# AC 2007-207: INTRODUCING CIVIL ENGINEERING UNDERGRADUATES TO THE PREMATURE CRACKING OF CONCRETE BRIDGE DECKS

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# Introducing Civil Engineering Undergraduates to the Premature Cracking of Concrete Bridge Decks


## Abstract

Early age cracking of concrete bridge decks is a major concern to the transportation industry. Although there have been numerous developments in concrete structural design and mixture design methods, this problem has not shown any sign of improvement. One of the major obstructions to solving this growing problem has been the lack of knowledge on the problem among personnel involved in the design and maintenance of concrete structures. This problem can be effectively addressed by educating those who are already in the transportation industry as well as those who will work in that industry in the future. This paper describes an attempt made at the University of South Alabama to introduce civil engineering undergraduate students, many of whom will work for the transportation industry in the future, to the premature cracking of concrete bridge decks and pavements. In the summer of 2005, a group of undergraduate students, under the supervision of a faculty member, made significant efforts to enhance the Civil Engineering Construction Materials Laboratory to increase its capacity for the purpose of studying the early age cracking of concrete. The students built an environmental chamber and devised several apparatus to simulate the mechanisms responsible for early age cracking of bridge decks. Several undergraduate students are currently using this enhanced laboratory to investigate the early age cracking of concrete. In addition, this laboratory enhancement has allowed to introduced several new topics and experimental demonstrations related to early age cracking of concrete to the Civil Engineering Materials theory and laboratory courses. The modified courses (theory and laboratory) were offered for the first time in the fall semester of 2006. To assess the effectiveness of this effort, the students were asked to complete a short survey at the end of the semester. Based on the results of the survey, it appears that this new program was able to contribute greatly to enriching the education and the understanding of the students where early age cracking of concrete structures is a concern.


## Introduction

The early deterioration of highway bridges due to transverse cracking has become a growing epidemic in the United States. A survey of the state departments of transportation in the past revealed that more than 100,000 bridges in the United States developed transverse cracking soon after construction[1]. Several years have passed since the survey but the problem has not improved. Studies have shown that the majority of this cracking occurs as a result of excessive shrinkage of the bridge deck concrete. Although the shrinkage of concrete is the major factor, addressing shrinkage alone will not lead to a solution because the overall mechanism is complicated. This form of premature deterioration of bridge decks is a major concern to the transportation industry, including construction contractors and state DOTs. The repair of a bridge deck is difficult and expensive. The most effective way of dealing with this problem is to prevent cracking from occurring in the first place by manipulating the properties of concrete to produce concrete with lower cracking susceptibility. In order to deal with this growing problem, personnel involved in the design, construction, and maintenance of highway bridge decks must have proper understanding of the mechanisms that cause shrinkage cracking of concrete. They must also be aware of the techniques available to assess the susceptibility of a concrete mixture to cracking. Today's undergraduate students will be tomorrow's engineers, many of whom will be involved in designing and maintaining bridge deck structures. The earlier these students are introduced to this problem, the better their understanding will be. Unfortunately, many civil engineers are unaware of this problem because the traditional undergraduate civil engineering programs do not discuss it. In order to effectively deal with this problem, it is vital to incorporate topics on shrinkage cracking of concrete structures into appropriate undergraduate civil engineering courses. This paper describes an effort initiated at the University of South Alabama to introduce the civil engineering undergraduate students to the premature cracking of concrete structures.

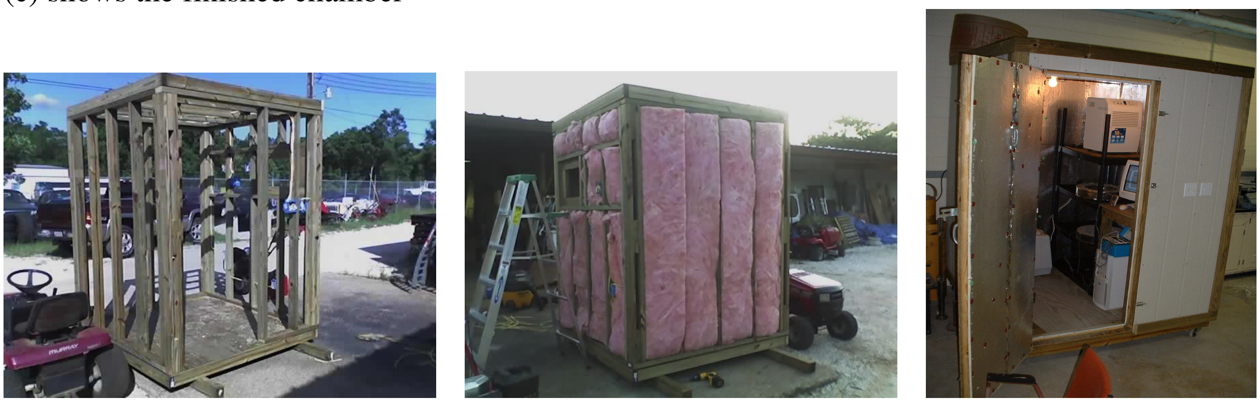
The University of South Alabama (USA), located in Mobile, Alabama, is a major center of quality higher education in the upper Gulf Coast region. The Civil Engineering Department at USA is the only civil engineering program within a 150-mile radius of Mobile. Due to the absence of any other quality civil engineering program within a convenient distance, many students from the southern part of Alabama, southeastern part of Mississippi, and northwestern part of Florida are attracted to the civil engineering program at USA. Thus, the University of South Alabama makes significant contributions to prepare future civil engineers for Alabama and adjacent states. Many of these engineers will be engaged in designing, building and maintaining the infrastructure of their respective states. Therefore, educating them about the premature deterioration of concrete bridge decks will be beneficial for a vast region within the United States.

**Laboratory Enhancement**

The laboratory simulation of shrinkage cracking of concrete can provide students with a better understanding of this complicated problem. However, many undergraduate civil engineering programs do not have the facilities to perform these laboratory simulations. The University of South Alabama has a Construction Materials Laboratory, but it did not have the capacity to perform the experiments needed to simulate early age cracking of concrete. The laboratory did not have the controlled environment chamber required to maintain the environment needed to simulate the premature cracking of concrete. In addition, there was an absence of the tools necessary to perform experiments related to early age cracking. In the summer of 2005, an initiative was taken to upgrade the laboratory with a very limited budget of $2500.

The first step in enhancing the laboratory was to obtain a controlled environment chamber capable of creating and sustaining a constant temperature and relative humidity. Several manufacturers of environmental chambers were contacted and it was discovered that the commercial chambers were too expensive for the available budget. Since buying a chamber was not feasible, a decision was made to have one built. A student was asked to design and build the chamber as a part of his undergraduate summer research project. The 10 week-long summer research was sponsored by the University Committee on Undergraduate Research (UCUR) at the University of South Alabama. The student received a summer stipend of $2500. Under the supervision of his faculty mentor, the student spent two weeks to survey the related literature and come up with a suitable design and a cost estimate.

After the design was approved by the faculty mentor, the student spent three weeks to build the 10 ft. x 10 ft. x 12 ft. chamber. The framework of the chamber was constructed with treated lumber frames as shown in Fig. 1(a). The chamber was carefully wired for the operation of the lighting, temperature control, humidity control, and auxiliary outlets. After the wiring was completed, the chamber was fully insulated as shown in Fig. 1(b). The exterior of the chamber was finished with fiber cement siding. To finalize the chamber, a 6000 BTU room air conditioner with digital control was installed in one of the walls to control the temperature within the chamber. In addition, a humidifier and a dehumidifier were installed inside the chamber to control the humidity within the chamber. The completed environmental chamber cost around $1500, which was much cheaper than similar chambers that are commercially available. Figure 1 (c) shows the finished chamber



*(a) Treated frames and flooring* *(b) Chamber insulation* *(c) Finished chamber*

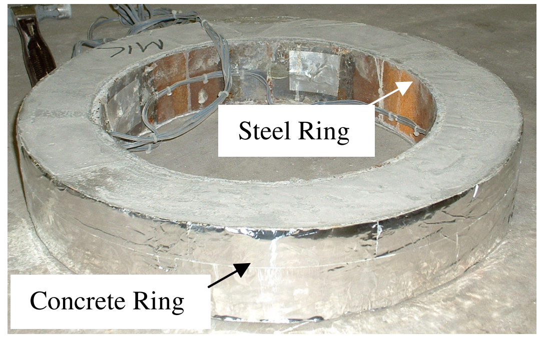
Figure 1. Environmental chamber construction.

After the chamber was built, a digital length comparator was bought and installed inside the chamber. The comparator allows the measurement of shrinkage of concrete, the major factor responsible for premature cracking of bridge decks and many other concrete structures.

Although shrinkage is the major factor responsible for shrinkage cracking, concrete structural members do not crack if allowed to shrink freely. They crack if the shrinkage is restrained by other members of the structures. Therefore, measurement of shrinkage of concrete alone does not completely describe the shrinkage cracking. The most effective way of enhancing students' understanding of shrinkage cracking would be to simulate the actual condition, the restrained shrinkage, in the laboratory. The American Association of State Highway and Transportation Officials (AASHTO) recommends a very simple test method to simulate the restrained shrinkage cracking of concrete[2]. The test consists of two concentric rings: an instrumented inner steel ring and an outer concrete ring as shown in Figure 2. The inner steel ring restrains the outer concrete ring from shrinking resulting in the development of tensile stresses. The tensile stress may be high enough to cause cracking in the ring specimen. The undergraduate summer assistant was asked to study the AASHTO ring test and prepare several instrumented steel rings. He obtained a standard steel pipe and had it cut into several rings as shown in Fig 2(a). He then attached four strain gages at the mid height of the inner surfaces of each steel ring. Fig. 2 (b) shows the details of a ring specimen.

The student successfully completed his undergraduate summer research project. In 10 weeks, the student built an environmental chamber, installed humidity and temperature controlled devices in the chamber, and devised several instrumented ring molds to simulate restrained shrinkage in the laboratory.

*(a) Steel ring*




*(b) Ring specimen*

Figure 2. Restrained ring specimen.

**Modification of Courses**

Civil Engineering Materials (CE 314) and Civil Engineering Materials Laboratory (CE 315) are the two civil engineering courses offered at the University of South Alabama that discuss concrete material in detail. Since shrinkage is a property of concrete and shrinkage cracking affects the performance of concrete structures, discussion on shrinkage cracking fits better into these courses than any other civil engineering course offered at USA. Therefore, these two courses were selected and slightly modified to introduce the shrinkage cracking of concrete to the students as discussed in the following sections:

*CE 314: Civil Engineering Materials*

Civil Engineering Materials is a required junior level theory course for civil engineering undergraduate students at the University of South Alabama (USA). The main objective of this course is to introduce students to the engineering properties of materials used in civil engineering construction. The following topics are covered in this course:

1. Review of mechanics of materials.
2. The atomic, molecular, and crystalline basis for the behavior of engineering materials.
3. Metals: strength and elastic properties.
4. Aggregate: properties and testing.
5. Portland cement: production, cement chemistry and properties.
6. Portland cement concrete: production and microstructure.
7. Portland cement concrete: properties and testing.
8. Portland cement concrete: mix design.
9. Durability of concrete structures.
10. Asphalt cement: production, properties and testing.
11. Asphalt concrete: properties and mix design.
12. Composite materials.

It should be noticed that the above list includes 4 topics (Topics 6,7,8,9) that discuss concrete material. Since shrinkage is a common property of concrete, discussion on shrinkage of concrete has been added to Topic 7, which discusses the common properties of concrete and the standard tests to assess these properties. In addition, a discussion on shrinkage cracking of concrete structures, a common problem that affects the durability of bridge decks and pavement structures has been added to Topic 10, which discusses the durability of concrete structures.

*CE 315: Civil Engineering Materials Laboratory*

Civil Engineering Materials Laboratory (CE 315) is a co-requisite of Civil Engineering Materials (CE 314) course, and the two courses are taught as coordinated courses. While the lectures (CE 314) introduce the students to the useful properties of common civil engineering materials, the laboratory (CE 315) teaches them how to evaluate those properties using standard test methods. Before implementing the new program, this hands-on laboratory course (CE 315) included the following experiments:

1. Laboratory data analysis using simple statistical methods.
2. Tensile test of mild steel specimens.
3. Sieve analysis (particle size distribution) of fine aggregates.
4. Determination of specific gravity and absorption capacity of coarse aggregates.
5. Determination of dry rodded density of coarse aggregates.
6. Concrete mixing and determination of slump.
7. Determination of compressive strength of concrete cylindrical specimens.
8. Concrete mix design project.
9. Determination of consistency and temperature susceptibility of asphalt samples.

The laboratory enhancement allowed the addition of the following experiments (demonstrations) on shrinkage cracking of concrete to this laboratory course:

1. Measurement of shrinkage of concrete according to ASTM C157 [3], using the digital length comparator that was bought as part of the laboratory enhancement (Fig. 3(a)). Shrinkage is a common property of concrete and is mainly responsible for early age cracking of concrete structures.
2. Demonstration of plastic shrinkage cracking of concrete using restrained concrete slabs as shown in Fig. 3(b). Plastic shrinkage cracking is a common problem for concrete bridge decks and pavements. It occurs within the first 24 hours after concrete is placed, while concrete is still in a plastic state.
3. Simulation of restrained shrinkage cracking of concrete using the steel rings (Fig. 3(c)) that were instrumented by a student during the summer.

## Student Involvement

*Classroom and Laboratory Activities*

The modified CE 314 and CE 315 courses were offered for the first time in the fall of 2006. Twenty-six students took both the courses. Theory and laboratory demonstrations were coordinated to provide the students with a clear understanding of the early age cracking problem of concrete structures. Whereas the theory course provided the students with the necessary background on the early age shrinkage cracking, the laboratory course provided the students with a hands-on opportunity to measure the shrinkage of concrete and observe the shrinkage cracking of concrete specimens. Fig. 3 shows the student activities in the laboratory related to early age cracking of concrete.

*Research Activities*

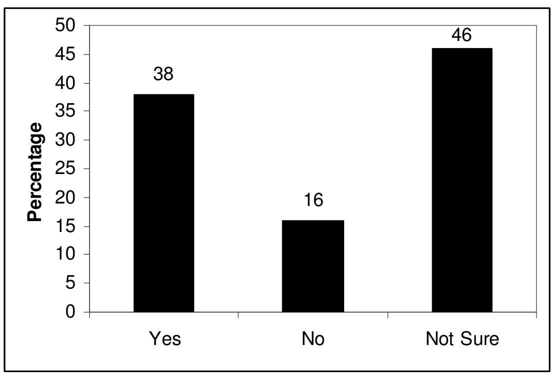
A student's learning can be enhanced significantly by active participation in research activities[4,5]. The research experience provides a student with the opportunity to apply classroom theories and assignments to solve practical problem.[6] In addition to students' classroom and laboratory involvement as discussed earlier, the program allowed several undergraduate students to become involved in research projects related to early age cracking of concrete. The laboratory enhancement attracted a small external grant ($8500) giving research opportunities to two undergraduate students. They spent three months studying the effects of a material additive on the early age cracking of concrete. The project was completed to the satisfaction of the organization sponsoring the research. The research project resulted in a report and two refereed conference papers co-authored by the undergraduate students. The results of this small project attracted another larger research grant ($50,000) to study the various aspects of shrinkage cracking of concrete. Currently, three undergraduate students are obtaining valuable research experience from this project.

*(a) Student measuring shrinkage*  *(b) Demonstration of plastic shrinkage cracking*  *(c) Simulation of restrained shrinkage*

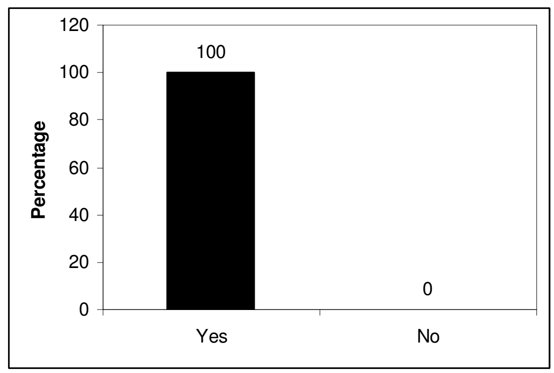
Figure 3**.** Student laboratory activities related to shrinkage cracking of concrete.

**Assessment**

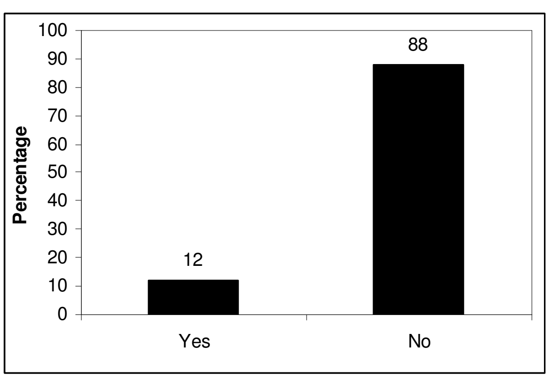
In order to assess the effectiveness of the aforementioned academic effort and to validate it, the students taking the Civil Engineering Materials theory and laboratory courses were asked to complete a simple survey at the end of the semester. The survey was completely anonymous and took less than five minutes to complete. The survey questions and the summary of the student responses are provided in Fig. 4. The first question was aimed at finding out the percentage of the students interested in working for the Departments of Transportation. This information was important because the DOT engineers are involved in the design and the maintenance of transportation structures, many of which are prone to early age cracking. It is therefore necessary that these engineers have sufficient knowledge of this problem. Fig. 4(a) shows the student responses to this question. It is evident that 38 percent of the students were interested in working for the DOTs, 46 percent were still not sure, and only 16 percent were not interested. Since a large portion of the class was interested in working for the DOT, it was appropriate to discuss early age cracking of concrete structures, a major problem faced by the DOTs. From the student responses to the survey (Figs. 4 (b) and (c)), it is evident that only 12 percent of the class already knew about the early age cracking problem of concrete structures before taking these courses, whereas 100 percent became aware of the problem after taking them. Therefore, the effort was successful in making the students aware of this critical problem which was unknown to most of them earlier. All the students agreed (Fig. 4(d)) that the problem of early age cracking of concrete structures can be effectively addressed by making the undergraduates aware of it. Finally, Fig. 4(e) shows that the discussion of the early age cracking problem of concrete structures in CE 314/ CE315 made them interested to know about it in more detail, which will help them learn how to effectively deal with it. From the students' response to the short survey, it appears that the effort has been successful in introducing the undergraduates to the premature cracking of concrete bridge decks and other structures, which is the main objective of this effort.



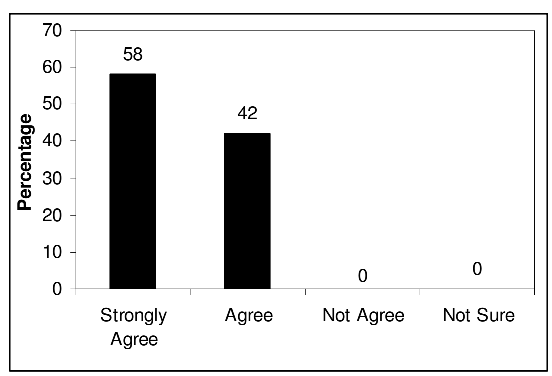

*a. Are you interested in working for the DOT in future?*




*b. Are you aware that the cracking of concrete bridge decks is a major problem faced by the State DOTs?*

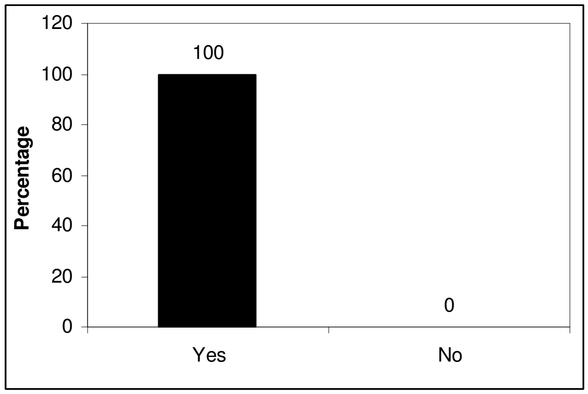



*c. Did you know about this problem before taking this course (CE 314/315)*




*d. Do you agree that informing the students of this problem at undergraduate level will be useful in addressing this problem?*

Figure 4**.** Student questionnaire survey and results.




*e. The discussions on cracking of concrete bridge decks and pavements in CE 314/315 have made you interested to know more about this problem.*

Figure 4 (continued). Student questionnaire survey and results.

**Summary and Conclusion**

The early age cracking of bridge decks is a significant and costly problem in the transportation industry. It is also a problem that is not well understood by many in the field. While educating those already in the transportation industry is certainly part of a comprehensive approach to solving this problem, another important component of the solution is to adequately prepare those who will work in that industry in the future. This paper describes one such effort made at the University of South Alabama to prepare the civil engineering undergraduate students to effectively address this problem in future. Both undergraduate education and research were integrated to achieve the goal of the aforementioned effort. As a part of the effort, the existing Civil Engineering Materials Laboratory was enhanced for the experimentation with the early age cracking of concrete. The available budget was very limited and was not sufficient to buy the tools necessary to conduct the experiments. With some creativity, hard work and a belief that this work was important, the facilities were built from the ground up. An undergraduate theory course and a laboratory course were slightly modified to include topics related to early age shrinkage cracking of concrete. The theory and the laboratory were carefully coordinated to give the students better understanding of the topics. At the end of the semester, the students were asked to complete a short survey. The students' response indicated that the attempt was effective in generating awareness among them about the early age cracking problem of concrete structures. To further enhance the student's learning about the early age cracking, several undergraduate students were allowed to participate in research related to shrinkage and premature cracking of concrete mixtures. The research endeavor resulted in a report and two refereed conference articles. The above effort will act as an example and encourage others to make similar attempts to prepare future engineers to address the problem of the growing deterioration of America's infrastructure.

## References


1. Kraus, P.D., and Rogalla, E.A., "Transverse Cracking in Newly Constructed Bridge Decks", NCHRP Report 380, Transportation Research Board, National Research Council, Washington, D.C., 1996.
2. AASHTO. Standard Practice for Estimating the Crack Tendency of Concrete. AASHTO Designation PP-34-89, 1989, pp. 179-182.
3. ASTM (1994), Annual Book of ASTM Standards, "Concrete and Aggregates"; Vol. 4.02, © 1994.
4. D. Lopatto, "Survey of Undergraduate Research Experiences (SURE): First Findings", Cell Biology Education 3: 270-277, Winter 2004.
5. K.W. Bauer and J.S. Bennett, "Alumni Perceptions Used to Assess Undergraduate Research Experience", The Journal of Higher Education 74.2:210-230 (2003).
6. P. Schuster and C. Birdsong, "Research in the Undergraduate Environment", Proceedings of 2006 ASEE Annual Conference, Chicago, Illinois (2006).