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Making, Curing, and Testing Concrete Cylinders in a Senior Level Construction Management Course

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There are few studies which expand upon construction management pedagogical content to guide professors, especially new professors, in the creation and development of hands-on labs. This paper is a case study adding to the construction management body of knowledge to show engineering and construction management educators a framework on how laboratory exercises for making, curing, capping and testing concrete compression cylinders, based on the American Society for Testing and Materials (ASTM) procedures, were developed and incorporated into a senior level construction management course. Included is a course history, description of the laboratory space and equipment and discussion of how the laboratory exercises relate to student learning. Numerical and graphical results of testing concrete cylinders at four different water-to-cement ratios are presented and discussed. Also, future opportunities for similar hands-on student laboratory exercises are identified and discussed.

Key Words: Concrete, Laboratory, Teaching Methods, Lab Exercises

Introduction

Creating a hands-on concrete laboratory is a challenging process to help students understand the essential properties found in a building material that is most widely used in construction. Students in the Construction Management program at Central Washington University (CWU) have a choice of two curriculum options: General Construction, which focuses primarily on building construction or Heavy-Civil Construction, which focuses mainly on roads, bridges, and utility construction. Regardless of the two tracks, all students are introduced the basic concepts of making, curing, and testing concrete cylinders for concrete placement applications whether for a building or bridge. Both courses are taught parallel to each other includes a required eleven-week four-credit (quarter system) senior level course entitled Concrete Construction for the General Construction and Asphalt and Pavement Design for the Heavy-Civil Construction students. The courses emphasize using concrete as a building material and managing concrete projects, as opposed to reinforced concrete design commonly found in engineering focused courses. These courses are not engineering design courses in concrete, but more of the management and understanding in the mechanical properties of concrete that are commonly found in a construction field operation utilizing concrete as a building material.

Literature Review

The laboratory exercises associated with the concrete construction course were developed to create an active learning environment, which has been found to be effective for most construction management students. Research at other institutions offering degrees in construction management indicates that construction students tend to be visual and hands-on learners (Arumala, 2002; Grier & Hurd, 2004). In 1999 a Midwestern university surveyed 73 undergraduate construction management students, mostly juniors and seniors, to better understand their personality types and learning style. Students were categorized by 16 different Myers-Briggs personality types. They were further separated into four simplified temperament groups. It was found that 75% of the students had a sensing/judging temperament and these students like to reach conclusions following a step-by-step approach and put what they have learned to use. It was also discovered that 67% of the students preferred hands-on learning (Stein & Gotts, 2001).

Offering an active learning concrete laboratory experience in a four-year construction management program does not appear to be common. Although other universities include a concrete lab, most of these universities incorporate this experience into a civil engineering curriculum, a technical certification degree program, or a degreed concrete management program, as opposed to construction management program. These universities include Purdue, California State University Los Angeles, Santa Clara University, University of Maine and Arizona State University. There are also universities which offer a degreed program in Concrete Industry Management (CIM) and these include Arizona State University, California State University Chico, Middle Tennessee University, New Jersey Institute of Technology, and Texas State University (www.concretedegree.com).

Course Background, History, and Topics

The concrete construction and asphalt pavement courses have both been offered at CWU for over 20 years in a consistent format, although changes are always being made to reflect advances in the construction industry, such as new concrete chemical admixtures and placing and finishing equipment. During this 20-year period laboratory exercises have been developed and refined, utilizing the acquisition of new lab equipment and a new lab facility. Topics incorporated into the course include concrete fundamentals, sustainability, desirable properties of fresh and hardened concrete, concrete aggregates, concrete mix water, air entrainment, admixtures, batching, mixing and transporting concrete, mix design, slabs-on-grade, placing, finishing and curing, hot and cold weather concrete placement, concrete formwork, and structural considerations in concrete.

The course incorporates a variety of delivery methods, including lectures, guest speakers, field trips and several laboratory exercises. The course typically averages about 24 students and the lab component of the course is divided into two separate sections with about 12 students in each section. Laboratory exercises assigned to students throughout the course include concrete aggregate and sand moisture content testing, concrete sand gradation analysis (ASTM C33), the slump test (ASTM C143) and making, curing, capping and testing 6 inch by 12 inch concrete cylinders (ASTM C31, C192, C511, C617, C39) (Kosmata & Wilson, 2011).

At Central Washington University the course is used to collect American Council for Construction Education (ACCE) Student Learning Objective (SLO) data for SLO #1 Create written communication appropriate to the construction discipline. The written communication created from these courses include written lab reports where students are required to calculate and describe water mix ratios, testing procedures, and report on the results of the testing procedures performed in the lab.

Methodology

A case study methodology approach was used to expand on the pedagogical content that can be utilized to create a concrete lab which will expand the construction management student knowledge in how concrete is tested and analyzed in either a lab or construction field situation. Therefore, the primary purpose of having the students make, cure, cap and test concrete cylinders is to familiarize them with proper ASTM procedures and provide a practical hands-on learning exercise where they can experience first-hand how varying the water-to-cement ratio for a concrete mix affects the compressive strength of the cured concrete. This information is covered in the text and in lecture, however the lab exercises give the students a better understanding and appreciation of engineering testing and also how technical specifications for concrete, as stated in a construction contract, relate to concrete on the job site. For example, specifications may call for a 14-day compressive strength for concrete in a building column of 3,000 pounds per square inch (psi). After going through the lab exercises the students can better visualize what is involved in making and testing concrete cylinders and what the fracture patterns on a 3,000 psi, 14-day cylinder break will actually look like. They also gain an understanding of the importance of proper concrete testing and how it relates to managing a concrete construction project to avoid delays and rework.

Facilities

The lab space is comprised of a 1,440 square-foot room on the first floor of a new technology building that houses the construction management program. The room is well lighted and has a concrete floor slab, work tables with stainless steel tops, casework and shelves for storage and a large integrated exhaust hood that vents to the building's roof. There are two stainless steel sinks in the room. One is a standard 30 inch double basin kitchen sink and the other is a larger four foot double basin industrial sink. Just outside the lab space is a large exterior concrete apron work area, complete with a grated washout pit and hose bib for cleaning tools and equipment used in the lab exercises. Water from cleaning is filtered by a drain system allowing cement and sand to settle in pit and manually cleaned and disposed of in a concrete recycling bin. Six 30-gallon galvanized steel garbage cans on wheeled dollies serve as storage containers for type I-II Portland cement, coarse aggregate and fine aggregate (sand). The aggregates are donated by a local batch plant and the instructor conducts the proper tests before the quarter begins to determine the absorption of the aggregates. This absorption value is provided to the students.

Equipment

Successful delivery of the labs is dependent on some basic tools and pieces of equipment, most of which are relatively inexpensive. Table 1 below shows a list of lab components and approximate cost. Much of the funding for the equipment was secured through donations from construction companies and private engineering and material testing firms.

Table 1

Concrete lab components and cost

Component	**Approximate Cost**
Plastic Mixing Tubs and Hand Tools	$300
Curing Tank (w/Thermometer and Spigot)	$500

Steel Garbage Cans w/Dollies (3 ea)	$650
Reusable Steel 6” x 12” Molds (6 ea)	$1,300
Capping Pots (2 ea)	$1,200
Compression Tester	$12,000
PPE: Rubber gloves, safety glasses, cleaning supplies	$300
Electronic Digital Laboratory Scales (3 ea)	$1,000

The concrete sand, aggregate and cement are stored in the steel garbage cans. For weighing and mixing the ingredients for the concrete cylinders students use electronic digital laboratory scales, small plastic buckets, a large plastic mixing tub, a mason’s trowel and an ordinary garden hoe. Reusable 6” x 12” steel concrete cylinder molds are provided. The concrete curing tank shown in Figure 1 was made in-house and consists of a 24” x 36” x 24” deep galvanized steel livestock water tank mounted on an elevated stand with a water spigot for drainage. The tank is heated by a simple 120 volt 1200 watt magnetic automotive oil pan heater that attaches to the bottom of the tank and is controlled by a digital wall-mounted thermostat unit. This unit senses the water temperature through a thermocouple probe mounted to the tank rim. The thermostat has a variable set point and is set to maintain the temperature of the water in the curing tank at the ASTM specified 73º +/- 3º Fahrenheit.

Figure 1. Concrete cylinder curing tank

Cylinders are capped using a sulfur-based concrete cylinder capping compound that is heated in one of two 110 volts thermostatically controlled, electrically heated pots as shown in Figure 2 below.

Figure 2. Capping compound pot

The heated capping compound is used in conjunction with a capping mold to ensure the caps are smooth and perpendicular to the longitudinal axis of each cylinder. Figure 3 shows the capping mold utilized in the lab.

Figure 3. Capping mold

The concrete cylinders are tested with a large hydraulically operated concrete compression tester with a 250,000 pound capacity, measured in 500 pound increments. The tester shown in Figure 4 has an analog readout with a manual follower needle to record the break point and a safety cage to surround the cylinder (cage is not shown in the photo).

Figure 4. Digital Concrete compression tester with readout

Lab Exercises

The lab component of this course occurs five times throughout the quarter and each lab correlates with the topic covered in lecture at the time. The first two lab sessions are dedicated to gaining an understanding of the moisture content for both fine and coarse aggregate and conducting a sieve analysis on concrete sand. In the next three lab sessions the students are assigned to one of four groups with three students in each group. A standard mix design is assigned to the four groups and is identical except for the water-to-cement ratio, which varies by group. This mix design, as shown in Table 2, is then used both for the slump test exercise and for making concrete cylinders.

Table 2

Concrete mix design

Ingredient	**Weight**	**Absorption**
Fine aggregate (sand)	12 pounds	1.5%
Coarse aggregate	22 pounds	1.8%
Type I-II Portland cement	6.5 pounds	
Water	Varies by group	

The four groups' water-to-cement ratios (w/c) are 0.45, 0.50, 0.55 and 0.60. The absorption of the aggregates is given to the student groups so that they can make proper aggregate moisture adjustments to their mix design to account for the fact that the aggregates are not in a "neutral" moisture content condition, known as saturated surface dry. By varying the water-to-cement ratio students gain an understanding of how the water-to-cement ratio affects not only slump but also, after testing the cured cylinders, how it affects the compressive strength. This relationship between strength and the water-to-cement ratio is emphasized in the lecture but the lab exercise significantly reinforces this point.

Lab Procedures for Making, Capping, Curing and Testing Concrete Cylinders

In about the eighth week of the quarter the student groups meet in the lab and weigh the ingredients based on their assigned water-to-cement ratio, adjusting the aggregate weights to account for absorption and the current moisture content in the aggregates. Prior to starting the lab, students are briefed on the safety procedures necessary for conducting the lab. On the outdoor apron they then mix the dry ingredients in a plastic tub with a garden hoe and then add the proper amount of water to create their assigned water-to-cement ratio. The ingredients are again mixed and each group casts one 6 inch diameter by 12 inch high cylinder in a reusable steel mold, sprayed with a release agent, per ASTM procedures. The cylinders are then stored in the lab until the following day when one member of the group is responsible for stripping, marking and placing the group's cylinder in the curing tank. Since the lab is split and there are four groups in each lab there are eight concrete cylinders, representing four water-to-cement ratios, in the curing tank at the end of the second day.

Two weeks (14 days, +/-) after the cylinders are cast the entire class meets as a group and the instructor demonstrates the proper procedure, including the use of personal protective equipment (PPE) for capping the cylinders using the heated sulfur capping compound. Because the heated capping compound smells strongly of sulfur, the two heating pots are turned on early in the day and placed beneath the vent hood in the lab. In prior years, before the new facility was available, the pots were placed outdoors using extension cords. After demonstrating the capping procedure with one cylinder the instructor supervises the students as they cap the remaining seven cylinders. As they are being capped (the compound hardens in minutes) the instructor places the capped cylinders inside the safety cage in the hydraulic compression tester. Each cylinder is slowly loaded until failure. Typically in a testing lab the cylinders are tested until the load needle on the machine just begins to fall from its peak. This avoids total destruction of the concrete and eliminates messy cleanup. However, in this lab, for learning purposes, the cylinders are loaded until they fail completely. At a high water-to-cement ratio the cylinders merely crumble. However, at the lower water-to-cement ratios, 0.40 and 0.45, the cylinders can "pop" with a very loud explosion. This in itself is a very effective tool to demonstrate to students the dramatic effect of varying the water-to-cement ratio.

Another benefit of breaking the cylinders completely is that the students can observe first-hand how the water-to-cement ratio affects the mode of failure. It is obvious that failure of the weaker mixes is the result of failure of the cement paste; it pulls away from the aggregate while the stronger mixes show marked aggregate fracture. In this case the cement paste has bound to the aggregate and is actually stronger than the aggregate itself. The load at failure, in pounds, for the eight cylinders is then recorded. The compressive strength is calculated using a spreadsheet and the corresponding results are graphed and presented to the students at the next class meeting.

Results

Students indicate that it is very beneficial to have the opportunity to see in person how concrete with a low water-to-cement ratio can become stronger than the aggregate itself after only 14 days of cure time, as demonstrated by the aggregate fracture shown in Figure 5.

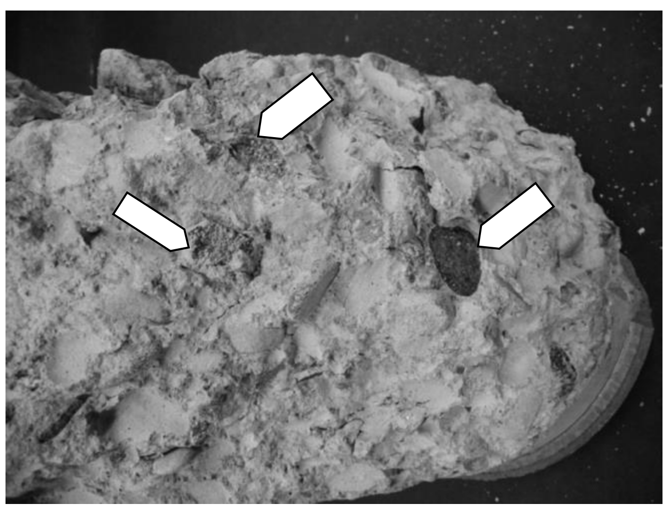

Figure 5. Aggregate fracture in cylinder with low water-to-cement ratio mix

Numerical results for the past year are shown in Table 3 and Figure 6. Note that the results from each of the two groups representing a specified water-to-cement ratio have been averaged before they are tallied. These results are presented to the students and clearly indicate that an increase in water-to-cement ratio decreases compressive strength. The results are also beneficial to the students because they are reasonably consistent with what is presented in the text and lecture. The class uses these results as a learning tool by discussing how water is often added to concrete in a mix truck on a job site to make the concrete more workable and easier to place, without thorough knowledge of the long-term effect this will have on hardened concrete.

Table 3

Concrete cylinder data

W/C Ratio	Area (in^2)	Group 1 Load (lbs)	Group 2 Load (lbs)	Avg (lbs)	psi
0.45	28.27	133,000	152,500	142 ,750	5050
0.50	28.27	130,000	124,000	127,000	4492
0.55	28.27	85,000	102,000	93,500	3307
0.60	28.27	61,000	84,000	72,500	2565

Curing time: 14 $^{+}/_{-}$ days

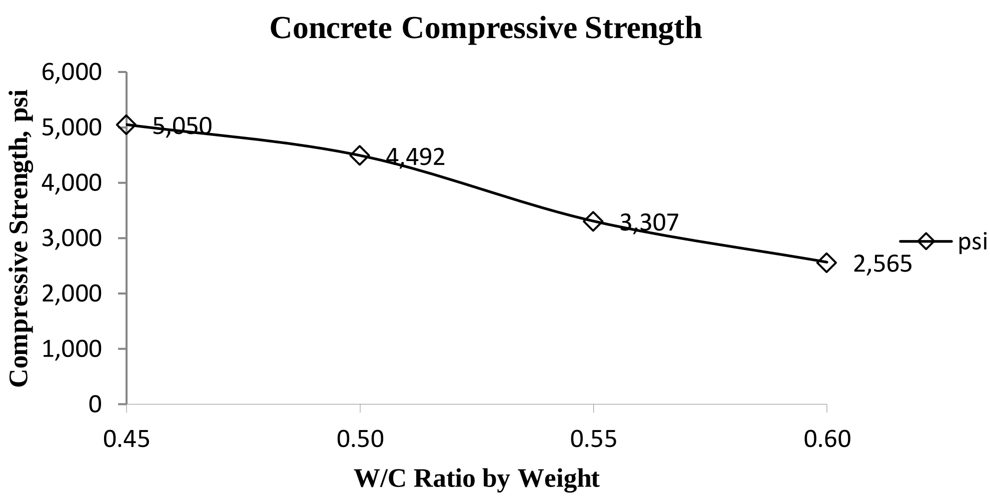

Figure 6. Compressive strength graph by water cement ratio

Discussion and Conclusion

Based on the results of this study, incorporating ASTM-based lab testing exercises into a concrete and asphalt materials class in a construction management program has proven to be a positive experience. Anecdotal evidence has demonstrated that the students thoroughly enjoy the chance to actually batch, mix, and place a concrete mix in test cylinders. They learn what a concrete mix will look like if the water-to-cement ratio is increased, about compression failures, and how compressive strength is affected by an increase in the water content of a mix. Additionally, when students are exposed in the lab to the different concrete mixtures, they can gain a "visual" or hands-on perspective as to the consistency of the concrete, which is a good reference for field applications as fresh concrete is placed in the field from the truck to final placement. Then referring to individual student calculations and the actual concrete mix in the lab brings the theory and hands-on application together.

Establishing the lab has been an ongoing process and a learning experience. Most of the equipment is relatively inexpensive, readily available at a local hardware store or from a testing/engineering supply company and easy to store and use. The one exception is the heavy and bulky hydraulic concrete compression tester, which carries a price tag of approximately $12,000. One possible way to create a lab experience for students without this cost would be to have the students make the cylinders in the lab and then use a field trip to a local testing lab to have these cylinders tested. Future hands-on laboratory learning opportunities for students include reinforced concrete beam and concrete mix design contests. These laboratory experiences will further expose students to the technical properties of concrete, the use of concrete as a building material and the managing of concrete on construction projects.

In conclusion, the real contribution of this study to the "construction management" body of knowledge shows there is little information on how educators can develop a concrete lab creating a hands-on environment for students to understand the engineering properties necessary for the proper testing and management of concrete construction in field operations. This case study identifies the types of equipment, costs, and basic lab approach that can be implemented at any construction management program. Additionally, this case study expands from the theory most civil engineering programs might offer to a virtual experience where students can see and experience the results when working with water to cement ratios. There are studies that do show how problem-based learning in a concrete lab can be facilitated, but these studies do not discuss the types of equipment or get into the specifics on how concrete cylinders can be utilized in a lab scenario following the ASTM standards. Therefore, this case study provides the necessary gap in the construction management education for any instructor to develop a hands-on lab for in concrete which is especially important for those newer professors who are looking for ideas on concrete construction lab content.

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