in the geotechnical engineering strand of the Civil Engineering degree follow a traditional structure with the fundamentals of soil mechanics taught in the second and third years of the degree program. These are followed in the final year, by a geotechnical engineering course, undertaken by students in the first semester, followed by a capstone geotechnical design course in the second semester. Anecdotal evidence suggests that a there is an increasing number of students that struggle with the capstone course as it is the first time they are exposed to real-life, open-ended geotechnical engineering problem, based on actual soil conditions and site constraints.

The development of a case study for the finite element course provided an opportunity to introduce students to aspects of geotechnical engineering projects prior to them undertaking any courses in this area. As the geotechnical engineering content is not a core component of the course, it is introduced only in the context of describing the case study and developing the problem to be analysed by students using the finite element software. This also allows the information to be introduced quite informally, as more of a discussion with the class, and in doing so providing students with a break from the finite element content.

Figure 1. Dunmore Bridge at Woodville.

3 DUNMORE BRIDGE PROJECT

The historic Dunmore Bridge (Figure 1) crosses over the Patterson River at Woodville NSW, Australia. Constructed late in the 19th century, the bridge is of significant heritage value as it is one of three surviving overhead braced timber truss road bridges in NSW (NSW Office of Environment and Heritage, Heritage Database). An unusual feature of the bridge, and of further heritage significance, is a steel truss lifting span (17.8m) that enabled river traffic to pass beneath the bridge. Known as an Allan truss bridge, its significance is described in various publications and reports of NSW Government departments (NSW Roads and Traffic Authority, Office of Environment and Heritage) on timber bridges in NSW as

> *"Allan trusses were the first truly scientifically engineered timber truss bridges, and incorporate American design ideas for the first time. This is a reflection of the changing mindset of the NSW people, who were slowly accepting that American ideas could be as good as or better than European ones. The high quality and low cost of the Allan truss design entrenched the dominance of timber truss bridges for NSW roads for the next 30 years."*

Dunmore Bridge, which still carries traffic, features three timber Allan truss sections that span approximately 34m each. Named after the designer, Percy Allan (a senior engineer in the Public Works Department) the Allan Truss bridges represented significant advancement on the previous McDonald truss design as Allan Truss bridges could carry 50% more load and, as it was constructed from mainly local materials, it was 20% cheaper to construct (MBK, 1998).

Planning for the upgrade of the Dunmore Bridge is underway with major site works expected to commence sometime in 2012. A significant component of the upgrade, which will increase the structural capacity of the bridge and reduce maintenance, involves the replacement the three Allan truss spans. To minimise the disruption to the community, it is proposed to only close the bridge to traffic for a period of up to 4 weeks. To prepare for this period of intense activity the new truss spans, each weighting approximately 125 tonnes, will be manufactured offsite and assembled on-site adjacent to the bridge. The replacement of the truss spans will then involve using a very large crane to remove each bridge span in a single lift, complete with the deck and other fittings. The replacement span would then be lifted by the crane from where it was assembled on the bank of the river into position on the bridge.

So that the construction works can be conducted from just one bank of the river, a preferred option for the removal of the existing structure and the erection of new bridge spans was the use of a Lampson LTL-1100 crawler crane, one of the largest cranes currently available on the east coast of Australia. The LTL-1100 consists of two crawler modules; the front crawler module supports the boom, with a counterweight carried by the rear module. The peak load to be carried by the crawler modules is approximately 1050 tonnes which, for the rear crawler unit, is mostly due to the 900 tonne counterweight required to lift the truss across the river at a lifting radius of approximately 80m.

The Dunmore Bridge upgrade is a project with a lot of community interest. It is expected that the project will be covered widely by the local media, not only due to the interruptions it will cause to the local community during the works, but because of the historic nature of the bridge and the large scale of the works. The bridge works are being continuously recorded by a camera located on a nearby structure with the expectation that a time lapse movie will be produced showing the entire construction project. These aspects also make the project topical and interesting to undergraduate engineers, confirming it as an excellent project on which to base a case study that will engage and motivate students.

4 DUNMORE BRIDGE CASE STUDY

The case study described in this paper is based on the preliminary geotechnical design of a working platform on the banks of the Patterson River. The platform is to support a Lampson LTL-1100 crawler crane to be deployed for the upgrade of the Dunmore Bridge. The subsurface conditions at the site consist of deep layers of alluvial soils which are underlain by conglomerate rock at depths of up to 30m.

The case study provides a basis for instructing students in the use of commercial finite element software for computer laboratories in a third year undergraduate course on finite element methods. The case study has two primary objectives; to provide a more realistic setting to instruct students in finite element modeling and to expose undergraduate students to the practice of geotechnical engineering.

Teaching of the course is conducted over a 12 week period with a typical week consisting of a one hour lecture followed by a one hour tutorial. In recent years computer laboratories were introduced to provide students with practical skills in the use of commercial finite element software. Due to resourcing issues, a total of only nine 1 hour computer laboratory classes can be scheduled. To accommodate this students are split into 3 groups with each group scheduled to attend a computer lab on a three weekly roster.

The case study is introduced within lectures providing students with a break from the theoretical content of the course. Initially, the Dunmore Bridge project is described to students and the proposed construction methodology explained. The use of the large crane provides an opportunity to discuss with the class what problems might confront a large crane operating on alluvial soils adjacent to a river, the need for a working platform, and the importance of the design in achieving a safe platform. The message is delivered to students though images showing the consequences of failed working platforms. Resources that were readily available from the internet were used, including:

- Images in the presentation on Safe Working Platform by the Federation of Piling Specialists (UK) or Piling and Foundation Specialist Federation (Australia).
- Video of the Waikato Crane accident in which a crane toppled into a river due to failure of the working platform.
- Video of the collapse of a crawler crane, during construction of Brewer's Ball Park Stadium, Milwaukee in 1999.

In the second lecture the case study discussion guides students through the role of desktop studies, geotechnical site investigations and in situ testing. This begins by asking students how much we can discover about the geotechnical conditions at the site before doing any field investigation, or even visiting the site. This leads to a consideration of resources such as Google Earth, regional geology maps, reports from previous investigations on nearby, or even the same sites and books and papers on the local geology. In this case, historic drawings from the construction of the bridge were provided by the NSW Roads and Traffic Authority (RTA). These drawing, an extract of which is shown in Figure 2, include logs showing the soils encountered during the construction of the bridge and the depth at which rock was encountered at the site.

This second lecture also introduces students to various methods of site investigation used in the project. Particular emphasis is given to describing CPT testing and how the results of such tests are used by engineers to interpret the subsoil conditions at a site and to obtain parameters for modeling the soil. A CPT probe is handed around the class for students to gain a better appreciation of the methods.

The students then undertake the three computer laboratory classes, which are spaced three weeks apart. The purpose of the first computer class is for students to learn to use the Plaxis finite element software. Under the guidance of a tutor, students follow a simple tutorial provided with the software: there is no reference made to the case study. To become more familiar with the software and to prepare students for the next computer class, students are asked to follow through additional tutorials from the Plaxis manual in their own time.

In the remaining two computing classes, a finite element model to determine the stability of the crawler crane on the banks of the river is developed. This begins by providing students with a spreadsheet containing representative results from CPT testing at the site. Students are required to use a correlation to determine undrained shear strengths and then use these to develop a simple geotechnical model for the site which consists of up five to six geotechnical units with a problematic soft clay layer present near the water table.

Survey data for the site is also provided to students allowing them to build a simple two dimensional finite element model. This includes the addition of a layer of fill to provide a hardstand for the operation of the crane. A significant problem to be addressed by the students is the modeling of the crane loads and how to adequately represent them in a two dimensional finite element model.

Students then use this model to perform a finite element analysis to assess the stability of the natural site and the stability the crane situated adjacent to the river bank. For the natural site, a factor of safety above one is required to verify that the finite model adequately represents the current state of the site. In this case the stability of the crane will clearly be inadequate and measures to stabilize the river bank need to be explored. Unfortunately, insufficient time is available for students to perform any finite

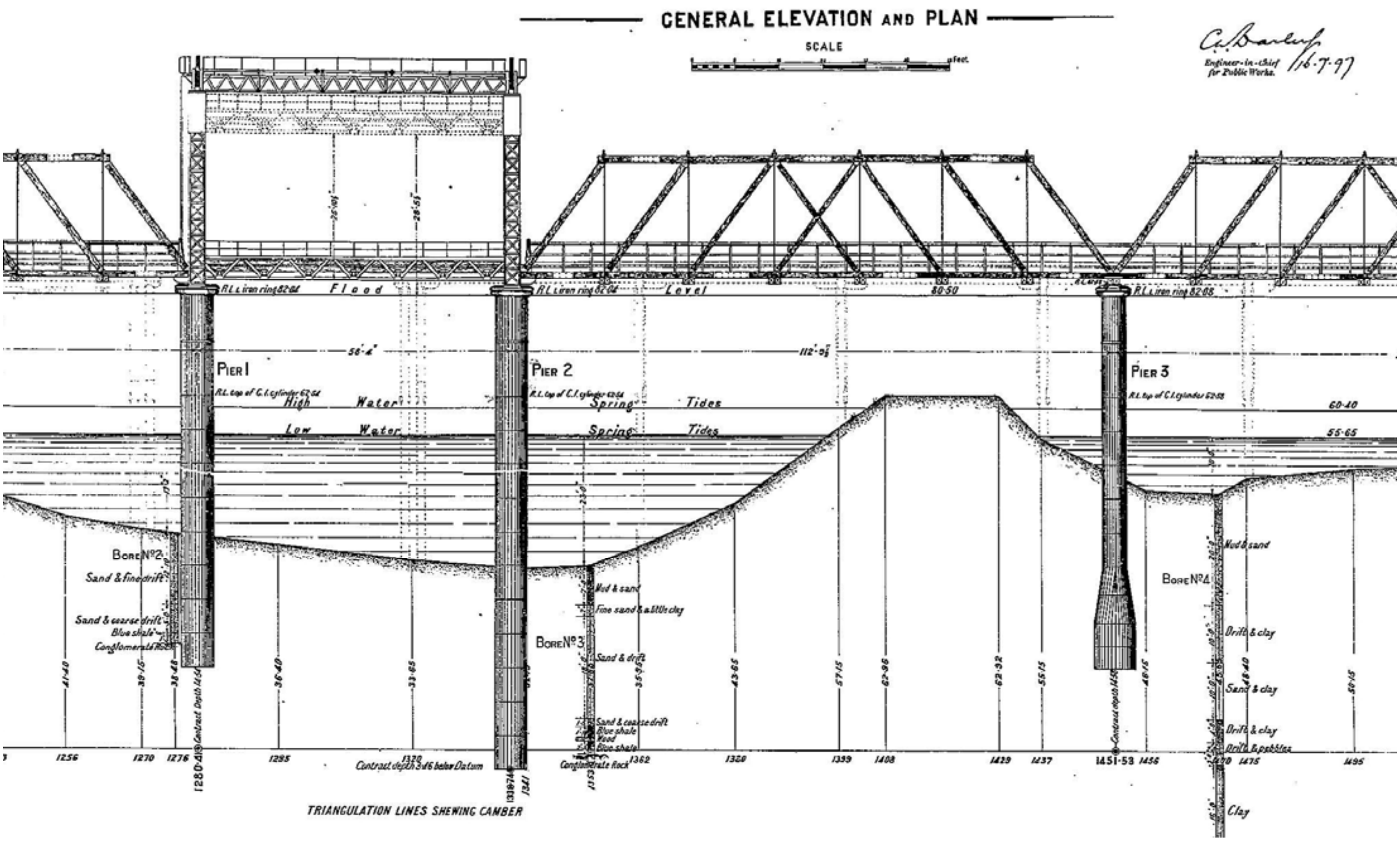

Figure 2. Extract from historic plans of Dunmore Bridge at Woodville.

element modeling of structural elements such as sheet piling and anchors which could provide students with insight into the complexities of the finite element modeling of many geotechnical problems.

Modern graphical user interfaces enable powerful finite element software to be used by novice users. In teaching the case study it is emphasized to students the importance of understanding the fundamental behaviour of soils and other materials, the complexities of finite element methods and modeling, and in scrutinizing and verifying results. In particularly, students are challenged to reflect on the behaviour of intermediate soils and how they might behave under short term loads.

5 STUDENT FEEDBACK

Feedback was sought from students on the use of the Dunmore Bridge case study as the basis for the computer laboratory classes. Initially students were asked to provide feedback via an online discussion board which permitted comments to be made anonymously. As the discussion board received no posts all students were emailed directly seeking their feedback. Responses were then received from only two students which is an extremely disappointing response from a class of over 90 students.

The comments received, however, generally valued the inclusion of the real world perspective.

“They were good as they related the course content to real stuff, which makes the theory seem more relevant.”

“I completed all three of the computer labs and found that they were beneficial. At first I struggled with the concepts but after practice got there in the end.”

Their comments also reflected the negative aspects of limited time available in the computer labs.

“I found the computer labs too short to actually learn what was going on, i.e. one hour isn't enough time to adapt to an entirely new program, whilst trying to understand the theory behind it.”

” I think one of the biggest problems was the time between the labs (especially when the third lab was postponed) meant that by the time we got into the lab I'd mostly forgotten how to use the program.”

One student also provided a useful suggestion:

”I think an actual demonstration of the tutorial (perhaps in the lecture) would be really good, as you could show the ability and concept without all the confusion of "how to run the program". I spent most of my time trying to figure out the layout of the program, and couldn't focus on the key content.

A demonstration on the use of the Plaxis software will be included in future courses to prepare students for their first computer laboratory class and to accelerate their competency in the use of the software. No mention is made of any time devoted to the activity outside of the classes, as was instructed by the lecturer. This is supported by anecdotal evidence from the class tutors who reported little continuity between computer laboratories, as most students had not undertaken any practice in using the software.

Poor attendance was also an issue for the computing classes with approximately half the students choosing not to attend these classes. This is now a common phenomenon among engineering students (Fityus, 2012). The second student remarked:

> *"One thing that I did notice was that because these labs weren't compulsory or assessable, half of the students simply didn't bother with them. I understand that this is their loss, and I'm not really sure what you could do to combat this (I don't think making them assessable is a good idea, however maybe a mark for attendance or something)."*

The computer laboratory classes were originally introduced to so that students could gain experience in the use the Plaxis finite element software. The motivation for students to attend was to learn to use the software, which would be beneficial to them in the subsequent capstone geotechnical engineering design course. This was perhaps a naïve assumption and it reinforces that assessments are also necessary to motive students learning.

6 CONCLUSION

A case study based upon a real geotechnical engineering project has been introduced within an undergraduate course on finite element methods. The introduction of the case study had two main purposes: to motive and engage students in learning finite methods and to introduce students to geotechnical engineering practice through exposure to a real project. The case study was developed around the geotechnical design of a working platform for the upgrade of Dunmore Bridge. As a project that is currently underway in the local region, it is topical and features many interesting aspects such as the historic nature of the bridge, the proposed construction methods and the use of large cranes. It provided an opportunity to introduce students to a real geotechnical engineering project and aspects of geotechnical engineering practice such as the use of pre-existing site information, in situ testing, real soils and soil profiles, and the uncertainty arising from a high degree of variability to be managed by geotechnical engineers.

Although only a small amount of feedback was received from students on the inclusion of the case study, the authors believe that the use of a real engineering project improved the experience of students and served to better engage students. The case study provides a means of introducing multimedia content into lectures and also provides topical information which can be used to engage the class in a discussion and provide for student-centered learning.

Further development of the case study and computer laboratory classes is required, in particular, additional computer laboratory classes are needed to improve the frequency and number of computing hours that students have to explore the case study and apply finite element modeling. An assessment task also needs to be developed to ensure participation by the majority of students and to encourage students to perform the work expected of them in their own time.

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