AC 2007-1161: INCORPORATING "GREEN" IDEAS INTO CIVIL ENGINEERING MATERIALS COURSES

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Abstract

Civil engineers are facing a new era where they must not only design structures and roadways to meet serviceability requirements, but they must also be conscientious of how these projects impact the environment. Rarely do civil engineering courses address issues of sustainability, and while it may be unrealistic to introduce new courses into an already crowded curriculum, some courses can easily be amended to include new "green" ideas. One such course, Civil Engineering Materials, is required in almost all curriculums at the sophomore or junior level and is one of the first true engineering courses in the degree sequence. In this article, three professors at different universities in different regions of the country share three projects which can help students learn how concrete can be an environmentally friendly material.

Introduction

Protecting the environment is becoming a ubiquitous aim of growing urgency.[1] More frequently, civil engineers are being called to meet infrastructure demands in ways that are less harmful to the environment and sustainable into the future. It is imperative that today's students learn about alternative energy sources, conservation of natural resources, waste management, and recycling. These "green" ideas are repeatedly encountered by environmental engineering students, but civil engineering students rarely study these topics in much depth. With many students already struggling with busy schedules, adding new courses is unfeasible. However, some "green" ideas can easily be incorporated into traditional civil engineering courses without sweeping changes to the core content.

Civil Engineering Materials is one such course where an opportunity exists to address environmental issues. Civil Engineering Materials is generally divided into concrete, steel, and wood topics. Concrete generally consumes the bulk of the effort simply because civil engineers are likely to design concrete mixtures and usually only need to specify types of steel and wood. This article presents three projects where experiments with concrete can be given a "green" touch.

Course Projects in Civil Engineering Materials

Three projects have been introduced into Civil Engineering Materials courses by three professors at different universities in different regions of the country to help students learn how concrete can be an environmentally friendly material. In the view of professors and students, the projects have met with some success in the last few years at Manhattan College in New York City, the University of Arkansas, and the University of Colorado at Denver. In the greencrete project, students are asked to improve the performance characteristics of a national brand of concrete while simultaneously using recycled materials and lowering the cost. The concrete Frisbee project teaches students how to push the limits of design using some of the most modern concrete materials. Finally, in the pervious concrete project, students learn how a new kind of concrete can make roadways less hazardous to the traveling public and reduce discharge of unclean runoff which is known to kill wildlife.

The Civil Engineering Materials course is typically arranged into one or two weekly lectures, each lasting one hour, and one weekly laboratory period lasting two to three hours. Usually two laboratory periods are sufficient time to allot to any of these projects, though some additional work by the students outside of class is almost always necessary. The laboratory periods may not be in consecutive weeks to allow sufficient time between batching and testing of the concrete. Concrete typically sets in a few hours, but the curing process requires several days or weeks. Additional class time can be reserved to allow teams to give presentations.

These three projects can be accomplished as a routine laboratory exercise or with the added incentive of competition. Students can be divided into teams of three to five.

Greencrete

In this project, students learn how to turn a conventional concrete mixture, one which contains cement, aggregates, and water, into a "green" concrete mixture by partially replacing some of the cement with supplementary cementitious materials (SCMs), which are recycled waste products. SCMs have properties like the volcanic ash which was used to build structures in ancient Rome.

A typical concrete mixture contains 20% cement by mass. Cement production is costly and energy intensive and emits carbon dioxide (CO_2), a greenhouse gas. Production of a quantity of cement emits about the same quantity of CO_2.[2]

Fly ash and slag are SCMs, and can improve the workability, strength, and durability of concrete. Both fly ash and slag are industrial byproducts; fly ash is the waste found by burning coal in power plants and slag is the waste found in the production of iron. These waste materials are abundant, with over 250 million tons of fly ash and 18 million tons of slag produced every year in this country. At present, however, only about 30% of fly ash and very little slag find its way into construction, with most of the rest headed to landfill disposal.[2]

Many organizations are pushing the use of "green" concrete materials. The American Concrete Institute (ACI) and the Environmental Protection Agency (EPA) encourage the reuse of waste materials like fly ash and slag by supporting the Resource Conservation and Recovery Act (RCRA). The RCRA compels agencies receiving federal funding to use products with the highest quantity of recycled materials that is practical. Many state departments of transportation have recently amended their specifications to allow fly ash and slag in concrete bridges and roadways. The Green Building Council's (USGBC) Leadership in Energy and Environmental Design (LEED) program is also gaining wide acceptance. Through the LEED program, new structures are awarded points on the basis of sustainability toward various grades of certification. The USGBC defines sustainability as development that meets the needs of the present without compromising the ability of future generations to meet their own needs.[3]

Market forces may soon drive the use of SCMs. Around the world, the demand for cement is at a record high and supply in this country is becoming tight.[4] By partially replacing the cement in concrete mixtures, the use of SCMs will extend the supply of cement.

Greencrete, as defined in this project, is a modification of Quikcrete 5000, a product which can be bought at any Lowe's or Home Depot. A bag of Quikcrete 5000 contains cement and aggregates, both coarse and fine. To start the project, students follow the instructions on the bag and add a suitable amount of water, mix, and place the concrete. True to word, Quikcrete 5000 usually reaches strength of 5,000 psi at an age of 28 days. Strength is tested on standard concrete cylinders. To design greencrete, students are asked to modify Quikcrete 5000 by partially replacing some of the cement with fly ash and/or slag. To do so, students use a series of sieves to extract the Quikcrete 5000 constituents, and then recombine these in different proportions. The students' greencrete must achieve strength of 5,000 psi to match Quikcrete 5000. With local prices of all the constituents, students must also design greencrete to be less expensive than Quikcrete 5000, a challenge that teaches them about the business side of civil engineering. Partial replacement of cement with fly ash and/or slag is known to ultimately improve strength though sometimes to the detriment of early strength gain. However, students have found the delay in strength gain to be minimal.

In the end, most teams are able to successfully design greencrete that meets or exceeds the strength requirement while using SCMs and costing as much as 30% less than Quikcrete 5000. Students have made efforts to get in touch with the Quikcrete company to report their results.

Concrete Frisbees

College students everywhere have always loved to bask in the sunshine on the campus quad and toss Frisbees, so why not ask civil engineering students to construct concrete Frisbees?

The goal of this project is to introduce students to some of the new and unusual concrete materials and teach them how to push the limits of design.

Students first construct molds employing wood and clay. Some of the teams choose a traditional Frisbee shape with a convex top face and a concave bottom face with ridges, while others choose an Olympic style discus or a hoop. Most concrete Frisbees are made about the same size as conventional Frisbees. To decide on a shape, students study the physics of Frisbee flight, concepts like airstreams and drag and lift. They learn about angular momentum and that without rotation, a Frisbee would quickly tumble to the ground.

Next, students design concrete mixtures light enough to allow the Frisbees to fly. Conventional concrete has a density of about 150 lb/ft^3, so students replace the coarse aggregate normally found in concrete with recycled Dow Styrofoam beads and/or tiny, hollow glass spheres made by 3M to reduce the density to as little as 50 lb/ft^3. It is believed that concrete of such low density could be employed in the construction of homes to increase energy efficiency. Silica fume, which is a SCM like fly ash and slag, is added as a partial replacement of cement to enhance strength. Small fibers of various types and materials made by SI Concrete Systems can be added to the concrete mixture to inhibit cracks. Just as concrete structures contain steel bars as reinforcement, students typically use one or two layers of mesh reinforcement made by Sika in the Frisbees. On the way, students learn how mesh reinforcement can be used to repair structures, or to increase the resistance of structures to earthquakes and/or blasts. Finally, chemical admixtures made by BASF Master Builders are added to enhance workability of the fresh concrete and ease placement into the molds. Following a curing period of several days to weeks, students are allowed to paint the Frisbees.

The Frisbees are judged on the basis of creativity or originality and aesthetics. Students then go to a sports field or grassy place on campus to toss the Frisbees. There are two events, a toss for distance, where many students have tossed their Frisbees more than 100 ft, and a toss for accuracy, where a target is placed at a distance of about 40 feet. (It is not recommended that students actually catch the Frisbees!) Everyone on each team gets one toss for distance and one toss for accuracy, with the final results of each team being the mean of the individual members' results. To introduce students to modern surveying equipment, it may be useful to perform the distance measurements using a total station and prism. After the field events are finished, the Frisbees are judged for durability. Because of durability concerns, each team is asked to make three identical Frisbees. With three to five students on each team, and with each student tossing the Frisbees for both distance and accuracy, the Frisbees see plenty of action, and many teams need to use all three of their Frisbees to finish the events.

Students come away from the concrete Frisbee competition with a full appreciation of the design process, and how some objectives come into conflict. Extremely thin and light Frisbees may fly far, but will likely develop cracks or simply crumble after a single toss. Thick and heavy Frisbees may stay perfectly intact, but will not fly very far.

The ACI has expressed interest in having a concrete Frisbee competition at its conventions.

Pervious Concrete

Pervious concrete has the potential to become the material of choice for our nation's roadways. It is a new idea, and the ACI and EPA, among other organizations, believe pervious concrete can make roadways less hazardous to the traveling public, reduce loads to storm water management systems, and exist harmoniously with the environment.

As the name implies, pervious concrete is pervious. It allows up to 4 gal/min/ft^2 of rainfall and snowmelt to pass through. Flooding and ice on roadways could be much less of a problem. On roadways now, storms frequently cause delays. More seriously, traffic accidents claim about 40,000 lives nationally every year.[5] Many of these crashes are undoubtedly due to poor roadway conditions.

Today's roadways are effectively impervious. Rainfall and snowmelt are largely collected by storm water management systems. As runoff flushes oil and other toxic substances off the roadways, it should receive some treatment. But with increasing land development, surges of unclean runoff frequently overwhelm storm water management systems and are released into oceans, lakes, and rivers without any treatment. Unclean runoff is known to be the cause of a multitude of environmental calamities, as confirmed by the widespread decline of wildlife.

Pervious concrete roadways will not upset the natural hydrology of the land. Pervious concrete allows rainfall and snowmelt to return to the ground where it belongs, so it can replenish the aquifers below. Consequently, pervious concrete reduces loads to storm water management systems. To provide treatment, it may be possible to sustain small plants or bacteria in the pervious concrete that will improve the quality of the water as it passes through.

Most of the nation's roadways are now built with asphalt, which has traditionally had the lowest initial costs. But asphalt has less durability than concrete and regularly needs repairs and replacement. Asphalt is also an oil product and subject to unpredictable price swings. The dark color of asphalt contributes to the heat island effect, where temperatures in cities can be more than 10 ˚F above those in the surrounding countryside, which substantially increases energy consumption in the summers. Light in color, the reflectivity of concrete could help reduce the heat island effect. Additionally, these roadways would need less illumination at night. Concrete materials are readily available everywhere and do not contain oil products.

Pervious concrete is made with the same basic constituents as conventional concrete, namely cement, aggregates, and water. But different from conventional concrete, pervious concrete contains about 20% voids and looks somewhat like a big Rice Krispies treat. The voids in pervious concrete are achieved with a special blend of aggregate sizes. However, up to now, the high voids content has limited the strength of pervious concrete at about 3,000 psi and restricted its use to a few parking lots and walkways. Strength in excess of 4,000 psi is necessary for use on roadways.

In this project, students are asked to design optimum mixtures in terms of voids content and strength. Students must determine the voids content in pervious concrete that is necessary to handle peak rainfall and snowmelt events in the region. By batching several different mixtures, students can also determine the relationship between voids content and strength. Students did such an excellent job in this project that the results have attracted the attention of state transportation authorities.

Conclusion

With growing media attention and the strong run of the movie *An Inconvenient Truth*, many people are coming to accept the significance of the environmental issues and the prospect of climate change which now confronts the planet. Everyone must act in a small way, Al Gore tells us. These three projects will likely increase civil engineering students' awareness of the challenges ahead and give them some ideas about how to find solutions with applications of concrete materials. Student responses to surveys have been largely positive.

On the greencrete project, one student at the University of Arkansas remarked, "It can be seen that 'green' materials are a realistic choice for concrete manufacturers." "If a company wishes to produce a less expensive concrete mixture," adds a second student, "they need only replace some of the cement with less expensive 'green' materials." "There are so many 'green' options to think about," comments a third student.

Most students have said the competitions increased their enthusiasm for the course material. "The Frisbee competition is a fun way for the students to demonstrate their knowledge about concrete materials and to be creative in design," says a student at the University of Colorado at Denver.

Almost all students enjoyed working with peers both in and out of class. "I have become friends with the members of my team," says a student at Manhattan College working with pervious concrete, "and we learned how to accomplish the task by combining our skills. It was a 'concrete' experience."

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[1] Gore, Al, *An Inconvenient Truth*, 2006
[2] Neville, A. M., *Properties of Concrete*, Fourth Edition, Wiley, 1996
[3] United States Green Building Council, www.usgbc.org
[4] Portland Cement Association, www.cement.org
[5] *Time Almanac*, 2007