Research Experiences for Undergraduate Students in Structural Engineering

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Abstract - **This paper describes a project conducted to provide research experience to engineering undergraduate students. It describes three Sites for research experiences for undergraduates (REU Sites) in Structural Engineering with a special focus on development of enhanced materials, structural components and structural assemblages used for seismic performance evaluation studies. Two REU Sites were offered at the School of Civil Engineering and Environmental Science, University of Oklahoma, Norman, Oklahoma, U.S.A. during 1996 to 1999 and 1999 and 2000, which was continued at Department of Civil and Environmental Engineering at University of Cincinnati, Cincinnati, Ohio, U.S.A. during 2001 to 2003 when the author moved there. In addition, the author is currently administering a three-year (2006-2008) REU Site at University of Cincinnati. All the REU Sites have been funded by the U.S. National Science Foundation (NSF). The primary goal of the NSF REU program is to introduce undergraduate students to, and encourage them to pursue, careers in research. A detailed evaluation plan has been developed for the REU Sites, which is also presented in the paper.**

Index Terms - Laboratory projects, Structural engineering, Research experiences, Undergraduates.

INTRODUCTION

Boyer's Commission [1] has asserted that in research universities links are often not made between undergraduate education and faculty research; opportunities to enrich and strengthen undergraduate education through exposure to the research process are missed. Recent statistics indicate a declining population of undergraduate engineering students that continue toward advanced engineering degrees [2]. The REU programs are widely promoted as an effective educational tool for enhancing the undergraduate experience [3]-[4] with multiple benefits [5], the most instrumental of which is an increased interest in a career in STEM workforce [6]-[7]. REU are associated with increased persistence in pursuit of an undergraduate degree [8]; increased levels of pursuit of graduate education [9]-[10]; and alumni retrospective reports of higher gains than comparison groups in skills such as carrying out research, acquiring information, and speaking effectively [11]. Several studies have supported the hypothesis that REU helps promote career pathways for members of underrepresented groups by increasing the retention rate of minority undergraduates [8] and increasing the rate of graduate education in minority students [9]. However, attempts to determine an empirically established set of benefits generated by REU are fairly recent [5, 12]. It still remains for researchers to establish that these findings apply to a broader range of institutions. Various REU projects have documented successes of programs that provide valuable research opportunities both through ongoing research programs and through projects specially designed for this purpose [5], [12]-[25]. It is obvious that both approaches must be promoted. Keeping these factors in mind the Research Experiences for Undergraduates (REU) Site projects presented in this paper are structured.

BASIC APPROACH USED

Today civil engineers face the grand challenge of updating the nation's infrastructure, which is vital to its economy, security, and international competitiveness, and provide for expanding populations while maintaining a balance between cost and adverse environmental effects. They are asked to ensure that this infrastructure is reliable during natural disasters, because the consequences of failure are staggering (1995 Kobe earthquake[1]). To address these problems, recent trends of research in structural engineering advocate the need for developing full-scale experimental testing programs (e.g., NSF NEES Sites) augmented by numerical studies promoting models-based simulation. Sometimes testing of full-scale structural systems and/or components is limited by the available resources and economics. Thus, in such situations research studies utilizing small-scale models are attractive.

In 2001, the American Society of Civil Engineers (ASCE) released a Report Card for America's Infrastructure, grading 12 infrastructure categories at a discouraging D+ overall. In 2003, ASCE released a Progress Report that examined the current trends for addressing the nation's deteriorating infrastructure; ASCE did not issue new grades because the condition and performance had not changed significantly in 2 years [26]. Health-monitoring (HM) concept is used in many engineering disciplines to monitor the condition of existing facilities, but is not yet exploited fully in Civil Engineering practice. While most civil engineers recognize forensic engineering, HM and its system-identification are yet outside the realm of applications in this profession.

Given the above challenges, four logical research topics to solve infrastructure problems are: 1) full-scale testing of structures and/or subassemblies to understand their behavior under adverse loadings and implement novel strategies to enhance performance; 2) developing improved materials and testing procedures for small-scale models which are cost effective; 3) field studies on health monitoring (HM) and retrofitting techniques to preserve and upgrade our aging structures; and 4) performance evaluation of various modern structural systems for aseismic design. Keeping this in mind, in this REU Site Program following three types of projects were selected: 1) the design of improved building systems; 2) the design of improved bridge systems; and 3) manufacturing and testing structural components used for small-scale models in seismic performance evaluation studies. The basic approach used in each project is discovery through actual construction, experimental testing, observing and recording, synthesizing the data collected, and generalizations. This approach provides an opportunity for individual growth and challenge to the young and inquisitive mind.

BRIEF DESCRIPTION OF THE RESEARCH PROJECTS UNDERTAKEN

Design of Improved Building Systems

Steel Frame Structures. In this topical area the REU Site projects were selected to: 1) understand the behavior of steel building frame connections, when subjected to cyclic loads expected during a severe earthquake; and 2) investigate novel strategies to enhance the behavior. Participants fabricated and tested beam-to-column connections, and used test results to characterize their behavior until failure. The behavior of such connections is described by its moment-rotation relationship (i.e., moment transferred to the connection verses the rotation produced). For static loads this plots as a nonlinear curve, whereas, for cyclic loads the plots consist of nonlinear hysteresis loops. In different years different connection were tested, which included: double web angle bolted to both the beam web and the column flange (most flexible); double web angle welded to the beam web and bolted to the column flange; top and seat angle connection bolted to both the beam flange (top and bottom) and the column flange; top and seat angle connection welded to the beam flange (top and bottom) and bolted to the column flange; extended four and eight bolt end plate connections; and T-stub (most stiff) connections.

Improved Coupled Wall Systems. Individual wall piers (shear walls) are coupled together to resist large lateral loads that typically occur during an earthquake. The walls if connected to each other by beams, called coupling beams, changes the load transfer characteristics in the walls to an axial tension-compression couple. Structural steel coupling beams provide a viable alternative in cases where height is a restriction and do not permit use of deep concrete beams or a concrete beam cannot achieve the required stiffness economically. In this REU project the participants conducted an experimental pilot study to explore the concept of splicing the beam at the center with a small beam, called the "fuse," which yields in shear when the shear walls are subjected to lateral loads caused during an earthquake. In an effort to further increase the energy dissipation characteristics of the coupled shear wall system, neoprene elastomeric pads were also added in the project. In this project, the energy dissipation capacity of the fuse beam, with and without the use of neoprene elastomeric pads was tested. The objectives of these tests were to compare the energy dissipation characteristics with and without the neoprene elastomeric pads and to determine the hysteretic response (load versus deformation) for both cases. A photograph showing one of the "fuse" beam test set-up used for the REU project is presented in Figure 1.

FIGURE 1
TEST SET-UP USED FOR THE FUSE BEAM TESTING

Design of Improved of Bridge Systems

Health Monitoring of a Fiber Reinforced Polymer Retrofitted Bridge Deck. The objective of this REU research project was to evaluate the performance of fiber reinforced polymer (FRP) bridge decks over a number of years, each year a REU group conducting the field monitoring tests and adding to the data bank. The bridges studied were on Five Mile Road in Anderson Township in Hamilton County in Cincinnati, Ohio, U.S.A. This county replaced three fifty year-old reinforced concrete bridge decks with the FRP deck. The bridges are supported by prestressed concrete I-beams. The project was concerned with only analyzing the composite action of the bridge, since additional analysis is dependent on this result. The field-testing consisted of static and moving loads applied to the bridges with loaded dump trucks, which was provided by the County Engineers Office. Data from ten different static load cases were collected for each bridge. Two runs of two different moving load cases were performed on each bridge. The data collected consisted of strain and deflection data. A photograph showing field testing of one of the bridges is presented in Figure 2.

FIGURE 2
TRUCK ON THE BRIDGE DECK FOR TESTING

Use of FRP Composite to Strengthen Reinforced Concrete Bridge Beams. The objective of this REU project was to investigate alternative anchorage systems to connect the FRP plate material to a concrete surface. Use of adhesive, mechanical anchors, a wrap, and a combination of these was investigated. In this project two major sets of tests were conducted. The first test was a tensile strength test to investigate the effects of drilling holes in the FRP plate. A total of 23 FRP specimens were tested to investigate this. Five non-drilled specimens were used as a baseline to compare with eighteen specimens with holes positioned in the center. The other major test performed in the project was a single shear test with plates epoxied to concrete and anchored in three different ways. The students did a total of sixteen tests, split into four sections containing four specimens each. The first of which was a baseline group that had a FRP plate attached to the concrete with only epoxy. The second group of four was like the first set, but with two mechanical anchors torqued to 10 ft-lbs. The third set was the FRP plate bonded to the concrete, with a layer of unidirectional carbon fabric wrapped, perpendicular to the plate, and applied with a saturating epoxy. The final set consist of the FRP plate bonded to the concrete, anchored with both the fabric and two mechanical anchors.

Connections Between Simple Span Precast Concrete Bridge Girders Made Continuous. In this REU project the participants conducted an experimental study investigating the performance of positive moment connections in long prestressed concrete girders used for bridges. Bent bar and bent strand connections between two 15 ft AASHTO Type II girders with a slab and a diaphragm were tested and performance compared qualitatively. In addition, the merits of embedding the girder ends into the diaphragm were also evaluated. The specimen construction and testing took place at Prestress Services Inc. (PSI), in Northern Kentucky, U.S.A., and all construction was a cooperative effort of PSI employees and the REU students. Loading and testing of the specimens, and casting, curing and testing of concrete material samples (for compressive and split cylinder tensile strength tests) were also preformed by the REU students. The specimen tested were loaded to critical moment at which the joint would crack if it were completely rigid, and then live loads were applied in a cyclic pattern.

Tensile Testing of High Performance Steel (HPS) for Bridges. This REU project was part of an overall ODOT (Ohio Department of Transportation) project to perform the background research necessary in order to develop or modify fabrication and design guidelines for HPS TMCP (Thermo-Mechanical Controlled Process) grade 70W steel. The objective was to determine the mechanical properties of HPS-70W TMCP, and the variability of these properties throughout the steel plate. Specifically, static and dynamic yield strengths, static and dynamic ultimate strengths, percent elongation, and modulus of elasticity were determined by tension testing of one hundred specimens from various locations throughout a HPS TMCP plate. In order to reach the objective the students first did a through literature review and then conducted tensile coupon tests on these large number of specimens; a few were fabricated by them, whereas the remaining were manufactured to precision by a local steel fabricator.

Manufacturing and Testing Structural Components Used for Small-Scale Models in Seismic Studies

Development of High Strength Microconcrete for Small-Scale Models. In this project students studied the designing, mixing and testing of various microconcrete mixes with compressive strengths ranging from 4 to 8 ksi and with tensile strength limited to 6% to 10% of compressive strength. In different years the students targeted designing different strength mixes. Using the strength related test results, they defined relationships between mix proportions and strength, and used these to suggest a procedure for designing a microconcrete mix with desired strength. The variables considered for this study were sand gradation, sand to cement ratio, water to cement ratio, and workability of the mix. Three sand gradations, four sands to cement ratios, and three water to cement ratios were considered. When the workability of a mix was found to be unacceptable for a particular water to cement ratio or sand to cement ratio, a superplastizer was added. If superplastizer was needed, two dosages were considered to investigate the effect of superplastizer on mix strength. Three types of tests were conducted to ascertain the microconcrete strength, and these included compressive cylinder tests, split cylinder tests and modulus of rupture (MOR) tests. In the compressive cylinder tests, for each microconcrete mix, 2 in. diameter and 4 in. height (2x4 in.) and 3 in. diameter and 6 in. height (3x6 in.) cylindrical specimens were cast and tested.

Study of Bond in Small-Scale Reinforced Concrete Beam Models. In this project students studied the testing and characterization of bond strength between reinforcing bars and microconcrete in small-scale reinforced concrete model beams. It was observed that with the small-scale deformed reinforcing bars, which we manufactured, the bond strength is excessively large. In order to investigate those prototype beams where bond strength may be a problem, there is a need to reduce the bond strength of the model reinforcing bars. This group worked on this task. In their study, an attempt was made to lower the bond strength values by varying the reinforcing bar diameters, rib heights and bar surface conditions. Results obtained from model tests were compared to results available in the literature for the corresponding prototype tests. Three types of tests were conducted to ascertain bond stress between the concrete and reinforcing bar, which included pullout, Texas bond beam, and lap splice tests. The results were regressed to develop empirical formulas to predict bond stress in small-scale reinforced concrete beams. The reinforcement cages manufactured by the REU participants for the small-scale model bond beam tests are shown in Figure 3.

Development of Small-Scale Prestressed Concrete Model Materials and Components. This project dealt with the development of construction materials and methods for pretensioned concrete beams, and determination of the bond strength between the prestressing strands and concrete. This group attacked a relatively new area, as there was very limited research information available even for the prototype pre-tensioned concrete members and none available for small-scale studies. This group utilized the same microconcrete mixes designed by previous REU groups. The first problem studied by the students was to find some commercially available material to replicate the prototype prestressing strands. Four types of galvanized steel cable, four types of stainless steel cable and a spring steel wire were chosen as candidates for prestressing strand material. The problem was to model the strength as well as the modulus of elasticity. Based on the tension test results so obtained, the 7x7 helical galvanized steel cables with 3/64 in. and 1/16 in. diameters and spring steel wire were found to be the best strand material that had a scaling factor close to 12 for strength and modulus of elasticity, which was equal to the geometrically scaling factor chosen to construct the small-scale versions of the prototype prestressed beams. The experimental test results for corresponding prototype beams were available from another ongoing project at the laboratory. To determine the bond strength between these three pre-tensioned strand materials chosen and concrete, specimens were cast to conduct simple pull-out, tensioned pull-out, and beam bending tests for different embedment lengths, different strand surface conditions, and different shear-to-moment ratios for beam bending tests. In summary, this group had laid down foundations on which future researchers can work.

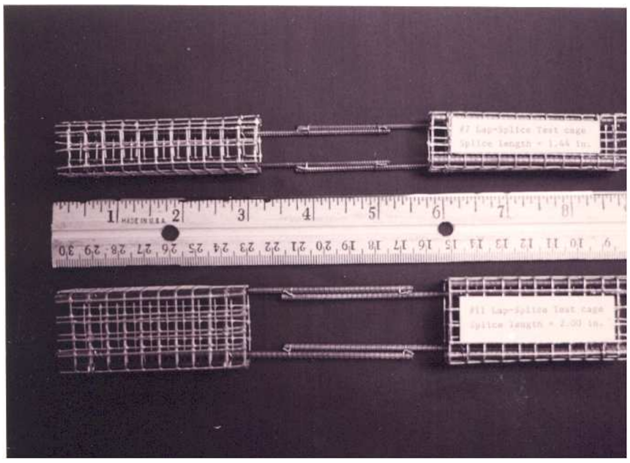

FIGURE 3
REINFORCEMENT CAGES FOR BOND BEAMS

Development of Small-Scale Building Models Fitted with Aseismic Devices. The objective of this REU Project was to test, evaluate, and compare results from small-scale models of steel frames fitted with various types of damping devices and subjected to base motions. The students first conducted six experiments on one- and two-story small-scale building models to explore their use: to experimentally determine their frequencies, mode shapes and damping characteristics; and to compare different damping devices to improve the capabilities of the model to better withstand base motion effects. The models used consisted of four spring steel columns for each floor, which have fixed connections at the base, and a large steel block mass for each floor. The effectiveness of following three types of dampers was explored: viscous, friction and beam yielding. In another year the project was extended to test, evaluate, and compare results from small-scale models of steel frames fitted with base isolators, mounted below each column to decouple the frame from the shake table, and subjected to base motions. This REU project evaluated the use of the two types of base isolators, the commercially available rubber mounts, and the in-house fabricated elastomeric base isolators laminated with steel plates and with and without lead plugs. To evaluate the use of such base isolator for aseismic design, experiments were conducted with three different size diameter rubber mounts, and three different types of elastomeric base isolators. Each of the rubber mounts selected was of the same height, but different diameter, thus varying in vertical and horizontal (shear) stiffness. The elastomeric base isolators included following types: 1) 3 layers, 2) 5 layers of very thin steel plates, and 3) optimum of 1) and 2) with a central lead plug. A two-story frame model mounted on the shake table and used for this REU project is shown in Figure 4.

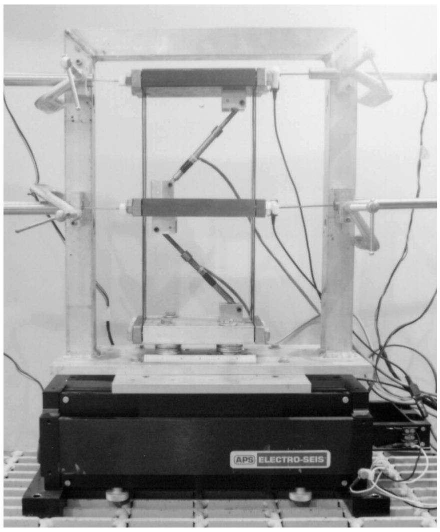

FIGURE 4
TWO STORY FRAME MODEL WITH DAMPERS ON SHAKE TABLE

PROJECT EVALUATION

The primary goal of the REU program is to introduce undergraduate students to, and encourage them to pursue, careers in research. A REU homepage was developed to inform students outside University of Cincinnati (UC) about the program, to present summaries of research projects completed, and elicit communication from REU alumni, which will be expanded. All past REU students were asked to fill every year, up to next 5 years, a Web-based Tracking Form. Some measures of success in achieving the primary goal of the REU include changes in attitudes and opinions about graduate school and research, increased enrollment in graduate school, and submission of research papers to student paper competitions and peer-reviewed conferences and journals. The attitudes and opinions of students were evaluated through administration of a survey before and after participation in the REU program. Survey questions probed students' perceptions about research as a potential career option: about themselves as a researcher, or about the role of research in improving quality of life. It is expected that perception of research will become more positive as students conduct research activities, view themselves as successful participants in larger project, and build mentoring relationships with graduate students and faculty members. In the REU Sites these questionnaires were distributed and collected electronically on the Web with anonymity. Another real measure of the REU program success was the number of participants who enrolled in graduate school at the UC or at other graduate institutions, as compared to the enrollment rate of non-REU students at the Department of Civil and Environmental Engineering at UC. A third measure of success, which will was tracked over an extended period, was the number of peer-reviewed papers submitted by faculty and students, both individually and jointly.

Internal and external evaluation of the project was provided by participants and judges. The students completed a survey on the last day, with specific questions to ascertain satisfaction with the administration of the Site. Within two weeks of their return an essay regarding their experiences was required. The narrative in combination with the questionnaire provided an overall picture. A direct measure of the effectiveness of the whole REU Site was also obtained from the judges. The judges filled out a scoring form evaluating each team's technical report with respect to: organization, method of analysis, critical path followed, reporting and synthesis of test data, goal achievement, and comments. Also they filled out a scoring form evaluating each student's presentation skill with respect to: organization and emphasis, clarity, use and quality of visual aids, and response to questions. The judges were also be asked to give suggestions for improving the overall project activities. The assessment plan was conducted during the academic year following the REU Site each year. The evaluation activities provide answers to: Formative: 1) Is this REU Site working as anticipated; 2) Are any significant changes needed? Summative: 1) Can REU students work on an open-ended research problem and articulate their findings to others? 2) Do REU students become more interested to CE programs? 3) Do REU students become interested in continuing their education in graduate programs? The control group will be the non-REU students. Information for these questions were gathered from the aforementioned student questionnaires, tracking form, and judge's evaluation forms each year.

SUMMARY OF REU SITE RESULTS

Number of Participants:

- Total REU participants = 91.
- Gender distribution = 64 men (70%) and 27 women (30%). The men consisted of 46 white men (50%) and 18 minority men (20%). The women consisted of 5 minority women (6%) and 22 white women (24%).
- Total ethnicity distribution = 62 white (68%) and 29 minorities (32%).
- Total underrepresented participants = 46 (51%).
- Figure 5 shows the growth of the REU program from 1992 to 2003.

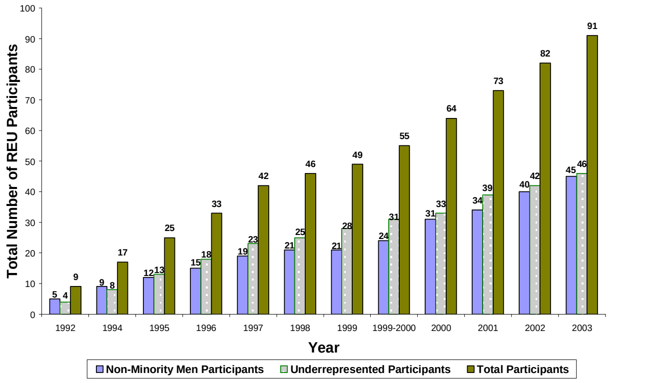

FIGURE 5
CUMULATIVE GROWTH OF THE REU SITES FROM 1992 TO 2003

Number of Participating Institutions:

- Total number of institutes from where the REU participants were recruited = 29.
- PhD Granting Institutions = 23.
- Undergraduate Institutes with Engineering Degree Programs = 1.
- Institutes with No Engineering Programs and Four-Year Colleges = 5.

Educational Placement of REU Participants (as of fall 2005):

- Degrees finished:
    - Bachelors = 82.
    - Masters = 26.
    - PhD = 2.
- Still in School = 32:
    - Undergraduate = 11 (2 finished BA (Physics/Chemistry) in four-year non-engineering school and then started BS Engineering program in a comprehensive university).
    - Masters degree program = 18.
    - PhD degree program = 3.
- Number of participants who have expressed a desire to pursue further graduate studies = 22.
- Figure 6 shows the cumulative educational placement of the REU participants.

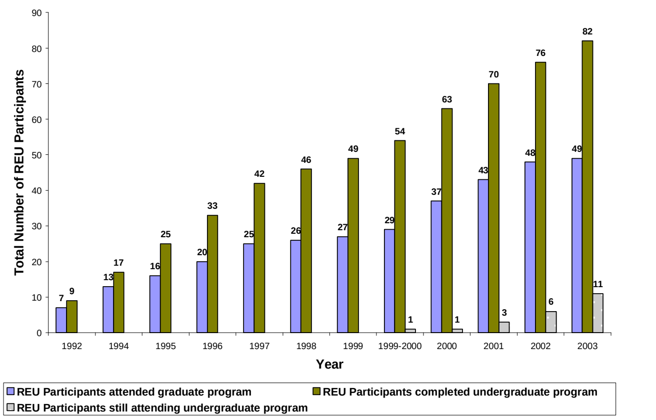

FIGURE 6
CUMULATIVE GROWTH OF REU PARTICIPANTS FROM 1992 TO 2003

Publications:

- By REU participants:
    - Total = 47.
    - Paper awards won = 8. Four students/groups won national/regional students paper competitions, and 4 students/groups won judged institutional paper presentation competitions.
- By Project Director:
    - Total = 12.
    - Conference proceeding papers = 11.
    - NSF REU Grantees Meeting special presentation = 1.

CONCLUDING REMARKS

Universal lessons learned by each group participating in the REU Site each year could be summarized as follows:

1) The identification of important parameters to be studied and appropriate testing procedures.
2) How to vary these parameters within practical limits.
3) Selection of appropriate parameter combinations so that the effects of each parameter can be isolated.
4) Manufacturing of test specimens.
5) Design and fabrication of test apparatus.
6) The importance of testing procedures and data recording.
7) Data synthesis.
8) Regression analysis of test data to develop prediction equations.
9) Teamwork and collaborative learning (between participant and participant, participant and graduate assistant, and participant and faculty mentor).
10) Use of visual aids in communicating the test responses.
11) Writing and presentation of technical reports.

It is noted that the key experience gained by the students was how to organize and conduct a research project with defined objectives. Every opportunity was provided to nurture and challenge the curiosity and creativity of the participants.

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