Getting Students to Think Green: Incorporating Green Building Rating Systems into Undergraduate Reinforced Concrete Education

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Abstract

This paper presents a plan for introducing undergraduate students studying reinforced concrete design to sustainable engineering. As increased emphasis on sustainable development initiatives continue to gain popularity it is imperative that young engineers entering into the design and construction industries understand the potential that concrete has for building green.

Beginning on the first day of instruction, students are encouraged to explore how the use of supplementary cementitious materials (SCMs) can increase the amount of recycled content in the construction of a building. This theme continues as the students are required to develop and implement a plan to optimize the amount of granulated ground blast furnace slag, fly ash, and silica fume that can be included in a concrete mixture without adversely affecting characteristics such as strength, stiffness, and workability. After gathering data through hands-on laboratory testing, the students prepare a report recommending an optimal SCM content.

This instruction method can fit easily into the existing curriculum of most undergraduate reinforced concrete design and laboratory courses. It introduces engineering students to the relevancy of reinforced concrete as a sustainable building option and lays the foundation for further study in this rapidly emerging field.

Introduction

Let's face it, the future is green! An increased emphasis on energy efficient, sustainable structures is sweeping through the building industry. Architects, engineers and developers alike are attracted to the increased marketability and decreased life-cycle costs of "green" buildings. Today's educators must ensure tomorrow's engineers embrace sustainable design. With most engineering courses already bursting with content, adding sustainable construction initiatives can prove a daunting task. Typically incorporating any new content means making tough choices about what to remove in order to make room. This paper proposes a viable method for weaving a green environmentality into a standard undergraduate reinforced concrete design course without sacrificing course content.

The United States Green Building Council has established an industry standard in Green Building Rating Systems with their Leadership in Energy and Environmental Design (LEED) certification. The LEED certification process involves earning credits for environmentally friendly construction processes and materials and the use of efficient building systems. The certification has several tiers (gold, silver, etc.) for different levels credit.[1] One way LEED credit can be earned is through use of recycled building materials. Fortunately for reinforced concrete, several common supplementary cementitious materials (SCMs) are classified as such. Slag, fly ash, and silica fume are waste products of various industrial processes. All three have been used to some degree in concrete mixes for years as a means of both reducing cost and modifying performance. Recently, however, engineers seeking to maximize the amount of recycled content have begun to specify their use in greater percentages. Although it is certainly desirable to use as much recycled content as possible, too much of an SCM can adversely affect the behavior of hardened concrete. Engineers must understand how much is too much. Extensive research into this topic can be found in the literature—some would even consider it a solved problem. Nonetheless, relooking it provides a great vehicle for an undergraduate reinforced concrete laboratory experimentation program.

The plan advocated below takes a three phased approach. The first phase focuses on self-learning as students design an experiment and prepare a research proposal aimed at determining the maximum amount of SCM (for use in earning LEED credits) permissible without sacrificing performance. The second phase includes conduct of the experimental regime and the gathering of relevant data. In the final phase students prepare a technical paper in which they recommend practical limits for slag, fly ash, and silica fume inclusion in structural reinforced concrete mixes based on their observations.

Phase I: Designing the Experiment

Our course became green before the first day of class. As an initial reading assignment, the instructors posted several documents pertaining to green building ratings systems, LEED, and SCMs on the course webpage. With each a hyperlink to a relevant internet site was included for the students to explore. Via email they were asked to review the material prior to the first class meeting. The goal of this was to pique student interest by starting off with a hot topic—one not expected to play such a prevalent role in a reinforced concrete course.

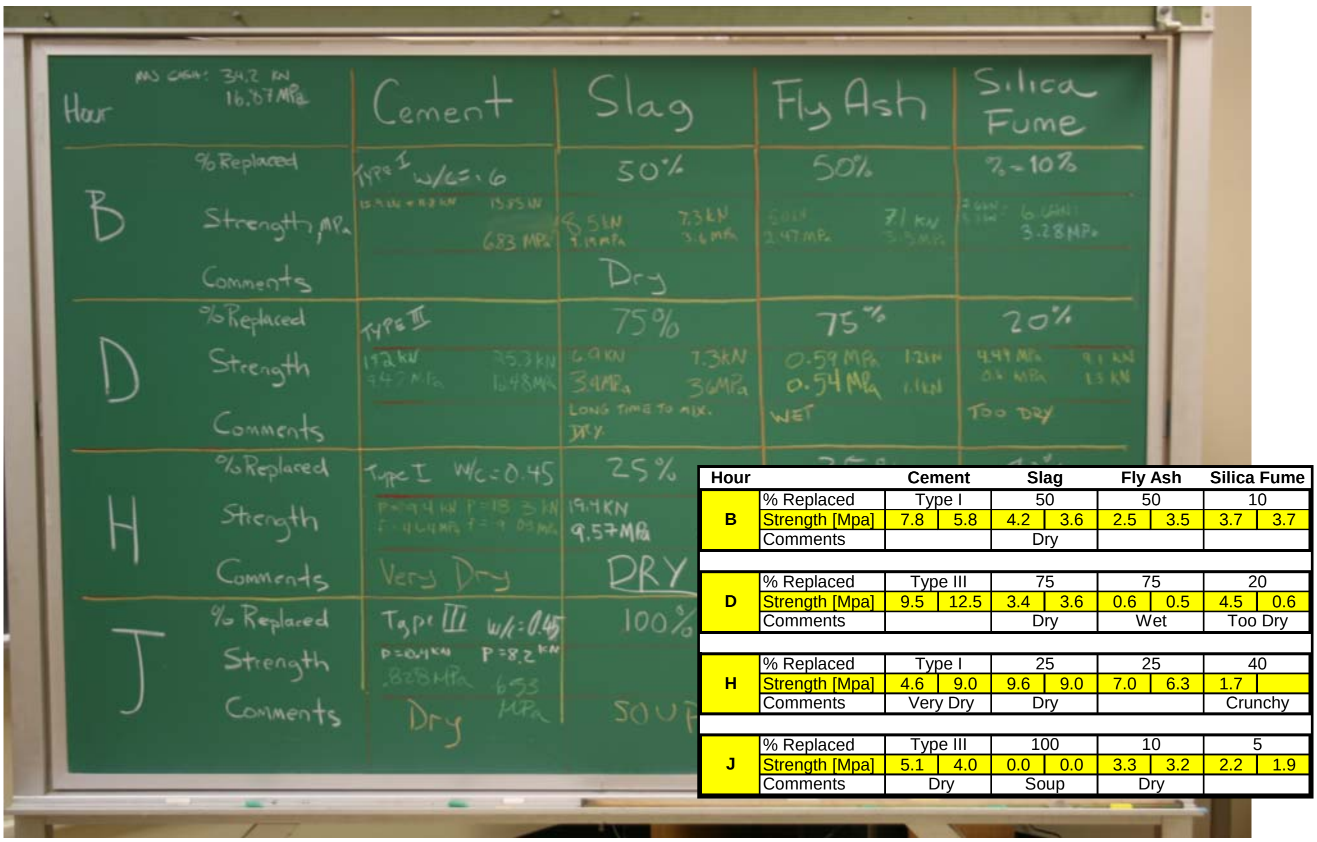
A brief explanation of the organization of the course is probably useful here. The US Military Academy requires that class size be limited to 18 students. With a reinforced concrete course of 57 students this year, the course consisted of 4 sections of about 14-15 students each. The course meets for 40 lessons of 55 minutes each and also for 8 lab sessions lasting 2 hours each.

On Lesson 1 the instructors challenged their students to design and mix their own concrete. A majority of the students had never made concrete or had any experience with slag, fly ash or silica fume. The class began with a brief introduction to LEED and a discussion of the potential for SCMs to help reinforced concrete structures achieve certification. The students divided into four groups (3 or 4 students per group) and set to work. Each group used the 3:2:1 heuristic for concrete mix proportioning (three parts coarse aggregate, two parts fine aggregate, one part cement) and a common water to cement ratio. One group per section served as a control and did not use any admixtures in their mix. The remaining three were each assigned either slag, silica fume, or fly. Armed with only what they learned from the online read-ahead, the groups with the SCMs were allowed to choose a percentage of their mix's cement to replace with their respective admixture. They mixed their batches in gallon sized zip-top plastic bags and cast two 2 inch x 4 inch test cylinders. As each group finished, they recorded their percentage of cement replaced and any observations about the wet properties of their concrete mixture on the classroom chalkboard. Subsequent sections added their data to the same board. Mixing required only a few pieces of basic equipment, as shown in Figure 1, and could easily be accomplished in a standard classroom.

Figure 1: Materials Used for Lesson 1

At the start of Lesson 2 the instructors devoted fifteen minutes for the students to load test their cylinders to failure in compression using a universal tension/compression machine. Each group noted the compressive strength of their concrete, along with observations of hardened properties, and added them to the chalkboard from lesson 1.

This exercise accomplished several important objectives. It allowed us to introduce green building ratings as the vehicle for our lab program. It got our students excited about concrete and sustainable design by encouraging discovery learning in a hands-on environment. Finally, it gave the students a quick introduction to common concrete admixtures. They were able to observe first hand how too much silica fume can make a mixture unworkable and likewise, how too much slag can drastically slow the hydration process. The chalkboard, shown in Figure 3 provided students with a set of basic performance data for sixteen concrete mixes spanning a wide range of SCM contents. This was transcribed and posted to the course web-site for students to compare with published SCM use guidelines as they prepared their research proposals.



Hour		Cement		Slag		Fly Ash		Silica Fume	
B	% Replaced	Type I		50		50		10	
	Strength [Mpa]	7.8	5.8	4.2	3.6	2.5	3.5	3.7	3.7
	Comments			Dry					
D	% Replaced	Type III		75		75		20	
	Strength [Mpa]	9.5	12.5	3.4	3.6	0.6	0.5	4.5	0.6
	Comments			Dry		Wet		Too Dry	
H	% Replaced	Type I		25		25		40	
	Strength [Mpa]	4.6	9.0	9.6	9.0	7.0	6.3	1.7	
	Comments	Very Dry		Dry				Crunchy	
J	% Replaced	Type III		100		10		5	
	Strength [Mpa]	5.1	4.0	0.0	0.0	3.3	3.2	2.2	1.9
	Comments	Dry		Soup		Dry			

Figure 2: Student Observations from Lessons 1 & 2

These individual research proposals formed the last step in the first phase of the program. In them students were asked to design and communicate an experimental regime to determine SCM that afforded the maximum amount of recycled content without compromising design parameters. The requirement for a research proposal was not entirely open ended. Students were informed of the capabilities of available laboratory facilities. They were asked to focus their testing regimes on compressive strength, modulus of elasticity and splitting tensile strength and limited to sixteen total mixes, the number of lab groups in our course. In addition, they were specifically required to address: a series of proposed concrete mixtures, the tests they intended to conduct on the hardened concrete from each mixture, and a detailed plan for evaluation and presentation of their results. An added benefit of this program, though not the subject of this paper, is using these research proposals, the instructors were able to evaluate their student's ability to design an experiment. This is often considered one of the more difficult ABET outcomes to evaluate. This phase ended with instructors providing feedback on the student research proposals.

Phase II: Conducting the Experiment

Unfortunately it is impractical for each student to batch and test his or her unique 16 mix series during the course of one semester. Instead, the instructors agreed upon a series of mixtures and an appropriate testing regime. They presented this to the course as one possible solution scenario. The class as a whole would then collectively execute this proposal. Course enrollments facilitated the use of four student groups in each of the four sections. Assigning each lab group to cast and test one batch afforded 16 possible mixtures, the same limitation imposed on the students for their research proposals. The schedule of mixtures used is presented in Table 1. Conduct of the experiment extended over the course of three lab sessions. The first included mix proportioning. During the second the students cast specimens for testing during the third and final session.

During the first lab session, each student group proportioned their respective mixture and prepared the materials for later batching. At the start of the session, the instructors discussed the collective mixture series. Specifically addressed were how the cement replacement percentages compared to published guidelines on SCM use and the effectiveness of the proposed percentages toward earning LEED certification credits. After the discussion, the students proportioned their mixtures according to the Portland Cement Association's absolute volume method of concrete mixture design[2]. Each designed a mixture large enough to cast the requisite test specimens. The session concluded with the students verifying their completed mix designs and weighing all materials they would need to batch the concrete during the next lab. Until then the materials were stored in air tight containers.

LAB Hour	Group	Admixture Replacing Cement	Percent Replacement (%)
R	1	Slag	5
	2	Slag	10
	3	Slag	20
	4	Slag	50
S	1	Slag	70
	2	Silica Fume	6
	3	Silica Fume	8
	4	Silica Fume	10
T	1	N/A	0
	2	Fly Ash	5
	3	Fly Ash	10
	4	Fly Ash	20
U	1	N/A	0
	2	Fly Ash	30
	3	Fly Ash	40
	4	Fly Ash	50

Table 1: Mixture Schedule

The second lab session consisted of mixing the concrete (this time using a mixer, not a plastic bag!) that was proportioned and measured in the first lab. Each group mixed their concrete and conducted tests on the fresh concrete properties. The purpose of the lab was to introduce students to typical ASTM testing methods (slump, unit weight, casting cylinders in the lab, etc.) and create the specimens for use in the following lab session. Students also observed the plastic state of each mixture for comparison to both what was found during the experimental session in lesson 1 and expectations based on reading they had done to prepare their research proposal.

During the third lab session the concrete cylinders were tested for compressive strength, modulus of elasticity and tensile strength. Again, the primary purpose was to get students familiar with applicable ASTM testing methods, but this lab also served as the source of the data they would use to draw conclusions about the viability of SCM percentages in the context of LEED certification. After all four sections of the course completed this third lab session, all of the data was consolidated and shared on the course website. Each student had access to the data and used that to write the report and draw conclusions about the experiment.

Phase III: Interpreting the Results

For their final lab reports each student was asked to write a technical paper, using the American Concrete Institute's journal formatting requirements. They were given the task of using the test data generated across the course to draw their own recommendations and conclusions about which SCM offers the greatest potential for LEED credits. To focus student effort the instructors provided an outline and a completed introductory paragraph for them to use if they desired. Not surprisingly, most did! The purpose of providing the introduction was to ensure each student understood the goal of the experiment before they began to interpret the data. The outline provided a common organizational format for their reports. The students did have freedom to generate their own methods of analyzing and interpreting the results of the experiment. They were required to determine and communicate their own decision criteria. In doing so, the students were not held to the methods they offered in their earlier research proposals. At this point in the course, the students had gained a much better understanding of the structural behavior of reinforced concrete. The introduction gave the students a starting point, but in order to properly address which SCM might be best from a sustainability vantage they needed to thoroughly research the Green Building Council's guidelines on LEED.

Was the Program Effective?

The instructors assert this program was effective. Introducing LEED as the vehicle for the course's laboratory program allowed the instructors to include Green Building Rating Systems in the course without sacrificing other content. The technical papers demonstrated the students had acquired some level of proficiency in this area. The fact that sustainable engineering is currently one of the hottest topics in our field certainly helped. The program was able to rely on student self-learning, at least in part, because the students wanted to learn. They see the value of building green.

The United States Military Academy department of Civil and Mechanical Engineering asks students about laboratory programs as part of their standard course end feedback. Figure 3 shows the results of Likert Scale responses to the statement: "In this course laboratory exercises contributed to my learning." The results for CE483 this term were significantly higher than the results for the department or the civil engineering specific courses. It is unclear why this is the case, but having a unifying theme from one lab session to another may contribute (most other courses do not have that in their lab programs). A further test of the program's effectiveness will come during term 08-2 when the students will be asked to address sustainability in their capstone design projects.

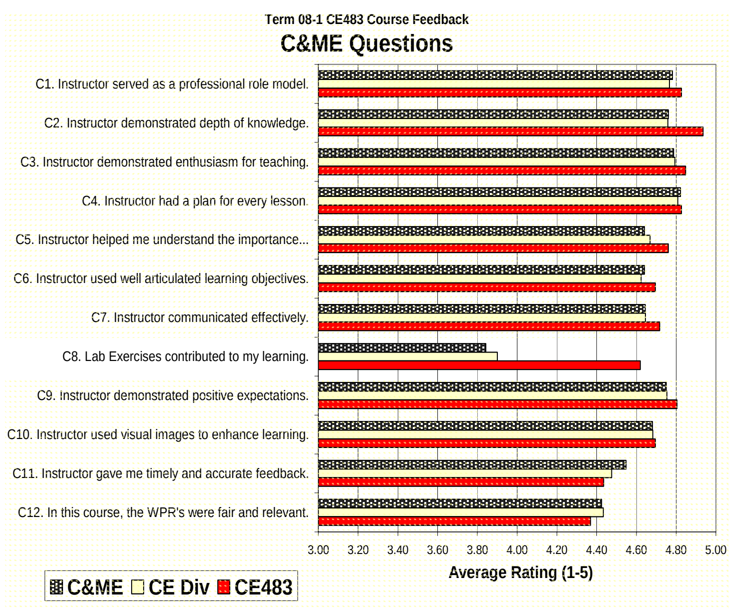


Figure 3: Likert Scale Responses

Conclusion

As popular demand and market trends continue to drive the construction industry toward sustainable development, undergraduate civil engineering programs must find creative ways to get their students to think green. Centering an introductory reinforced concrete laboratory program around the US Green Building Council's LEED certification provides one way to do so. This program allowed the United States Military Academy's Department of Civil and Mechanical Engineering to introduce students to Green Building Ratings Systems without sacrificing other course content. It requires few additional resources and can be easily incorporated into most standard undergraduate courses of study.

1. U.S. Green Building Council, *LEED for New Construction and Major Renovations, Version 2.2*, October, 2005.
2. Kosmatka, S., Kerkhoff, B., and Panarese, W.; Design and Control of Concrete Mixtures, 14th Edition, Portland Cement Association, Skokie, Illinois, 2002.