AC 2007-2802: STUDENT FEEDBACK AND LESSONS LEARNED FROM ADDING LABORATORY EXPERIENCES TO THE REINFORCED CONCRETE DESIGN COURSE

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Student Feedback and Lessons Learned from Adding Laboratory Experiences to the Reinforced Concrete Design Course

Abstract

In an effort to demonstrate lecture course material, a class project was added to the senior level Reinforced Concrete Design course that incorporated beam testing. The concept of beam testing is not new. Many universities test reinforced concrete beams in flexure and in shear. What sets this experience apart is the effort to coordinate beam testing with lecture topics, the types of failures illustrated, and requiring the students to illustrate in the laboratory a concept they learned in the classroom. For most semesters, beams were cast and tested to illustrate tension and compression controlled failures, shear failures, and finally inadequate splice length failure. Once their beams were tested, the students were required to prepare a project report. Overall, most student responses were positive in nature. Typical student responses were centered on lessons learned in the laboratory, such as tying steel, that are not covered in classroom lectures. Also presented in the paper are lessons learned from the faculty members' point of view, along with several areas of improvement for the project.

Introduction

Reinforced Concrete Design (or Concrete I) is generally a junior or senior level course in most civil engineering curriculums. At the University of Arkansas, Concrete I is a three hour course consisting of three, 50 minute lectures per week. Depending on the University, there may or may not be an additional laboratory or drill section. Typically this first course in concrete design covers materials, flexure (analysis of rectangular beams, irregular shapes, T-beams, one-way slabs, doubly reinforced beams), shear and diagonal tension, column design, and development of reinforcing steel. The objective of integrating laboratory beam testing into the course was to illustrate classroom lessons, lectures, and homework. This project required each student group to meet outside of the normally scheduled lecture time to cast their reinforced concrete beams, but testing was conducted during the lecture periods.

Background

Practical experience whether it is design experience or construction experience is a desired trait in civil engineering graduates that many employers seek. In an article directed to young engineers wishing to enter the construction industry, an industry that many civil engineers choose to enter, an executive vice president advised young engineers "to get a good understanding of how the work is done".[1] Students may gain this understanding during part time jobs while they are in school, but there are students in most civil engineering programs that have never been exposed to a construction site. Additionally there are students and engineers who have never built something they had designed yet their designs may be detailed to fractions of an inch. One of the many goals of building and testing reinforced concrete beams as a class project is to provide this type of experience to undergraduate students.

Beam testing in Reinforced Concrete Design is not new. In 1996, the LaFave et al. of the University of Michigan reported on the testing performed in their Reinforced Concrete Design course. For their course, three sets of beams and columns were tested during the design lab that accompanied the course. Specimens were prepared outside of class by volunteers, and the beams specimens measured 3" by 6" by 55" while the columns were 5.5" by 5.5" by 24". The students were required to calculate the nominal moment capacity using the ACI 318 Building Code and compared their results to the actual behavior of the specimens. The students also compared the behavior of the beams using the given material properties to the measured material properties. The testing was coordinated with the lectures so that each series of tests followed the lecture on that specific topic.[2]

In 1998, John Schemmel of the University of Arkansas published a paper on the beam design project that was a requirement in their Reinforced Concrete Design course. The class was broken down into groups depending on the size of the class, and each group of students was required to build a reinforced concrete beam. The groups were required to obtain the materials (reinforcing steel and formwork) through purchase orders, design the concrete mixture, build the formwork, test the beam, and prepare a written and oral report. A local company provided the concrete used in the beams. The width and depth of the beams were limited so that the beams could fit into the loading frame, but the length was a constant 8 ft. for all beams. The students designed their beam for a targeted nominal moment capacity of 30 kip-ft and were penalized if their beams did not attain this value.[3]

In 2004, Griffin and Meyer of the United States Military Academy reported on a similar project. In their course, the cadets cast 4" by 6" by 84" beams for shear and flexure tests. Their beams contained two No. 3 rebar along with 1/8" diameter stirrups. The laboratory tests were scheduled so that they immediately followed classroom instruction. The students, which were divided into groups, compared the experimental results to those predicted using ACI 318 Building Code design methodologies. They also examined the affect of concrete mixture proportions on strength and the affect of compressive strength on member behavior. Student feedback was positive with 25 of 33 cadets "agreeing that the laboratory portion contributed to their understanding of the course material".[4]

Finally, in 2006, Cleary of Rowan University presented a paper on a project that incorporated laboratory testing into a reinforced concrete class that did not have a laboratory component. Cleary tested beams that were ductile and brittle, and he tested one beam that failed in shear and another that experienced an anchorage failure. The beam testing was coordinated with the lecture schedule. Originally he had planned that the students cast the beams, but due to the time restrictions of the course and the desire to demonstrate a multitude of beam failures, the beams were cast prior to the beginning of the semester. The outcomes of the beam testing were measured through course evaluations, student comments, and final exam scores. Final exam scores improved as did the course evaluations, and student comments regarding the project were generally positive.[5]

As shown above, beam testing to illustrate classroom topics is not a new idea. However, this paper includes the additional testing presented by Cleary, but this project also requires the students to develop their concrete mixture proportions and cast their beams.

Project

Typically on the first day of class, the students are divided into teams of five to six students. Each team was randomly assigned a beam to cast and test. The students are provided a packet that gives the details of the beam they are to cast (for example, tension controlled or compression controlled), project requirements, and specifications. The loading information and cross-sectional dimensions that are provided to the student groups is shown in Figure 1.

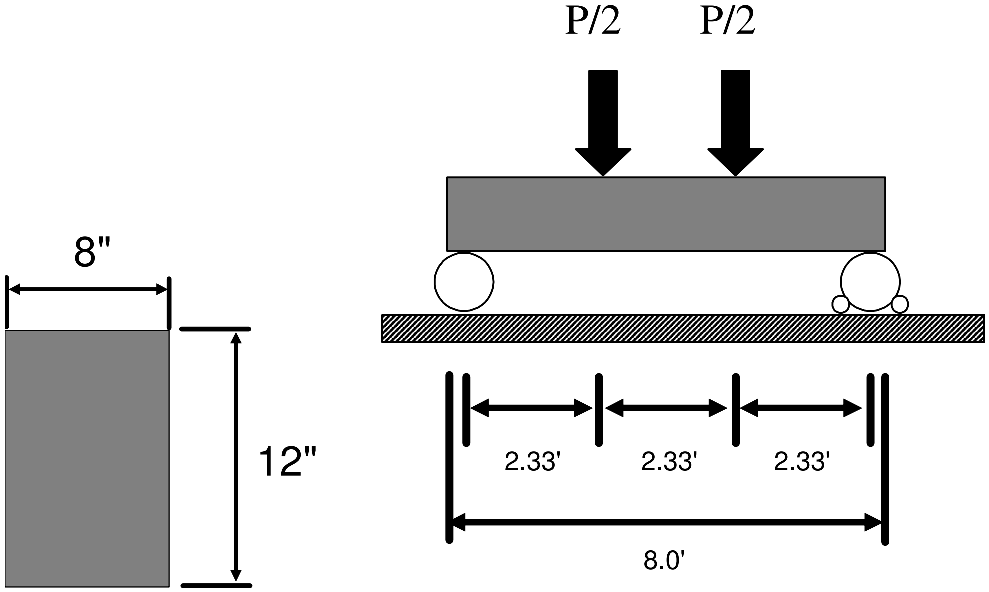

Figure 1. Beam Dimensions and Loading Configuration.

Design Requirements

Prior to the beginning of the semester, three reusable forms were made. Beam dimensions were 8” x 12” x 8 feet long. The capacity of the beam could not exceed 200 kips and all beams were third point loaded. Knowing the type of beam they were to cast (tension controlled, compression controlled, etc), the students used the given maximum load information and the required failure mechanism to select the longitudinal (flexure) and vertical (shear) reinforcing steel. Additionally, the student groups must develop a concrete mixture that would attain a compressive strength of at least 4000 psi at the time of testing.

The Beams

In the Spring 2004 semester, a total of seven beams were cast and tested. The enrollment in the course for that semester was 35 students and these 35 students were divided into seven groups of five students. The beams that were cast are described in detail below.

Tension and Compression Controlled. A tension controlled beam, as defined by the ACI 318-05 Building Code, is a beam or section with a net tensile strain of at least 0.005 in the extreme tension steel when the concrete in the extreme compressive fiber reaches its maximum strain of 0.003. Basically, this assures that the steel yields long before the concrete crushes and the beam displays a ductile failure mode resulting in significant member deflections. On the contrary, compression controlled members are those sections where the net tensile strain in the extreme tension steel is equal to or less than 0.002 when the concrete reaches its maximum strain of 0.003. Compression controlled failures would generally be described as being brittle and occur with little or no warning (little deflection observed).

For this project, both a tension controlled and compression controlled beams were cast and tested. Beam 1 was designed to be tension controlled and to exhibit a ductile failure. Beam 2 was designed to be compression controlled and to exhibit a brittle failure. The objective to testing Beams 1 and 2 was to show the benefits of ductility through the large deflections for Beam 1 before failure versus small deformations before failure of Beam 2. Beams 1 and 2 were cast together using the same concrete mixture proportions, and scheduling of the construction and batching was done entirely by the students.

Shear Design. As with the compression controlled failures, shear failures also occur with little warning and can be catastrophic. To prevent shear failures, beams contain vertical rebar, called stirrups, which resist the shear forces that exceed the capacity of the concrete. Beams 3, 4, and 5 were cast to illustrate the necessity of shear reinforcement. All three beams contained the same longitudinal reinforcement and were batched with the same concrete mixture proportion. The differences between the beams were in the shear reinforcement. Beam 3 did not contain any shear reinforcement. The shear reinforcement in Beam 4 consisted of steel fibers. Beam 5 contained No. 3 stirrups at spacings that met the ACI 318-05 Code requirements.

Development Length. Development length, l_d, is the length of bar necessary to develop the yield strength, f_y, of the reinforcement. If the distance to a point where is f_y is required is less than the development length, the bar will pull out of the concrete. Many times beams or columns require reinforcement longer than what can be provided. In those cases, it is necessary to splice the reinforcement together. Splices are used to transfer the force in one rebar to another. Splice lengths are dependent upon the development length. ACI 318 – 05 Code requires the splice length to be $1.0l_d$ or $1.3l_d$. Beams 6 and 7 were cast to illustrate the importance of adequate splice lengths. Both beams were cast with the same concrete mixture proportion along with identical shear reinforcement detail. Both beams contained 2 No. 6 rebars which were spliced at mid-span in the constant moment region. The splice length for Beam 6 was 27 inches ($1.3l_d$). The rebar in Beam 7 was spliced at approximately 25 percent of the length required by ACI 318-05.

Beam Casting

In addition to designing their beams, the teams had to coordinate with each other to plan the time and date their beams would be cast. The construction time could not be during a regular lecture time of Concrete I or any other class. During a typical semester, the students would build their rebar cages and cast their beams on the same day. Depending on the number of students in the groups, this would take approximately four to five hours. Usually the groups would divide into two, where half of the group would begin building and tying the rebar cages and the other half of the group would weigh out the approximately 900 lbs. of materials needed to cast the 5.33 ft^3 beam. The students would also measure the slump, unit weight, and air content of the fresh concrete and cast cylinders for compressive strength testing. Figures 2 and 3 show a beam prior to and during casting.

Figure 2. Wood Form Prior to Casting.

Figure 3. Placing Concrete into Form.

Beam Testing

Unlike casting which took place outside of class time, beam testing took place during lecture so all students could benefit from the exercise. Prior to the arrival of the students, the professor along with the Teaching Assistant and any available graduate students would load the beam into the testing frame, attach the necessary hydraulics, and prepare the beam for testing. Once the students arrived, the group members measured the compressive strength of the cylinders cast from the same concrete used in the beam. The beam was then incrementally loaded until failure. The load was applied at 5000 lb. increments during the initial stages and was reduced to 2000 lb. increments at the later stages. Throughout loading, the students measured midspan deflections and recorded loads. Shown in Figures 4 and 5 is a beam prior to and after testing.

Figure 4. Beam Prior to Testing.

Figure 5. Beam After Testing.

Report

The final aspect of the project is a final report prepared by the students. On the day of the final exam, each group was required to submit a final report for their project. The project and report accounted for 15 percent of the students' grade. The report summarized the findings of the beam fabrication and testing. The students were also required to compare the measured values (cracking moment, deflections, total load, etc.) to the predicted values and discuss why there were differences between the two.

Project Modifications

The student project began in Spring 2004 and since that time there has been several changes made to the project. These changes were made in an effort to improve the learning experience for the students and to ease the time requirement on both the professor and the students. The project changes are listed below.

1. In the Spring 2004 semester, the student groups specified No. 4 (0.25 in.) stirrups for the beams, but the steel fabricator was unable to bend the No. 4 stirrups to the correct radius. For future semesters, a tool was made that allowed the students to bend their own stirrups.
2. The width of the beams was reduced from 8 in. to 6 in. which reduced the total quantity of concrete needed to cast the beams.
3. For the Fall 2006 semester, strain gages were attached to the tension steel and placed in the compression zone (2 in. from the extreme compression fiber). This allowed the students to monitor strains during testing and they were able to compare measured strains to those that are assumed during design.
4. Students are now required to provide the professor a list of all the reinforcement needed to cast their beams at least one week prior to casting. The students provide the rebar sizes (both tension steel and stirrups), the dimensions, and the quantity. This ensures that the steel company has ample to provide the steel. For the inaugural project, casting was delayed because the steel company did not have adequate time to bend the stirrups.

Conclusions

Beam testing has become a core project in Reinforced Concrete Design at the University of Arkansas since Spring 2004. The time commitments required for the professor can at times be somewhat overwhelming, but the lessons the students learn from the project are not easily learned in the classroom. It can be difficult in a classroom to teach students about tying steel, placing rebar chairs, and vibrating concrete. Additionally, seldom do students actually build something that they have designed and then test it to failure. These are just a few lessons the students learn during beam construction and do not include the many lessons that are learned during testing. Overall, student comments regarding the project have been positive and the project will continue to be a part of Reinforced Concrete Design. Below are just a few student comments taken from the course evaluations and project reports.

- "There was a significant amount of learning during the construction of the beam that you could not get from normal lectures, only from actually building the beams."
- "Being able to get the hands on experience, not just designing alone, was invaluable. Even though our beam did not behave as planned, our understanding of design criteria was positively influenced."
- "Beam breaking in lab was excellent demonstration."
- "Beam designs are also really good. I enjoy lab work (and it helps me learn the material better)."

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