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Project-based Learning to Enhance Prestressed Concrete Design: Connecting Theory with Real-world Applications

Chamila Gunasekara[a]*, Roshan Jayathilakage[a], Sujeeva Setunge[a]
Department of Civil and Infrastructure Engineering, RMIT University, Melbourne, Australia[a]
*Corresponding Author Email: chamila.gunasekara@rmit.edu.au**

CONTEXT

Traditional educational methods in structural engineering have emphasized classical problem-solving techniques involving manual calculations. However, the integration of computational software within project-based learning, facilitating the application of acquired knowledge, has been neglected for many years. In today's engineering landscape, professional roles demand proficiency in teamwork, effective oral and written communication, and efficient learning strategies.

PURPOSE OR GOAL

This course aims to offer a comprehensive exploration of computational design principles concerning prestressed concrete. It encompasses the analysis of bridge structures under traffic loads, grillage analysis, and investigates the durability, and maintenance aspects of prestressed concrete structures. It also covers various types of suspended slabs and floor systems typically utilized in construction, alongside simplified methods for analysing and designing flat slab floor systems.

APPROACH OR METHODOLOGY

This module has been structured to align closely with the Engineers Australia competencies. The primary objective of the class is to prepare students with a theoretical understanding of prestressed concrete principles and the proficiency to interpret relevant design codes. Through their project work, students further deepen their knowledge by engaging in the design of a real-world prestressed application. They utilize commercial software for analysis and design tasks followed by validating their designs through manual calculations employing theoretical methods.

ACTUAL OR ANTICIPATED OUTCOMES

This course will provide knowledge and hands-on experience of: (1) prestress on the behaviour of uncracked and cracked pre-stressed concrete sections; (2) serviceability limits of prestressed concrete at both transfer and under full-service loads; (3) ultimate flexural and shear strength in the design of prestressed members; and (4) design of real-world prestressed bridge structure and flat slab floor system.

CONCLUSIONS/RECOMMENDATIONS/SUMMARY

This module fulfills the gap between academic theory and practical application, blending technical and computational expertise in structural design to safeguard critical infrastructure vital for societal requirements. The learning outcomes will also be a guide for future technology development that will enhance sustainability.

KEYWORDS

Project-based Learning; computational design; real-world applications

Introduction

Communication skills and proficient teamwork are vital elements in the education of engineering students, serving not only to enhance their learning experience but also to equip them for contemporary Engineering employment. Within the Industry 4.0 landscape, the significance of collaboration reaches new heights. The educational process modernization involves the introduction of new teaching approaches related to the development of additional competencies of students which allows them to implement complex projects, consequently increasing the competitiveness of university graduates in Oceania. RMIT University is committed to enriching student learning outcomes and engagement while strengthening retention rates through the adoption of project-based learning strategies. With a focus on preparing students for their future careers, RMIT ensures a high-quality teaching and learning environment that fosters adult learning principles. This approach encourages students to take ownership of their learning journey and actively engage both individually and as part of collaborative teams.

RMIT has implemented various project-based learning initiatives within its undergraduate courses. This approach, which has acquired significant interest in engineering education, aims to simulate real-world engineering experiences and enhance the development of desired graduate attributes (Hall et al., 2012; Palmer & Hall, 2011). Instead of simply imparting knowledge, project-based learning empowers students to take charge of their own learning, with lecturers playing a supportive role in guiding them on how to learn effectively (Frank et al., 2003). The project-based learning serves three main purposes (2006): providing a concrete and holistic understanding of processes, integrating subject material, and fostering self-regulated deep-level learning. Compared to traditional lectures, this active learning approach employs various trainings such as problem-based learning, case studies, tutor-led exercises, and debates, allowing for a more comprehensive development of competencies related to complex systems and holistic solutions. However, the integration of new teaching methods and concepts to address sustainable engineering challenges poses a considerable challenge in restructuring engineering education.

The primary reason for project-based learning stems from the constraint to adapt to a constantly changing world. Project-based learning endeavours to establish a student-centric atmosphere where challenges are confronted and resolved. A key characteristic setting it apart is the imparting of content through the development of skills. By engaging students in real-life projects, and involving them in active inquiry, the learning process is intensified and improved. Through engagement in authentic projects and active inquiry, the learning experience is enriched and elevated. This approach shifts the focus from the outcome to the process, with instructors transitioning from central figures dictating in the classroom to supportive guides. Described clearly as a shift from being a "sage on the stage" to a "guide on the side," this transformation underscores the process-oriented nature of project-based learning over its product-centric counterpart. To prepare engineering students for collaborative careers in the advancing Industry 4.0 landscape, universities are increasingly adopting computer-supported collaborative learning approaches. The collaborative learning facilitated by easily accessible software tools under free licenses, not only enhances engagement and teamwork but also fosters social relationships among students, thus aligning them with the demands of Industry 4.0, driven by digital technology.

This paper presents an elective course tailored for third and final-year engineering students, offering a comprehensive overview of Prestressed Concrete principles, both at the individual and network levels. It covers foundational concepts of pre-stressing concrete, addressing the analysis of bridge structures under traffic loads and grillage analysis. Additionally, it explores various types of suspended slabs and floor systems commonly employed in building construction, along with simplified methods for analysing and designing flat slab floor systems. The focal point of the course involves designing a reinforced concrete bridge deck and pre-stressed concrete girders, providing a hands-on learning experience affiliated with real-world engineering projects. Emphasizing project-based learning, the course fosters active student engagement. Students are expected to participate effectively and ethically within learning teams, contribute meaningfully to peer learning, and seek clarification from both peers and academic staff when needed. They are required to complete all pre-reading and preparatory tasks before each class, utilize available academic resources efficiently, submit assessments punctually, and integrate knowledge gained from laboratory sessions and lectures to bridge theory and practice effectively. Time management skills are emphasized to optimize study efficiency and learning outcomes.

Context

Course Overview

CIVE1151 is an elective course that demonstrates an in-depth understanding and knowledge of fundamental engineering and scientific theories, principles, and concepts and applies advanced technical knowledge in the specialist domain of engineering. This is designed for third and final-year students in the Bachelor of Engineering (Honours) program in the Civil and Infrastructure Engineering discipline at the School of Engineering, RMIT University. There are approximately 150 students enrolled annually. This is a 12-week, 12 credit-point course giving 39 hours of face-to-face teaching that comprises 2-hour lectures for 12 weeks; 2-hour tutorials for 6 weeks; and a 3-hour workshop on bridge design group project. This course aims to introduce the concepts of pre-stressed concrete, dealing with traffic loads in the analysis of bridge structures and grillage analysis. It also demonstrates types of suspended slabs and floor systems in common building use and simplified analysis and design methods for flat slab floor systems. The design of a reinforced concrete bridge deck and pre-stressed concrete girders is the major learning activity.

The course contributes to the development of the RMIT engineering program by considering five main learning outcomes, namely: the effects of prestress on the behaviour of concrete beams and slabs, and determining the combined stresses induced by prestress and applied loads using basic concepts of analysis, equivalent load method and load balancing approach; analysis of uncracked and cracked prestressed concrete sections and determine the different types of losses of prestressed concrete; the serviceability limits of prestressed concrete at both transfer and under full-service loads and ultimate flexural strength and shear strength in the design of prestressed concrete members; application of the bridge design codes to determine loads acting on a bridge structure, design slab, and beam girder elements and develop skills using software package Spacegass for analysis of design actions; and design of flat slab floor system for serviceability and ultimate limit state loads.The course is organised with project-based learning approach. Students also gain skills in using collaborative teamwork and supplement their knowledge via lectures from industry speakers, including experts in design of prestressed concrete members in bridges and practical construction methodologies. The learning activities are framed around a major project of design of a reinforced and prestressed concrete bridge structure. Refined methods of analysis is introduced as well as approximate qualitative methods to ascertain design actions on bridge structures. Students are encouraged to use innovative engineered precast products introduced to the market in their designs while critically evaluating issues in designing bridge structures with such products, utilizing the technical knowledge they have developed. Assessments for the course are as listed in Table 1. Assessment will be based on both individual and collaborative performance of requisite assessment tasks, namely the bridge design group project report and individual assessment tasks.

Table 1: Course assessments

Assessment Item	Description of Task	Weighting	Arrangement
Bridge design Project	Technical and computational expertise in structural design	35 %	Group work
Mid Examination	Prestressed concrete design and analysis	25 %	Individual work
Final Examination	Design of flat slabs for flexure and shear	40 %	Individual work

Collaborative Group Project

The analysis and design of a two-lane traffic bridge include a reinforced concrete deck supported by prestressed concrete girders. The bridge is constructed with twelve prestressed concrete beams each 25 meters in length, spanning three sections of 25 meters each. These beams are supported by two abutments and two headstocks. Students are engaged in a design project in groups of five. All group members are expected to have knowledge of and contribute to all parts of the bridge design project. The assessment criteria are based on the quality of a written report with Spacegass software analysis for loads, design calculations, and drawings performed by the students. The development of this collaborative group project benefited from the input of a former student who worked on the structural design and evaluation of the structure. This ex-student provided valuable data that increased the project's industry relevance, enhancing the learning experience, knowledge, and employability of the current students. This task enables students to apply theoretical engineering knowledge, skills, and techniques learned in lectures to identify real-world engineering issues and define complex problems across various contexts.

Each student group focuses on the grillage analysis of a bridge deck and its girders, incorporating the section properties of both components, traffic load inputs, and the adopted load combination cases. The analysis begins with a detailed introduction outlining the key assumptions and methodologies used, followed by the specification of load cases to be adopted. In the grillage setup, the configuration of longitudinal elements (beam girders) and transverse elements (slab) is defined, specifying the types of bridge girder and deck sections, Figure 1. Traffic load inputs are modelled based on lane loading and truck loading in accordance with the Austroads bridge design code, and load combinations are applied for both serviceability and ultimate limit states. Utilizing Spacegass software, the analysis yields design actions for these states, presenting results through bending moment diagrams, shear force diagrams, and deflected shapes for maximum serviceability and ultimate limit cases. These results are crucial for determining the design actions for ultimate strength and serviceability designs of the bridge girders, ensuring compliance with safety and performance standards. The accurate design of prestressed concrete girders in compliance with Australian standards demands a comprehensive understanding of various critical parameters. Students engaged in this discipline are tasked with the complex calculation of essential factors such as the appropriate prestress force, prestress losses, stress limits under service loads, deflections under service conditions, and the determination of flexural and shear strengths at ultimate design loads. These aspects not only align with theoretical lectures delivered in the classroom but also serve as a practical application, imparting invaluable skills for their future endeavours in real-world projects. This holistic approach not only fosters theoretical knowledge but also prepares students with the practical proficiency essential for the successful implementation of prestressed concrete structures.

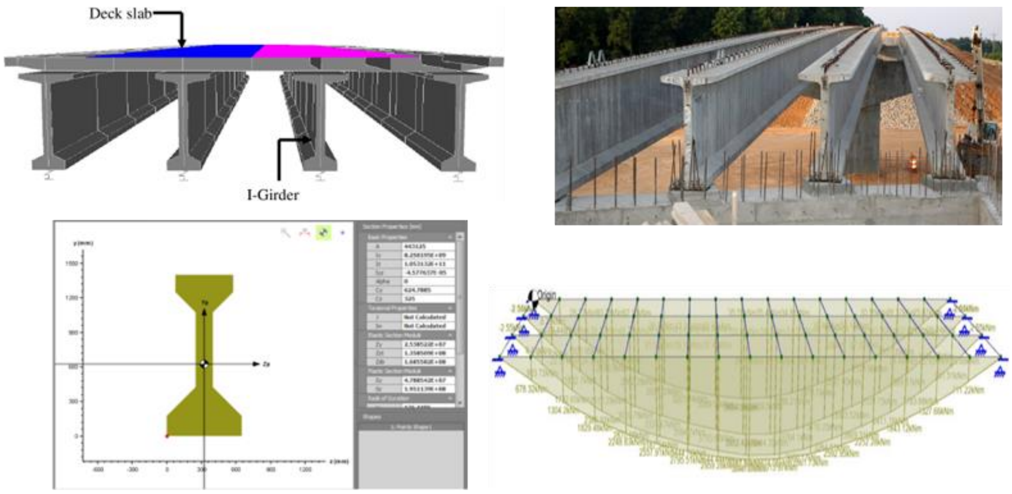

Figure 1: Bridge design layout and grillage analysis

Individual Examinations

The assessment structure for mid and end examinations in this study focuses on evaluating individual proficiency in designing prestressed concrete elements and complex flat slab systems. During the mid-examination, students are assessed on their comprehension and application of theoretical principles acquired from lectures and tutorials on prestressed concrete design. The final examination challenges students to design a complex two-way flat slab system supporting a retail shopping mall embodied by a repetitive floor plan, with reinforced concrete columns arranged in a rectangular grid pattern. Specifically, in the flexural reinforcement design of the flat slab, students are required to demonstrate their ability to detail steel reinforcement across the column strips. Moreover, in the shear design checks, students are expected to account for the region surrounding all pertinent columns. It is essential for students to incorporate generic safety factors mandated by Australian standards to ensure a conservative design approach. This comprehensive evaluation framework facilitates the assessment of students' proficiency in applying theoretical knowledge to real-world design scenarios while adhering to industry standards and safety protocols.

Discussion

The course on computational design principles for prestressed concrete offers a thorough investigation into various aspects crucial for aspiring civil engineers. Covering a spectrum from analysing bridge structures under traffic loads to researching into the working of grillage analysis and the durability of prestressed concrete structures, this curriculum trains undergraduate students with indispensable skills for their future careers. Emphasizing practical experience, students engage in problem-solving scenarios, fostering innovative solutions vital for both organizational success and societal benefit. Upon graduation, students emerge as highly sought-after professionals, possessing not only technical prowess but also strong abilities in decision-making, leadership, and effective communication. Through group assessments and collaborative activities, students enhance their social skills, teamwork dynamics, and time management, essential qualities for success in the field. Encouraged to apply interpersonal skills and adhere to international standards, students navigate complex engineering challenges with both independence and collaborative spirit, ensuring their readiness to tackle real-world scenarios in the construction and design sectors.

This course is presently being delivered to undergraduate students as part of a Civil Engineering program at a Hong Kong TAFE institution. While the essence of the curriculum remains consistent, adjustments are made to lecture notes, assignments, and group projects to suit the construction and design parameters relevant to each country's civil engineering context. Furthermore, the course is designed to align with the Australian Government’s National Science and Research Priority of Advanced Materials and Manufacturing. It specifically tackles the practical research challenge of understanding "Australia's comparative advantages, constraints, and capacity to meet current and emerging global and domestic demand" by introducing sustainable design methodologies focusing. Through this course, students are empowered to contribute to the UN Sustainable Development Goals while addressing challenges in resource recovery and management. This is achieved by integrating solutions within the context of the infrastructure expansion driven by population growth and urbanization. One of the key goals is goal 9.1, which is;

“*Develop quality, reliable, sustainable and resilient infrastructure, including regional and transborder infrastructure, to support economic development and human well-being, with a focus on affordable and equitable access for all”*.

With the practice and training gained through project-based learning, students are expected to implement sustainable solutions and designs in their future projects, that utilize resources more efficiently and reduce and manage production costs. This allows for more affordable infrastructure and supports the country's economy. For example, the CIVE1151 course allows students to choose more cost and performance-efficient innovative pre-cast products in their designs, so they can critically evaluate the most sustainable product to incorporate in their design.

The UN sustainable development goal 11, “Make cities and human settlements inclusive, safe, resilient and sustainable” also is another major area of contribution expected from learners through this course. The CIVE1151 course and the project-based learning teach students to design safe and reliable structures conforming to Australian and international standards. Furthermore, engagement with visiting industry lecturers and insight gained from industry experts while working on the collaborative group project, allow the learners to clearly understand the importance of the above UN sustainable development goal.The outlined course also target to address and deliver the Engineers Australia competencies and elements of competencies such as knowledge and skill base competencies, engineering application ability and professional and personal attributes. Comprehensive theory-based understanding, conceptual understanding as well as the knowledge development of concrete and prestress design will implement the knowledge and skill base competencies. Additionally, the focus towards sustainable design will cover one of the main elements of knowledge and skill base competency. The usage of real world materials, methods, standards and design tools/softwares will fulfill the engineering application competency. The interaction with project group and engineering professionals throughout the project-based learning via group design project will address the professional and personal attributes.

Project-based learning is a student-focused instructional method based on three key principles: context-specific learning, active learner involvement, and goal achievement through social interaction and knowledge sharing (Cocco, 2006). It involves inquiry-based learning through real-world questions and problems, leading to meaningful experiences(Wurdinger et al., 2007). Blumenfeld et al. (2000) describe project-based learning as a process where students solve real problems by asking questions, conducting investigations, analyzing data, drawing conclusions, and reporting findings. In connection with the CIVE1151 subject, students are involved in designing a real-world reinforced and pre-stressed concrete bridge structure, following a similar methodology and process typically followed by a bridge design engineer. Also, the students can use innovative precast products in their design, which promotes problem-solving skills and innovative thinking, while identifying the pros and cons of implementing those products. Therefore, through project-based learning, students will not only learn and develop their skills but also will get trained to join the industry and be involved in real-world projects.

Project-based learning encourages teamwork and collaboration, helping students learn to work effectively with others. The collaborative group project in the CIVE1151 subject incorporates project-based learning mechanisms by encouraging students to collaborate to solve a complex real-world concrete bridge design problem. The students will not only collaborate among group members but also will communicate with an industry expert (former student) who will provide useful data and feedback required for the design project. This is a good opportunity for the students to be exposed to industry practices and norms while networking with industry personnel. Nevertheless, when creating a project team, the teacher must consider its size. Authors Chen and Yang (2019) mention, that a group of three to six students enables more interpersonal interactions in project-based learning. If the group size increases, it is more difficult to ensure that all group members contribute their share to the team effort and have a strong voice in team discussions. For the group project of CIVE1151, the group size of five is ideal to enable effective interactions between students to design each component of the bridge structure, while all the members contribute to each aspect of the project.

A two-phase project-based method has been suggested in academic literature as an effective way to help students gain competence. Initially, this method focuses on developing the necessary knowledge and skills, allowing students to design and create products independently in the second phase(Drain, 2010). The approach followed in the CIVE1151 subject is similar. The face-to-face lectures and lectures from visiting industry personnel will provide the necessary knowledge to students at stage 1. In stage 2, students will bring their insights and ideas to tackle a design problem at mid and end examinations.

Another key component in project-based learning is that the assessment should match the unique features of the process and its outcomes, with teachers identifying key moments to create 'teachable moments' and provide formative support throughout the project. Authentic assessment in project-based learning, includes reflection, self-assessment, and peer evaluation, along with performance rubrics. Self-assessment skills help students manage their learning and take ownership of the process (Ertmer & Simons, 2005). The bridge design project in the CIVE1151 subject demonstrates this well. The assessment rubric is provided to students, where they can self-evaluate each assessment component of the project before the final submission of the report. Also, the students are provided with several tutorial sessions, which provide an opportunity to self-evaluate their skills in problem-solving. Also, the tutorial classes are a great opportunity for students to interact with their peers and evaluate different approaches to solving a given problem.

Modern digital technology significantly aids students in the design and development of their projects, allowing them to document and share their work in digital formats with ease. Integrating technology into educational processes has proven beneficial for both high and low-performing students in constructing knowledge within a project-based learning environment (Erstad, 2002). The CIVE1151 subject uses modern analysis tools such as Spacegass software, where the analysis results can be easily documented and shared in a digital format. The ability to share the results in a digital format not only benefits students in troubleshooting and checking their analysis results but will also help lecturers provide feedback.

Classroom lectures and traditional learning methods primarily provide students with the basic theoretical knowledge of a subject. While these theoretical foundations are essential for highly technical and practical civil engineering topics, students also need opportunities to prepare for industry employment, collaborate effectively, and address real-world problems. Delivering knowledge and skills that meet industry standards, particularly in non-technical areas such as management, engineering, and personal skills, is challenging within a classroom lecture environment. The project-based learning approach used in the CIVE1151 course offers a valuable solution. It enables students to acquire theoretical knowledge through classroom lectures while also developing critical thinking and problem-solving skills in tutorial classes. Additionally, students collaborate in groups to design a real bridge structure, applying their knowledge and skills in a practical context. This collaborative group project simulates a realistic industry environment, providing students with hands-on experience in both technical and non-technical aspects. As a result, students gain confidence, and practical experience, and become industry-ready.

Finally, the student feedback surveys and student grade distribution proved that the project-based learning implemented was more efficient compared to conventionally delivered lectures. The Student Experience survey consists of 5 major questions related to understanding the course, course experience, course resources, application of the things learned in the course, and satisfaction with the course. According to the survey, understanding and satisfaction with the course scored the highest with a score of 4.35 out of 5 (which is nearly 90%). The other 3 criteria also scored more than 4 out of 5. The survey also consisted of two teaching questions, which are inspiration and helpfulness. In comparison to the other teaching courses in the School of Engineering, the teaching survey responses to the CIEVE1151 subject received a higher survey score (more than 4 out of 5), where most of the students mentioned that the course was helpful. Hence, it is evident that the project-based learning and teaching approaches were successful compared to the other Engineering subjects, which mainly followed conventional teaching methods. Most importantly, the question “Which aspects of this course did you find most effective?” was asked at the end of the course survey. The majority of the students gave positive feedback on the bridge design group assignment and the face-to-face tutorials, where project-based learning was implemented the most.

The final grades of the students also reflect the efficiency of the project-based learning and teaching methods followed. The pass rate of the course is 98% with 50% of the students achieving distinction grades and 19% achieving high distinction grades. This shows the efficiency of project-based learning implemented.

Conclusion

In conclusion, the implementation of project-based learning in this undergraduate course has demonstrated its effectiveness in engaging engineering students and bridging the gap between theoretical knowledge and practical application. Through detailed discussions on translating theoretical concepts into real-world structural design scenarios, this approach has not only enhanced students' learning experiences but also provided valuable insights for future technology development aimed at sustainability. By blending technical proficiency with computational expertise, this module has contributed to safeguarding critical infrastructure essential for meeting societal needs. The documented learning outcomes serve as a roadmap for advancing both educational methodologies and innovative solutions in structural engineering, thereby fostering sustainable progress in the field.

It was demonstrated that the project-based learning techniques and approaches were implemented efficiently throughout this undergraduate course. The two-phase approach, the use of modern digital tools, and allowing self-evaluation and peer evaluation are some of the key concepts implemented. The course encourages students to participate in achieving UN sustainable development goals mainly focusing on goals 9.1 and goal 11 to develop resilient, cost-effective infrastructure and create inclusive, safe, and sustainable cities. Also, the course address and deliver the Engineers Australia competencies and elements of competencies. The student course experience surveys conducted revealed that the project-based learning method provided a better student learning experience compared to conventional teaching, and also reflected in the student grades with a 98% pass rate. Through practical training, industry insights, and adherence to international standards, students are prepared to design and implement innovative, sustainable solutions that enhance economic development and human well-being.

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