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ABSTRACT

In 1996, a comprehensive project was introduced in the first course of Reinforced Concrete Design, CVEG 4303 at the University of Arkansas. The primary purpose of this project was to highlight issues related to the construction of reinforced concrete elements. This semester-long project involves the design, fabrication, and testing of 8-foot long reinforced concrete beams. Benefits of this project have proven to be many and diverse. Students must rely on knowledge they have gained from prior structures and construction courses and are forced to consider how to get from their own paper designs to an actual constructed element. Analysis and communication skills are refined as students must prepare written and oral presentations. Additional benefits of the project include exposure to project scheduling, preparing purchase and work orders, having to adhere to project specifications, coping with unexpected problems, and working in teams. The paper explains how this project can be introduced into the civil engineering curriculum. A description of the project and its specifications, equipment needs, costs and benefits of the program, and optional approaches are included. (SAH)

Reinforce Design and Construction Issues with a Comprehensive Laboratory Project

By John J. Schemmel[1]

Introduction

While there is often an emphasis on structural design, it is not uncommon for a civil engineering program to have few courses related to construction. Moreover, courses on construction tend to stress contract and management issues with only limited discussions on fabrication. Thus, it is expected that a civil engineering graduate be able to compute the dimensions of, and detail the reinforcement for, a reinforced concrete beam. However, while their employer might expect it, it is much less likely that a recent graduate will have the knowledge to address the practical and economic aspects of constructing their design. As a result, contractors are all too often faced with the problem of an otherwise acceptable design being difficult, impractical, or even impossible to assemble in the field. Therefore, any effort to educate a student on issues related to the fabrication of a structure should pay long-term dividends in terms of fewer, or less serious, problems in the field.

In 1996 a comprehensive project was introduced in the first course in Reinforced Concrete Design, CVEG 4303, at the University of Arkansas. The primary purpose of this project is to highlight issues related to the construction of a reinforced concrete element. Simply stated, this semester long project involves the design, fabrication, and testing of an 8-foot long reinforced concrete beam. Benefits of this project have proven to be many and diverse. Given that the students are faced with an unfamiliar and open-ended problem, they must rely upon and apply the

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knowledge they've gained from prior structures and construction courses. Moreover, the students are forced to consider, possibly for the first time in their academic careers, how to get from their "on paper" designs to an actual constructed element. Further, their analysis and communication skills are refined as they must prepare a written report and make an oral presentation. Ancillary benefits of the project include exposure to project scheduling, preparing purchase and work orders, having to adhere to project specifications, dealing with unexpected problems, and working in teams.

This paper explains how this project can be introduced into the civil engineering curriculum. A description of the project and its specifications, equipment needs, costs and benefits of the program, and optional approaches are presented herein.

General Project Description

On the first day of the semester, the students in CVEG 4303 are presented with the task of designing a reinforced concrete beam to carry a specific load. In order to confirm the adequacy of their design, it is necessary for the students to build a beam and test it to failure. Although fairly simple in concept executing this project is somewhat involved, as there are a number of tasks and sub-tasks that must be completed. Thus, planning, on the part of the students and instructor, is critical to the success of this endeavor.

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In developing this project, every effort was made to insure that the experience be as realistic as possible. Thus, after being separated into teams of four, each team is given a general description of the problem and a set of project specifications. The main body of the specifications covers issues relating to design, fabrication, testing, record keeping, and the construction schedule. Throughout the project, each student must maintain a dairy of the work they have performed. They must also prepare an invoice in order to be paid for their efforts. A wage scale is provided and covers tasks from secretarial work to drafting to professional engineering design. Purchase and work orders must be written to obtain materials, services, and equipment. Memos, updating the progress of the project, must be submitted to the project manager, or course instructor, on a regular basis. To avoid a pay (grade) reduction, the project must be completed on schedule.

Throughout this project the instructor will wear many hats. At any time the instructor's role may be that of teacher, project owner, mentoring engineer, or outside consultant. While providing encouragement and guidance is very important, the author feels strongly that the students should be allowed to learn from their own mistakes. This is evident by one aspect of the grading policy for this project. A problem, or error, that is clearly explained, and for which there is a recommendation on how to rectify it in the future, is scored equally with a technically proper solution.

It should be noted that CVEG 4303 is a 3-credit course and it does not include a formal laboratory. Consequently, all laboratory work performed by the students is done outside the regularly scheduled class meetings. As a reward for the work performed outside of class, the grade for the project is used in lieu of a final exam.

Materials Evaluation and Structural Design

This phase of the project includes the following duties; establishing the proportions for a concrete mixture, evaluating the engineering properties of the concrete and reinforcing steel, determining dimensions for the beam, and finally, detailing the reinforcement. These tasks require that the students understand and abide by the project specifications. This phase also integrates subject matter presented in the department's Structural Materials and Reinforced Concrete Design courses. Furthermore, use of American Society for Testing and Material (ASTM) standards is incorporated in this phase.

Each group of students must proportion a concrete mixture to satisfy a given compressive strength requirement. Constituent materials are limited to those available in the department's concrete materials laboratory and at the concrete batching facility. Typically, the design strength is specified as 3,500 psi at 14 days. A 14, rather than 28, day strength is established so that the students can meet the project schedule. Generally, students must begin trial batching within the first week to ten days of the semester.

It is necessary for each group to evaluate the engineering properties of their concrete mixture and reinforcing bars. These measured values are used later in the structural design process. To obtain this data, the students are obligated to test concrete cylinder specimens in compression and samples of reinforcement in tension. The longitudinal steel is limited to #3, 4, or 5 bars, while the shear reinforcement must be #3 bars.

concrete, form removal, and curing the beam. It is at this stage of the project that the students begin to encounter problems. Difficulties arise, primarily, as a result of inexperience. Problems also arise due to a lack of planning. Addressing the issues of inexperience and planning is a major objective of this project. Hence, most of the learning takes place during this phase of the project.

A financial constraint, $50, is placed on the materials used to build the forms. Purchase orders must be submitted in order to receive the forming materials, reinforcement, and concrete. This requires the students to make inquires at local lumberyards, steel fabricators, and the batch plant in order to properly prepare their purchase orders.

Given that the majority of students in this course have little experience working with, or designing, formwork for concrete, a concerted effort is made to simplify this task. As previously noted, the span length for the beam is set at 8 feet. This dimension allows use of standard 4 ft. x 8 ft. sheets of plywood and eliminates having joints in the formwork. Next, two publications on formwork (1,2) are made available to the students. Additionally, staff in the College of Engineering's Wood Shop performs milling operations upon request. Students need only provide a cut sheet, along with a written work order, to receive this service.

Once both are fabricated, the reinforcement cage is placed into the forms. The forms are then transported to a local precasting plant where the concrete is batched. The students are aware that a forklift is available to move the formwork, and hardened concrete beams, within the laboratory and at the batch plant. Each group must provide the plant operator with the proportions for their specific mixture. Placing, consolidating, and finishing the concrete is the sole responsibility of the students. Likewise, the students must determine the properties of the fresh concrete and mold cylinders for later testing.

A number of problems typically develop during this phase of work. Examples include, improperly specifying the dimensions of the longitudinal or shear reinforcement, improper positioning of the longitudinal or shear reinforcement, forgetting to install lift hooks, placing lift hooks at the loading points, ordering an insufficient quantity of concrete, providing inadequate lateral support for the formwork, and others. As work on this task progresses, many teams discover their mistakes and take appropriate action. Others do not discover their mistakes until it is too late. Although it's the hard way, these are often the groups that learn the most.

Testing the Beams

For both the students and instructor, this phase often proves to be the most exciting aspect of the project. Here the beams are loaded to failure. Students monitor the behavior of their beam as load is increased and later analyze the results. The students are fascinated to see the cracking pattern develop and the beam's deflection increase. They often react as if they were unaware of how a reinforced concrete beam behaves. Predictions of a beam's load carrying capacity are proclaimed as teams vie to be closest to the specified moment capacity. However, once a beam fails these predictions transform into explanations for the beams actual strength and the ultimate cause of failure. All of this is an eye opening experience for these young engineers.

Testing begins with the beams being placed into the loading frame. The beams are tested as close to 14 days after casting as possible. Testing provides a second opportunity; working at the precast plant was the first, to address issues of safety. Once positioned in the load frame, load is manually applied via a hydraulic pump. With each incremental increase in load, the mid-span deflection is recorded and the cracking pattern is marked on the beam itself.

As a part of their final report, each group must evaluate the performance of their beam. They are required to compute the beam's maximum moment capacity, it's shear strength, and the development length of the reinforcement. They also plot the load-deflection curve, graph the cracking pattern, and provide an explanation for their beam's failure. In addition, recommendations must be made regarding improvements to their structural design or construction methods. All of this information is then compiled in a written document and presented orally to the entire class.

Establishing Grades

Three primary issues are considered when evaluating the final reports and presentations. First, there is an appraisal of the project's technical merit. Here, issues such as completing the required tasks and satisfying project specifications are addressed. It is also here that a well-addressed problem will be found equal to a technically correct result. Technical merit accounts for approximately 40 percent of the project grade. Communication skills are examined next. An assessment is made of the quality of the final report and oral presentation. This accounts for another 40 percent of the grade. Finally, the contribution of individual team members is addressed. This part of the grade, which amounts to the remaining 20 percent, is based on input from a peer review and self-evaluation.

Equipment Needs

There are two key pieces of equipment needed for this project. The first is a forklift, or crane, which is used to move the formwork and beams. Second is a loading frame, with hydraulic ram, large enough to handle an 8-foot long, approximately 18-inch deep, beam. As will be noted below, this type of project can still be conducted in the event that these pieces of equipment are not available. Other materials and pieces of equipment, such as wood, hardware, cement, aggregates, drills, hammers, concrete mixers, universal testing equipment, etc. are mainstays in a concrete materials laboratory.

At the time this project was conceived, the concrete laboratory at Arkansas did not have a load frame that was adequate for this endeavor. Therefore, one was designed by the faculty using standard rolled steel sections. A local steel fabricator donated part of the cost to construct and paint the frame. Total cost to the department for this apparatus was under $700. The department already owned a hydraulic ram. The loading frame has proven to be quite versatile and has since been used for research projects and industrial testing.

Costs and Benefits

Initially, the biggest expense for this project was the loading frame. However, as noted above, this item is providing benefits which far exceed its' purchase price. Other monetary costs for this project include those associated with the concrete and forming materials. On average, these cost run between $75 and $100 per team.

By far, the greatest cost of this project is the time spent by students, faculty, and technical staff. Four person teams report spending up to 100 man-hours over a 10 to 12 week period completing their work. However, much of this time is expended as the students "chase their tails" or consult with the other groups. Faculty spends time keeping track of the progress of each team, consulting with the various groups, and scheduling deliveries. Technical staff work with the students to load, test, and unload their beams from the load frame.

Even with a notable time commitment for all involved, the benefits of this project are extensive. Students gain hands-on construction experience, which is something they may otherwise never obtain. They discover the need to consider construction issues at the design stage. Further, they find that care must be taken when ordering materials or requesting the services of others. During testing, they witness the behavior of the beam and discover that it correlates with classroom discussions. All in all, the author believes that this project makes the students better prepared for their first job as a civil engineer.

Optional Approaches

In the event that facilities, manpower, or finances are inadequate or non-existent, there are a number of modifications which can be made to this project while still maintaining its' educational value. Modifications can also be made to examine other behaviors or characteristics of reinforced concrete design and construction.

One area where changes could be made is with the construction materials. A lower, or higher, concrete compressive strength, or grade of steel reinforcement, can be specified. As an alternative to having each team develop their own concrete mixture and casting at an industrial site, all teams could use the same mixture proportions with the concrete supplied by a ready-mix plant. Removing the development of a concrete mixture simplifies the project and allows more time for the other phases of work. Moreover, problems associated with trial batching and the transport of formwork to a batching facility are eliminated. If a common mixture were used, then some other aspect of the project, such as moment capacity or span length, should vary among the teams.

On the structural side, longer beams, smaller cross sections, or a reduced bending moment capacity could be specified. LaFave et. Al. (3) report on a project involving beams only 3 x 6 inches in cross section and 55 inches in length. These beams were tested in a 110,000-lbs. universal testing machine. Benefits of this approach include lower materials and construction costs, a more manageable beam size, and the elimination of the need for a forklift or load frame. The biggest disadvantage of this approach is the loss of "real world" construction experience.

In the most recent version of this project ready-mixed concrete is used, beam length has been increased to 10 feet, and each team is given a unique combination of concrete compressive strength and required moment capacity to design for. These changes have stream lined the project schedule. Further, since this change all beams have failed in flexure.

Summary

While there has been no formal assessment of this project, students have found it to be a valuable learning experience and worthy of their time and effort. The following excerpts and paraphrased comments, taken from student reviews of the project, confirm this.

- The opportunity to construct the beam complements the design portion of the class well.
- The educational value of this project was very high. Overall, this project did a very good job of reinforcing design concepts and provided a basis in reinforced concrete design that we will remember for a long time.
- The most important part of the project was the opportunity to translate a design into something tangible.
- Trying to construct the forms to meet the design specifications was definitely the hardest part of the project.
- The most demanding part was trying to find what we needed to construct the beam. It was hard to meet our deadlines when others outside our group, supply people, were involved.
- The most interesting part of the project was breaking the beam and finding out if our design would hold up.

- This was a good experience. Every class should have "hands-on" learning like this project. Too many classes are "here's what's given, now solve the problem".
- I had no idea how to approach this problem or how my team was going to complete the work. By the end of the semester, however, I was very confident in my knowledge of reinforced concrete design and now know things I never expected to learn.

A final clue to the success of this project is the requests by students that the beam project is included when they take the course.

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