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Teaching Design in the Civil Engineering Undergraduate Curriculum: Hong Kong Experience

Y. S. LI
Department of Civil and Structural Engineering, The Hong Kong Polytechnic University, Hong Kong

The Hong Kong Polytechnic University lays special emphasis on the teaching of design in its civil engineering undergraduate curriculum, as the majority of graduates from this programme choose to join the industrial sector rather than to pursue full-time graduate education. There are altogether four compulsory design projects in the curriculum and all are organized as short-term, full-time activities so that students can concentrate entirely on the design work in the absence of other academic activities. The design projects are scheduled sequentially, gradually to instil the design methodology and skills, culminating in the complete design and detailing of a facility in the final year of study. The department treasures the contribution of experienced practising engineers to the teaching of design, and they are invited to supervise and assess students jointly with full-time faculty members. The organization, professional support and examples of design projects carried out by students are described.

INTRODUCTION

IT IS generally accepted that design-project type activities in the undergraduate programme have significant educational value. However, the teaching of civil engineering design is a difficult task. The first difficulty is on the part of the student who has to integrate his or her knowledge acquired from isolated courses, such as structural analysis, foundation engineering, construction technology and project management, to conceive a facility and to choose among several competing solutions of which no single optimum solution can be clearly differentiated. Secondly, much effort is required of the academic department to recruit visiting professional engineers to work together with full-time faculty members to select suitable real engineering projects to enable students to gain real-world experience in an academic setting.

The Department of Civil and Structural Engineering at The Hong Kong Polytechnic University lays special emphasis on the teaching of design, as the majority of graduates from the undergraduate programme choose to join the industrial sector rather than to pursue full-time graduate education. A series of design projects is scheduled sequentially in the undergraduate curriculum—which is a structured programme of 3 years duration, similar to the British system—gradually to instil design methodology and skill. This is in contrast with most of the undergraduate curricula in the United States and the United Kingdom, which usually include only one design course, examples of which are described by Dolan and Searer [1] and Morris and LaBoube [2].

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There are altogether four compulsory design projects in the curriculum and all are organized as short-term, full-time activities so that students can concentrate entirely on the design work in the absence of other academic activities. The class is divided into teams of five or six students to simulate the real-world situation and to convey to the students the importance of an organized team effort. The first two projects, both of 1 week duration, are undertaken by first-year students. The objective is to introduce the design procedure through the creative solution of simple problems and to cultivate students' confidence in preparation for subsequent, much more complex, real construction projects. The third design project, undertaken by second-year students, is of 2 weeks duration. The project is usually an engineering feasibility study and conceptual solutions are required of student teams, with individual team members concentrating on the development of outline designs for the different major components of the overall scheme. The fourth design project is of 4 weeks duration and is carried out by final-year students. The project requires the complete design and detailing of a facility, including any necessary major temporary works and cost estimation of key items of the chosen scheme. Proper completion of these projects will not only draw upon the academic content of the programme, but also upon the students' appreciation of more practical issues.

ORGANIZATION AND SUPERVISION OF PROJECTS

The department treasures the contribution of experienced practising engineers to the teaching

of design. Their comprehensive design experience and their up-to-date knowledge of the current trend in design practice and construction technology ensure that students are exposed to real-world design activities.

At the beginning of each academic year, the department approaches several large consulting firms to solicit their help in organizing the second-year and final-year design projects. Two staff project groups, each comprising two faculty members with extensive design experience and two professional engineers from the same consulting firm, are formed to look after the design projects. The contents of the design projects are suggested by the professional engineers and are usually tailored from recent projects undertaken by them after consultation with the faculty members of the design groups. Usually, two projects would be proposed if the class size is large. The staff project group responsible for the first-year design projects consists only of faculty members, since the projects are intended only to stimulate an understanding of the design process. It is important that the level of design detail required of the student should be compatible with the extent of the student's knowledge and experience. It is our experience that students would lose interest in the project if they find it totally beyond the limit of their knowledge.

The project brief is distributed to students at least 2 weeks before the start of the project weeks, so that students can ask more relevant and sensible questions about the project at the briefing session, which usually takes place on the first day of the project weeks. Besides briefing the students on the first day, the professional engineers also participate in the supervision and assessment of student teams. During the project weeks, two consultation sessions, each of 30 min duration, are usually arranged each week for each student team to discuss its problems and progress with their supervisors. In order not to unduly disturb the daily work of the professional engineers, each engineer is asked to come to campus only once each week, and thus only one engineer and one faculty member meet the student team in each consultation session. On the last day of the project weeks, each student team is required to give a verbal presentation of its work before all the members of the staff design group. A project report is to be submitted on the following Monday. Each student is assessed individually, based on his or her performance at the consultation sessions and the verbal presentation, and also his or her contribution to the design project report. The staff design group members meet to finalize the grades awarded to individual students before they discuss with individual student teams in a feedback session the merits and shortcomings of their chosen schemes in satisfying the project criteria. Each member of the staff project group comments on the part of the project report which falls within his or her expertise. Feedback to students is considered to be a very important step in the teaching and learning process, and students usually find the feedback sessions extremely useful.

FIRST YEAR DESIGN PROJECTS

First-year students are required to complete two projects, one in the first semester and the other in the second semester. Both projects are of 1 week duration.

First semester project

Students are given a handout on the design process 1 week before the start of the project week. The handout briefly describes the design methodology. The design procedure is visualized as a common-sense approach to solving engineering problems. The first step is a clear definition of the problem to be solved and the constraints. In addition to the financial cost as the most obvious constraint, students are reminded of the possibilities of other important constraints, such as environmental problems and the negative impact on traffic in trunk-roads during construction. The second step is a feasibility study to work out a range of alternatives and to have a critical evaluation of them to identify the best scheme. The final step is to perform the detailed design of the chosen scheme. Students are also reminded that they will encounter problems during the design process and that it is normal to go through the whole procedure several times, including even a reformulation of the problem statement, before a satisfactory solution can be devised.

In this first project, each student team is required to generate a solution to a simple problem of its choice, following the design steps outlined in the handout. The projects are not necessarily civil-engineering related and can be of any discipline. Examples of problems tackled by students are:

- Automatic table tennis ball ejector—a device that can eject table tennis balls at different speeds and angles to train table tennis players.
- Automatic fish feeder—a device to be used at home to feed fish at selected regular time intervals.
- Suitcase trolley—a small portable trolley that can even negotiate stairs for travellers to carry their suitcases.
- Multi-function camping light—a device that has several functions comprising an ultrasonic mosquito repeller, a flashlight, a fluorescent lamp, a clock, a timer and a radio. The device also includes a sound-activated switch to turn on a dim light for easy location in darkness.
- Portable stationery case—a plastic case that is slightly larger than A4 size paper. Besides having a number of compartments for storing stationery, notebooks and drawing instruments, it can also be used as a drawing board for outdoor use.

Second semester project

This project is a design–construct-test exercise for a simple engineering structure. Student teams are asked to design and build a wooden truss structure, usually a model bridge or a tower. The design teams are free to choose the types of truss structures. The only constraints imposed are the overall dimensions of the structure and the loading points. On the last day of the project week, student teams are required to assemble in the structures laboratory and all bridges or towers are loaded to failure. The ultimate loads recorded are compared with the calculations of the student teams. Each student team is assessed on the basis of:

- accuracy of the estimated ultimate load;
- ratio of the ultimate load to the weight of the structure;
- quality of construction of the model;
- engineering sense in the choice of structural form;
- application of available analytical tools in the design of the chosen structural form;
- report writing.

SECOND-YEAR DESIGN PROJECT

Second-year students are required to complete a project of 2 weeks duration at the end of the first semester. An example to illustrate the types of work performed by student teams is described below.

Example: an elevated transport terminus on reclaimed land

A new town is proposed to be created on a reclamation located on the north shore of Lantau Island, which is one of the outlying islands of Hong Kong. The size of the reclamation is 1500 m × 500 m. The current reclamation practice in Hong Kong involves either complete removal of marine mud and backfilling with compacted sand-fill or the marine mud being dried out using vertical drains and surcharge to accelerate consolidation settlement.

As part of the infrastructure development project, an elevated transport terminus of two storeys will be constructed on a drained reclamation. On possession of the site, the residual settlement of the reclaimed land is expected to be less than 50 mm in 100 years. The design requirements for the transport terminus are as follows:

- The ground floor is used as a lorry park while the top floor is a bus terminus. Typical column grids are at 12 m × 12 m (layout plan available).
- Typical loadings on an internal column are specified.
- The water table is located 2 m below ground level. All relevant geotechnical design parameters and typical reclamation profiles are provided to students.

Student teams are required to perform the following tasks:

- To carry out a literature survey of the extent of environmental impact likely to be generated by the current reclamation practice.
- To describe a possible method to detect the presence of contaminated mud and the treatments required to safely dispose of it if it is present.
- To devise three possible structural solutions to support the transport terminus and to compare the relative merits of the alternatives.
- To outline the necessary modifications to the chosen scheme if the terminus were located on a dredged reclamation.
- To describe the range of chemical tests required on soil/water samples to define the degree of aggressiveness of the ground and to explain the measures to be adopted under chemically aggressive conditions.

Although the knowledge of the students is limited, it is our experience that students can learn quickly, and all design teams were able to provide sensible foundation schemes to support this low-rise structure. In particular, the literature surveys on reclamation practice and consequent environmental impacts were well prepared. However, the differences between a drained reclamation and a dredged reclamation were only partially appreciated. Nevertheless, students had made attempts to estimate the bearing capacity and settlement of the chosen shallow foundation schemes for a dredged reclamation.

FINAL-YEAR DESIGN PROJECT

Final-year students are required to complete a project of 4 weeks duration at the end of the first semester. An example of design projects which students are normally asked to do is given below.

Example: box culvert through reclaimed land

The reclamation along West Kowloon waterfront cuts across the outfalls of existing major storm drains. The existing nullah at the West Boat Dock conveying the storm water from the hinterland has to be extended by a 3.5 m × 3.1 m, three-cell concrete box culvert of length 500 m through the reclaimed land to the new waterfront. The hydraulic design of the box culvert and other box culverts in the reclaimed area has been undertaken and is not required in this design project.

In order to maintain the stability of the existing sea wall, and for environmental reasons, the Civil Engineering Department of the Hong Kong Government decided that there would be a 50 m non-dredging zone extending from the existing waterfront, in which no dredging would be allowed before reclamation. Hence the box culvert will be constructed without prior removal of the marine mud and large residual settlement is thus antici-

pated after the reclamation. Marine mud at further distances away would be dredged and backfilled with compacted sandfill. The thickness of the sandfill is estimated to be 20 m. The design requirements of the design project are:

- The formation level is at 4.5 m Principal Datum (PD).
- Mean high high water level is at 3.6 m PD and mean low low water level is at −0.5 m PD.
- A new expressway will run perpendicular to the box culvert at 6.6 m PD.

Student teams are required to provide the following in the project reports:

- A geotechnical assessment of allowable bearing pressures of founding materials, settlement, negative skin friction on structures, and the suitable value of subgrade reaction (records from four boreholes and basic soil data are available).
- A schedule of design data including material properties, concrete covers and allowable crack widths, load factors and safety factor for stability.
- An assessment of highway live loads, including load arrangements and dispersions.
- Structural design for the culvert and foundation, taking into account various load combinations.
- A complete set of construction drawings.
- A brief description of the construction method to be used and the necessary temporary support.
- A cost estimation and a full Bill of Quantities.

It is our experience that final-year students are able to handle real-world design projects if sufficient guidance is given. All student teams succeeded in generating reasonable designs and in completing the design project on time.

CONCLUSIONS

The objectives of design projects are to integrate the students' exposure to specific design techniques within individual subject areas, to help students to realize the importance of teamwork in the synthesis of satisfactory solutions to multidisciplinary problems faced by professional engineers working in the construction industry, and to help develop the skills needed to communicate their solutions lucidly through written and verbal presentations.

It is found that design projects organized as regular short-term, full-time activities are very effective in achieving the stated objectives. The format of the design projects has evolved for nearly 10 years before it finally consolidated to the present arrangement after several reviews based on student feedback and staff experience in the operation of the projects. The contributions of visiting professional engineers to the contents of design projects are particularly valuable and also the opportunities for students to interact with practising engineers have helped them to appreciate the more practical aspects of their future career.

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Dr Y. S. Li is a Professor of the Department of Civil and Structural Engineering at The Hong Kong Polytechnic University. Besides computational hydraulics, his interests include the continuous development of the undergraduate civil engineering curriculum to meet the needs of the construction industry.