Enhancement of Learning by Hands-On Experience in Design of Reinforced Concrete Structures

Abstract:

For a better learning experience, students taking the "Design of Reinforced Concrete" course at the Kansas State University were required to design, construct and test a real-size reinforced concrete beam. In their design they evaluate the beam capacity in terms of the first cracking, first yield, and ultimate loads; as well as service limits such as crack width and beam deflection under various service loads. Their design covers approximately all of the material taught in the course including flexural analysis and design, shear design, bar development length, serviceability in terms of crack width and deflections.

Students are divided into 4 groups to do the "formwork", "caging", "pouring", and "testing" in 4 different 2 hour laboratory sessions.

All of the students participate in the first session for introduction to the laboratory and general procedure; the third session to observe the pouring process and making concrete sample; and the last session for testing concrete samples and beam specimen.

The project provides students with a real-world design and hands-on experience to enhance their understanding of reinforced concrete structures.

In the survey conducted at the end of semester, students consistently and unanimously stated that the project effectively provides them with a better learning experience.

Keywords: Reinforced Concrete; design; construction; test; hands-on experience

Introduction

Design of Reinforced Concrete Structures is one of the basic design course for civil engineering students and a required course for those with "structural" option. Understanding design procedure, construction and real performance of a reinforced concrete structure and structural member is a basic requirement.

Hands-on engineering, which means learning by doing, has proven to be an effective approach to learn any subject, especially engineering subjects and particularly design courses (Carlson 1999).

To address this need, a “project” component was designed and implemented as a part of the “Design of Reinforced Concrete Structures” (CE 544) course.

Project

The project included the design, construction and testing of a reinforced concrete beam. The project was introduced to students by providing the drawing of a reinforced concrete beam, on which the dimensions, and initial reinforcement for flexure and shear was provided.

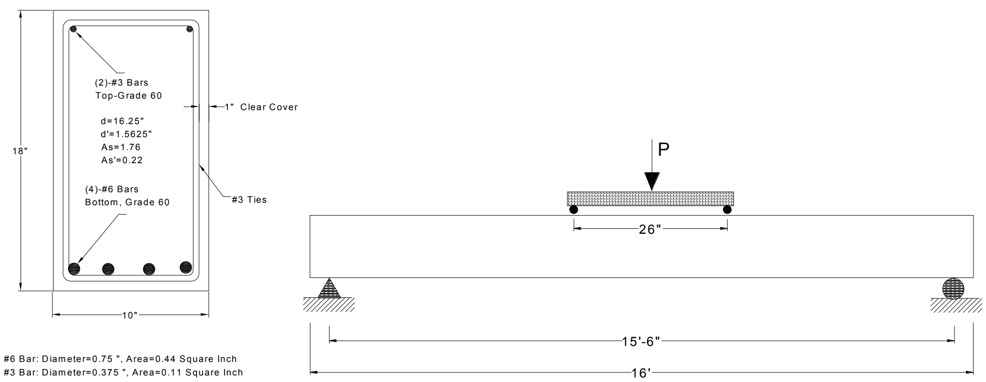

Figure 1: Cross-section and test setup of the beam

The project was intended to cover the main parts of reinforced concrete analysis and design, various aspects of construction process, and assessment of the real performance and capacities compared to design values. Each year, usually 2 beams were constructed with 2 different lateral reinforcement arrangements. Though the confining effect is not considered in the current ACI code for strength evaluation of the section, students can observe its effect on the beam strength, ductility and failure mode.

Also, strain gages are affixed on the longitudinal bars and transverse ties in the middle of the beam on the top, bottom and middle of the section and the test data containing this information is provided to students to help them with a better understanding of the behavior of reinforcement especially in lateral direction and its role in providing the confining pressure, enhancing the flexural capacity and altering the failure mode.

Analysis: Parallel to the course progress, each student was required to do the following analysis.

1. Analyze the section for:

    a. Cracking moment of the section as a total section (M_{crack}, considering steel and concrete in the full linear-elastic section).

   b. Moment corresponding to the first yield of steel, (M_y, assuming the section is cracked, linear and elastic).

   c. Nominal flexural strength (M_n).

   d. Available design moment capacity (ϕM_n, considering the proper strength reduction factor)

2. Use the results from 1 and considering the test setup to evaluate:

   a. Applied force at the first crack (cracking force P_{cr}, note that the self-weight should be considered as a uniformly distributed load and the force P_{cr} as a concentrated load applied as shown in the figure)

   b. Applied load at the first yield, P_y (linear elastic section)

   c. Applied ultimate force P_n (no reduction or load factor) corresponding the M_n

   d. P_{serive} if the only dead load is self-weight and the applied load, P_{serive}, is treated as live load. Note that ϕM_n should be used in calculations, and load factors should be applied to the loads.

3. Using the above results:

   a. Determine the deflection at the first crack (right before and right after cracking)

   b. Deflection at the first yield of steel (if elastic-linear)

   c. Deflection at ultimate capacity

   d. Instantaneous deflection due to $P_{service}$

   e. Find the crack width for a crack at the center of the beam (a) right after the first crack, (b) at the first yield, and (c) under self-weight and service load $P_{service}$ using both crack equations

4. Check the beam for shear (find the spacing of the stirrups) so that the failure is controlled by flexure and not shear, and see if the given spacing for the beam is enough.

5. Check if the given spacing for the beam is enough if the critical section for seismic considerations is located at the mid-span. (see the ACI codebook, chapter 21, section 3)

6. Check the development length of the main bars (the #6 bars which are under tension).

7. Using the test data, compare the forces predicted in 2, with the test results

Laboratory Work (construction): students were be divided to 4 groups to do the “formwork”, “caging of the reinforcement”, “pouring concrete”, and “testing the specimens” in 4 different 2 hour sessions in the laboratory.

Group#1: Formwork: preparing the form for the RC beam as shown, so that the next group can prepare the cage and put it in the form. This includes cleaning the form as will be explained in the lab.

Group#2: Caging (putting the rebars and stirrups together, and then put the cage in the form. It is critical to place the bars in a right position in the beginning to avoid difficulties in completing the cage).

Group#3: Casting the concrete (including vibrating the concrete, and especially clean up after the job is done. Be careful to fix the forms in lateral direction before casting the concrete and especially starting vibration. Also, watch for the instrumentation and be careful not to damage them.) Prepare 6 cylindrical samples following the correct procedure. These samples will be tested on the test day to get the actual compressive strength of the concrete.

Group#4: Stripping the specimen and moving it to the test place and setting up the specimen to be tested. (Be careful not to damage the wires coming out of the specimen(s).) Complete clean up after the test and removal of the specimen tested. (Test date)

Testing: Students attend the laboratory to test the beam and concrete samples. Students in testing group conduct the test under the supervision of the instructor and laboratory personnel. The test setup and test procedure and protocol is explained for the students. For this specific beam with an approximate yield load of 48 kips, test starts in a force-controlled mode from 0 to 40 kips, with a rate of 2 kips/ minute and then switched to displacement controlled mode at 40 kips up to the end of the test at a rate of 0.2 inch/minute. Experimental data, including the force recorded by 2 load cells, displacement at the mid-span recorded by 2 LVDTs, strains recorded by several strain gages on the longitudinal and lateral reinforcement, and local deflections recorded by 3 displacement potentiometers is sent to individual students. This data is treated and initialized before sending to students and is used to compare the actual performance with their predictions.

Figure 2: Construction and testing

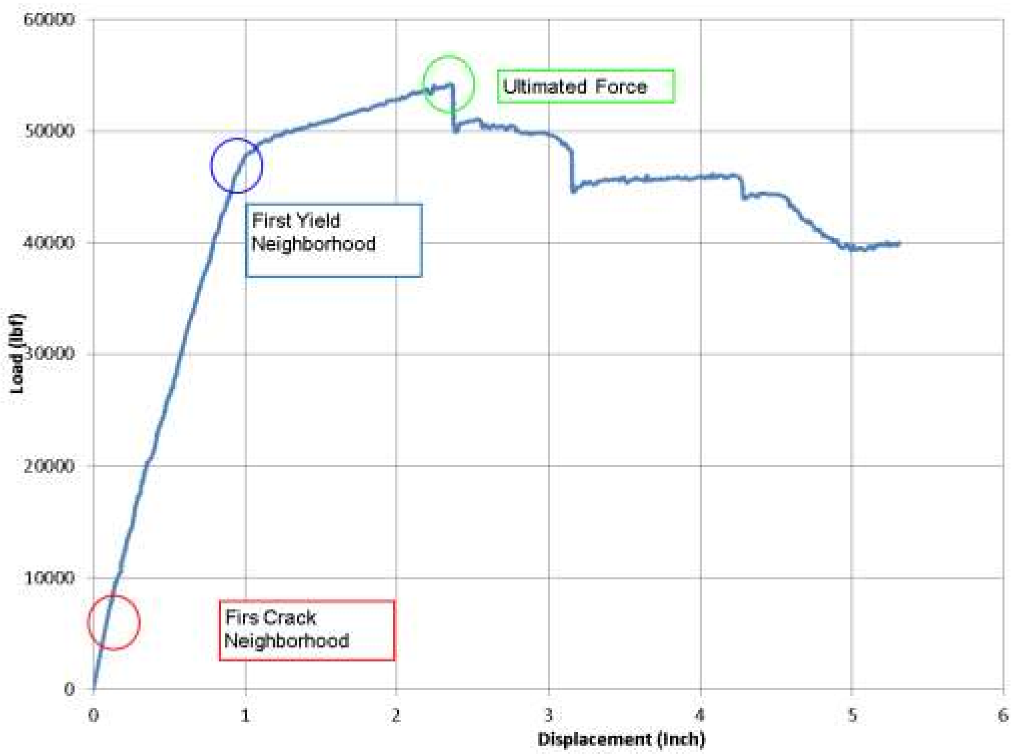

Figure 3: A figure showing the experimental force-deflection (Fall 2012 – test on December 2012)

Students Project Report

Each individual student will submit a brief report consisting of the details of the beam with sketches, complete analysis of the beam as described in directions and project assignment, a brief description of the whole construction process including the procedure followed on the day of pour and the procedure followed on the day of testing, type of failure that occurred when testing the specimen, a schematic of the crack development in the beam, comparison of theoretical versus recorded data (this includes comparison of the predicted forces and deflections at different stages with the actual values from test.)

Pictures and videos from the 4 laboratory sessions and the beam during the test are posted on the class site.

Conclusion

For a better learning experience, students taking the “Design of Reinforced Concrete” course at the Kansas State University design, construct and test a real-size reinforced concrete beam.

The project provides students with a real-world design and hands-on experience to enhance their understanding of reinforced concrete structures.

Progress of the project work, including analysis and design, construction and testing is parallel to the course progress and covers all of the basic components of the material addressed in this course.

In a survey conducted at the end of semester, students consistently and unanimously have stated that the project effectively provides them with a better learning experience.

The project is also a complete review of the course material combined with real-world application and hands-on experience which helps students to have a deep understanding of the subject matter and maintain their knowledge on reinforced concrete structures years after graduation. This claim is based on the responses from our former students graduated more than 5 years ago, in 2004 and after.

References:

Carlson, L. E., & Sullivan, J. F. (1999). Hands-on engineering: learning by doing in the integrated teaching and learning program. *International Journal of Engineering Education*, *15*(1), 20-31.