NDT and Instrumentation In an Undergraduate Concrete Lab

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ABSTRACT
The first year implementation of an NSF-ILI project for enhancing the concrete lab with NDT and instrumentation modules is discussed. A two-semester laboratory is developed to parallel the lectures in the two concrete courses; namely, Reinforced Concrete Structures and Concrete Design project. The new laboratory has significantly increased students' interest in, and learning from, the courses.

INTRODUCTION
University of Central Florida is a member of the Florida State University System, offering over 100 degree programs to a student body of over 28,000. Department of Civil and Environmental Engineering offers B.S., M.S. and Ph.D. degrees to about 600 undergraduates and 135 graduates. The structural program includes Statics, Mechanics of Materials, Structural Analysis I & II, Structural Lab, Steel Structures, Steel Design, Reinforced Concrete Structures, and Concrete Design. All civil engineering students have to take either steel or concrete in their curriculum. While those interested in structures take both courses, other students have traditionally favored concrete among the two. Feedback from the alumni and local industry had indicated a need for comprehensive concrete lab and field experience. Previously, concrete tests were limited, and combined with other materials in a one-credit Structural Lab. Most students take this course with Structural Analysis I, at least one semester prior to their first exposure to concrete materials. Although, this arrangement made for a good coordination with Structural Analysis, there was no such correspondence between the concrete tests and its subsequent lectures. This project had two objectives; (a) enhancement of existing concrete lab and coordination between experiments and lectures, and (b) incorporating Non-Destructive Testing (NDT) and instrumentation techniques in concrete lab.

BACKGROUND
NDT methods have undergone significant advances in the last two decades. The main driving force is the need for evaluating damages and characterizing the integrity of existing structures in general, and infrastructure in particular [5]. Construction industry has adopted new inspection programs with several NDT techniques, many of which initiated in the research units of universities, and were then transferred to the industry for use and further development. However, in most cases, they did not infiltrate the classrooms. As a result, engineering graduates are not properly trained to utilize NDT equipments. Other countries have placed a greater emphasis on NDT in their education system [6]. Similar efforts exist in the U.S., but are rare. Collins and Alexander [1] indicate that proficiency in NDT is best learned hands-on, as industry has found, where all the variables become apparent, and the role of judgement is as important as equipment and techniques. Civil engineers need to fully understand both the capabilities and the limitations of NDT techniques, if they are going to undertake the important task of inspection and rehabilitation of the nation's aging infrastructure [2].

As a highly non-homogeneous and non-magnetic material with poor electrical conductivity, concrete does not lend itself to common NDT methods as easily as steel. NDT methods can be used to estimate strength, moisture content, density or thickness of concrete sections [3]. An old NDT method for evaluating concrete strength is the Schmidt hammer test (ASTM C805), based on the principle that the rebound of an elastic mass depends on the hardness of the surface against which the mass impinges. Penetration resistance techniques using the Windsor probe device correlate hardness of concrete to its strength (ASTM C803). Another method for measuring in-situ strength of concrete is based on breaking off a 55 mm x 70 mm cylindrical specimen of in-place concrete. To determine concrete strength at various ages and curing conditions, use of maturity functions is suggested (ASTM C1074). Commercially available maturity meters monitor the temperature history, and automatically perform the necessary maturity calculations [3].

Modern NDT techniques for concrete include resonant frequency, ultrasonic pulse velocity, short pulse (impulse) radar, radioactive, infrared thermographic, acoustic emission, stress wave propagation, and magnetic and electrical methods. Acoustic emission methods are based on monitoring the audible or sub-audible sound emitted by concrete as it experiences cracking, slip of rebars, or debonding of fibers. Infrared thermographic testing methods can be used for determining voids and delaminations in concrete. However, the depth or thickness of voids can not be determined. Radioactive methods including gamma radiometry, x-radiography, and neutron-gamma techniques are not widely used due to their high initial costs and licensing requirements. Resonant frequency methods are used to detect significant changes in the dynamic modulus of elasticity of concrete (ASTM C215). The resonance tests, despite their limitations, provide an effective means for studying the deterioration of concrete specimens subjected to repeated cycles of freeze and thaw. Magnetic and electrical methods can locate reinforcements, defects and corrosion, and measure member thickness, concrete cover, and moisture content of concrete. Commercially available rebar locators, moisture meters , and half-cell potential measurement devices (ASTM C876) have become popular in concrete inspection. Short-pulse (impulse) radar imaging techniques are gaining acceptance as powerful inspection tools for detection of delamination, locating the reinforcements, and monitoring the strength development in concrete. The apparatus uses a single transducer for transmitting and receiving, together with signal processing and recording hardware. The radar pulse is directed into the concrete member, and patterns created by the reflected waves are observed. The speed of pulse in concrete is about 38 to 64 $x10^{-9}$ mm/s, as compared to approximately 305 $x10^{-9}$ mm/s in air. Penetration depth ranges from 0.5 to 30 m depending on antenna frequency and bandwidth. Usually, frequencies of 0.1 to 1 GHz are selected depending on the penetration depth and resolution desired. The most difficult aspect of the inspection with radar imaging techniques is the interpretation of radar signals. The signature of concrete delamination often assumes the shape of a depression on a graphic profile.

Ultrasonic stress wave propagation methods are very suitable for concrete. The two common applications are *Through Transmission*, and *Impact-Echo* methods. In the first method, one measures the time it takes for a pulse to travel from a transmitting transducer located on one surface of the member to a receiving transducer on the opposite side. The wave speed as determined from the known distance can point to the condition of materials between the transducers. In the second method, both transmitter and receiver are located on the same surface, and one measures the time it takes for the pulse to reflect back from an interface, i.e., delamination within the member [3,4].

Depth of the reflector can then be determined based on the known wave speed from the amplitude spectra [3].

PROCEDURES AND METHODS

This project improves quality of undergraduate education at UCF through implementation of a comprehensive concrete laboratory and field experience with NDT and instrumentation modules. The pedagogical drive of this program is to parallel the lectures and laboratory experiments as much as possible. A complete laboratory manual is being prepared to help students with various steps and test procedures. Following is a list of sessions and topics that are being included in the program:

1. Introduction to laboratory work: general guidelines for student groups, assignments, cleanup, safety and environmental issues, care of equipment, test procedure, and preparing reports.
2. Concrete technology: materials, mixing, placing, vibrating, finishing, curing, control, compliance, concreting in hot and cold weather, and in-situ testing.
3. Aggregates for concrete: sieve analysis (ASTM C136), moisture content (ASTM C70) and unit weight (ASTM C29).
4. Mix design methods: volume methods versus weight methods, normal-weight, air-entrained, and high-strength concrete, effect of admixtures (e.g., plasticizers).
5. Making and curing of concrete cylinders (ASTM C31), slump test (ASTM C143), density of fresh concrete (ASTM C138), and air-content determinations (ASTM C173).
6. Compression test (ASTM C39), flexure test with third-point loading (ASTM C78), and splitting test (ASTM C496).
7. In-place concrete strength: Schmidt hammer (ASTM C805) and Windsor probe (ASTM C803), and comparison with results from standard compression tests.
8. Monitoring the variation of acoustic emission of a concrete beam specimen in flexure test.
9. Use of rebar meters for detection of rebars and depth of concrete cover.
10. Ultrasonic pulse velocity (ASTM C597) experiments on cracked beams.
11. Strain gage instrumentation of a reinforced concrete beam to develop stress-strain response using a data acquisition system.
12. Field trip: ready mix plants, prestressing plants, or construction sites (one trip per semester).

At this stage, since the number of available equipment is limited, some tests are conducted as a demonstration experiment.

EVALUATION AND DISSEMINATION

A three-member advisory board consisting of a senior faculty at UCF, another from University of Florida, and a member of a local prestressed concrete industry was proposed to assess the technical and pedagogical content of the laboratory experiments developed before its use in pilot testing. Initially, a complete laboratory and field experiment program was developed and modulized to fit the two existing concrete courses over a two-semester time span. The experiments are presently being packaged in a laboratory manual that will be further examined by the board. The program will then be revised to address the comments. It is also intended that during the second year of the program, a list of laboratory experiments and their contents be sent to selected universities including the members of the Florida State University System for their comments and suggestions. Also, the surveyed universities will be asked to provide a list of experiments that they include in their concrete labs, and whether they conduct any NDT experiments for their students. The comments will be shared with the board, and will be used to re-evaluate the program.

CONCLUSIONS

The focus of this project is to improve the quality of undergraduate concrete education by enhancing the concrete laboratory to include new modules for *Non-Destructive Testing (NDT)* and *Instrumentation*. A two-semester laboratory is developed to parallel the lectures within these courses. The planned experiments include rebound methods, probe techniques, mapping reinforcement topology in concrete, detection of various forms of flaws in concrete, ultrasonic methods, acoustics emission, and instrumentation of concrete members. It is believed that the new laboratory will significantly increase students' interest in, and learning from, the concrete coursework.

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BIOGRAPHICAL INFORMATION

AMIR MIRMIRAN, Associate Professor of Structural Engineering at the University of Central Florida is a graduate of the University of Maryland, and a recipient of NSF CAREER Award. His research is focused on fiber reinforced plastic composites, and non-destructive testing of hybrid FRP-concrete structures. He received the Outstanding Teacher of the Year in his department in 1995-96, and the Florida SUS Teaching Incentive Award in 1996.