AC 2009-1953: RESEARCH EXPERIENCES AT UNDERGRADUATE SITES FOR TOMORROW’S ENGINEERS

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“Research Experiences for Undergraduate Sites for Tomorrows Engineers”

Abstract

This paper documents the programs implemented in the Research Experiences for Undergraduates (REU) Sites offered from 1992 to 2008 at two different institutions, University of Oklahoma, Norman, Oklahoma and University of Cincinnati, Cincinnati, Ohio. The programs 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. The paper presents how the whole research program was planned and conducted, the research training provided to the students, an overview of the projects completed by the students, the procedures used to evaluate the impact of the programs, the process used to track the students, and the outcomes of the programs. This paper will help others plan similar research experiences for engineering undergraduate students.

Introduction

The engineering schools in the U.S. now face internal and external challenges, impacting the marketability of our students. From 1985 to 2005, high school graduates went up 20.7% while engineering bachelor degrees went down 5.7%. The number of students indicating interest in engineering has dropped from 11% in 1985 to 7.2% in 2005. As we face this internal challenge, expanding global economy has further created a growing concern regarding the ability of America to remain competitive. With improved telecommunications and digitization, more engineering can be done without close proximity. However, off-shoring is likely to have little impact on the most highly educated engineers. Thus, engineering education is evolving, with more emphasis on graduate education, as outlined in a recently released series of reports by the National Academy of Engineering. Educators recognize that undergraduate research motivates students to apply for graduate school.

The Boyer’s Commission asserted that research universities often miss opportunities to enrich and strengthen undergraduate education by providing exposure to faculty research and the research process. Recent statistics indicate that declining populations of engineers pursue advanced degrees. Research experiences for undergraduates (REU) programs are widely promoted as an effective educational tool for enhancing the undergraduate experience with multiple benefits, the most instrumental of which is an increased interest in science, technology, engineering, and mathematics (STEM) careers. REU fosters increased persistence in the pursuit of an undergraduate degree; increased interest in pursuing graduate education; and gains in skills by REU alumni over comparison groups (conducting research, acquiring information, and speaking effectively). REU helps develop career pathways for underrepresented students by increasing minority retention and the number of minority students pursuing graduate degrees. Attempts to determine an empirically established set of REU-generated benefits are fairly recent. U.S. NSF and Howard Hughes Medical Institute funded three studies to find the benefits of REU initiatives. Lappotto compares how learning occurs in an REU experience with that reported in How People Learn. Various papers have documented successes of REU programs.
Other disconcerting trends are emerging in the U.S., which includes: (1) The 19.3% of BS degrees awarded to women in 2005-2006 was the lowest representation since 1998. This pales in comparison to the larger pool, where women make up 56% of the undergraduate college population in the U.S. About 22% of enrolled engineering students are women. (2) The master’s engineering enrollment decreased by 9% from 2003 to 2005, and this trend will continue. (3) The share of African-American and Hispanic students has remained low and virtually unchanged for the past decade. Despite comprising 25% of the U.S. population, these two groups earn just 11% of BS degrees. At the MS level, African-Americans receive 4.4% of degrees, while Hispanics receive 4.7%. Doctoral representation was lower for each population with African-Americans receiving 3.7% and Hispanic students receiving 3% of the degrees. (4) In 2005-2006 more than 61% of all U.S. engineering doctoral degrees were awarded to foreign nationals. U.S. security concerns are reducing the number of foreign students, while competition from other countries and opportunities to return to their home countries are increasing. For decades, other countries have strengthened their investment in science and engineering higher education. If current trends continue in the next five years, more than 90% of all scientists and engineers in the world will be living in Asia. A 2005 U.S. Senate Budget Committee report pointed out that other countries are investing heavily in research that produces talented, highly-educated workers and cutting-edge companies. China graduates almost four times as many engineers as the U.S. India is pouring money into technology parks to lure back native talent and produce world-class companies. South Korea graduates nearly the same number of engineers as the U.S. though it has 1/6th the population and 1/20th the GDP. If this continues the percentage of foreign doctoral recipients who stay in the U.S. may return to the lower 50% level that existed until 1992.

Recognizing the needs identified above, the U.S. NSF established the Research Experiences for Undergraduates (REU), to fund both summer and academic-year REU Sites. A REU Site is designed for engineering, science, and mathematics undergraduates who are U.S. citizens or permanent residents. This paper documents REU Site programs implemented by the author as the Project Director (PD) from 1992 to 2008 at two different institutions in the U.S., University of Oklahoma, Norman, Oklahoma and University of Cincinnati, Cincinnati, Ohio. The goal of each REU Site was to provide eight week summer full-time in-residence research training and professional development program on the use of modern technology in conducting and disseminating research in "Structural Engineering," with special focus on techniques to study the "Development of Enhanced Materials and Structural Assemblages for Seismic Performance Evaluation Studies." Each year six to nine students were selected, based on a national application process, who were divided in three teams, and each team worked on a well-defined research project under the guidance of faculty mentors(s) and a graduate research assistant (GRA), preferably a doctoral student. An attempt was made to fill one-third of the positions with women and minority students. The primary objective of each REU Site was to introduce undergraduate students to, and encourage them to pursue, careers in research. This objective was considered to be fulfilled if the participants enrolled in any appropriate graduate program. Students participated in a seminar series training them to conduct research and hands-on interactive workshops providing the necessary skills to disseminate their findings. The participants were encouraged and mentored to pursue co-authored presentations and publications after the
Research Professional Development Plan

Basic Approach Used. The need for cultivating learning environments to stimulate student’s learning in undergraduate engineering is well established. Today’s engineering students must have full access to emerging technologies to be fully prepared to contribute to their respective fields. Educators have found that students who engage in hands-on-activities, in addition to solving equations and developing analytical models, have a much better understanding and “feel” for how things work, leading to better judgment and ultimately more reliable designs. Recognizing these factors and the importance that experimental testing plays in conducting structural engineering research and education, the basic approach to the proposed research in the REU Site is discovery through actual construction, experimental testing and/or computer simulation, 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.

Pre-Preparation. To prepare the students for the research, reading material is sent four weeks prior to their arrival, which includes: project goal and objectives, important literature, tentative study plan, descriptions of test procedures and equipment, weekly activities, and information of team partners.

Targeted Progress. The first day of the REU Site, 8:00 a.m. to noon, is devoted to welcome by the Project Director, introductions, and presenting: general project schedule; alternative day meeting format; weekly group leaders’ concept and responsibilities; biweekly reports and presentations schedule; seminars and workshops; field trips; safety rules for use of the laboratory facilities; policies for use of office equipment and facilities; evaluations to be conducted; final day presentations; and activities beyond the summer REU experience. Finally, the faculty mentors(s) and GRAs give an overview of the three research projects to be executed. In the afternoon the students are taken to the laboratory facilities and are introduced to the lab technicians and other graduate students working in the labs.

Research Content and Laboratory Facilities Training Seminars. Students are trained to conduct research through a custom-designed seminar series offered by each faculty mentors(s) and GRA for their REU team participants. These seminars are structured such that no prior knowledge is expected and includes following elements:

1. Research seminars to educate the students on the theories, basic principles, and prior work on the topic they will be researching.
2. Training on the use of welding and metal fabrication machines by the lab technicians (see Figure 1).
3. Training on laboratory testing procedures, use of specific laboratory equipment, and data acquisition system software for their specific research project (see Figure 2).
4. Training on the use of Excel, statistical analysis tools, and graphical packages to report test data and to conduct analysis and interpretations.
Figure 1. Students Learning Fabrication, Instrumentation, and Erection Procedures

Figure 2. Learning Use of Data Acquisition System
Research Skills Training Workshops: Students participate in mentored longitudinal writing assignments and oral presentations through Biweekly Progress Presentations and a juried final Poster, PowerPoint, and Technical Paper presentation competition. To train and guide the students to acquire the skills to do this effectively this workshop series is offered. The goal is to train the participants to become proficient disseminators of research—written reports, papers, posters, and oral presentations. Eight hands-on interactive workshops, each of 3 to 4 hours duration, are held on following topics:

1. **Online Literature Search Workshop.** Is held in the first week to introduce the students to the University of Cincinnati (UC) library facilities and to the resources available for their research. These resources include the online catalog, book and journal collections (both in paper and online), as well as numerous indexes for accessing articles pertinent to their research. Also included are literature research techniques, methods for acquiring off-site material, and strategies for pursuing their research interests once the students leave this program and return to their classrooms. The workshop is conducted in a PC-Lab and the participants are actively engaged in first-hand experience in using the search engines for their literature search.

2. **Communicating Science Effectively Workshop.** Is held in the first week and consists of three components: “Writing Science,” which will support trainee co-authorship of research results; “Speaking Science,” a means to prepare undergraduate trainees for effective slide presentations; and “Presenting and Defending Science,” where the trainees are guided to construct effective posters and engage in informal dialog with science and non-science visitors and judges.

3. **Public Speaking and Communications.** Is held in the third week and includes topics such as speech content and organization, visual aids design and use, and aspects of delivery. As part of this workshop students have the chance to practice a short presentation in front of the group and receive critical feedback. This workshop is scheduled after the student teams have given their first biweekly presentation, which is attended by the instructor of the workshop. The observations made regarding the strengths and weaknesses of these presentations are used as a context to discuss the topics presented to the students.

4. **Project Documentation.** Held in first week, is designed to provide a practical approach to recording the project and preparing materials for presentation. It offers: an introduction to selecting photographic and/or video equipment using a film or digital format; an overview of correct exposure technique and the relative controls (aperture, shutter, film sensitivity), and setting to account for desired depth of field; and a discussion and demonstration of lighting and its practical application for the projects photographed. A discussion of image and text in PowerPoint presentations is also reviewed as preparation for the final presentation at the conclusion of program.

5. **Ethics in Engineering Research.** Is held in first week with the following main goals: (i) Familiarize with the grey area of ethics; (ii) Discuss ethical decisions using a board game with presented situations; (iii) Discuss the difference between a legal resolution to a problem, a moral solution, and ethical solution; and (iv) Ethics in research. The topics covered familiarize the participants with the ethics and problems that arise when researching. Ethics case studies are presented using an Ethics Challenge Board Game, which involves group discussions of real life situations and the course of actions, whether it required an ethical, moral, or political response. The other discussion involves ethics in actual research. The topics covered are quality assurance, peer reviews, and publishing.
The main purpose behind research is to accomplish things that no one has dreamed of and if the data acquired does not fit, there must be more experiments done to describe the inconsistencies. The seminar concludes with intellectual property rights and a group discussion on patents and the ethics and morals pertaining to knowledge founded through research. The student groups finally discuss the ethics of being on a review board for a research paper and what the decision should be in a situation where their research sparks an idea.

6. **Statistical & Uncertainty Analysis.** Is held in third week, and provides an understanding of statistical analysis, measurement precision, and uncertainty propagation in the design of experiments, data processing, and eventual optimization of devices and systems that are developed. Since all research projects selected require statistical analysis of data collected this fundamental knowledge is considered essential across the board for all teams.

7. **Poster Making.** Undergraduates lack experience in creating posters. Two 2-hour sessions are held during the third and fifth weeks on how to design a research poster and how to display a sample poster, respectively.

8. **Preparing e-Portfolio.** Is held during the second week. A central tool in achieving transparency and a critiqued final research paper is the e-portfolio. Each student is asked to track his/her progress by including evidence of research progress, reflections (lessons learnt) on seminar/workshop presentations, their own presentations, and periodic written critical evaluations from the faculty mentors(s), which are discussed in this workshop. The workshop guides the students in creation of their e-portfolio and provides support throughout the REU project period on request basis.

**Research Enrichment Training Seminars.** This seminar series introduces the role of interdisciplinary research in modern society, the scientific research process, and the opportunities it creates. The following four one-hour seminars are organized:

1. **Research in an Academic Setting.** This seminar instills a sense of discovery and the challenges of finding or improving solutions to problems. The development, progress, challenges, and final outcome of a research project are presented. A sample research project is selected to include graduate, undergraduate, and high school interns to explain project organization and distribution of responsibilities. The statement of the objectives and the needs for the research are defined. Background on the students’ research and their career paths, successes and failures, as well as changes in the course of research and adjustments to objectives and plans are discussed. Differences between research performed in a University setting and that carried out by a Research Laboratory are also discussed. Research laboratories are staffed by full-time employees and results are of the utmost importance. University research adds the mission of education and learning.

2. **Creative Thinking.** Undertaking a research program for an undergraduate poses several challenges. The initial encounter with an ill-defined problem can overwhelm students. The main purpose of this seminar is to introduce REU students to simple strategies in problem solving. The presented methodology provides insight into identifying the real problem, generating and implementing solutions, followed by an evaluation of the accomplished task. These basic ideas are re-enforced using graduated exercises intended to expand creativity in the problem-solving process.
3. **Taking Research from Lab to Real-World - Intellectual Property and Patent Issues.** “Is Having a Good Idea Enough to be a Start a Successful Business?” This workshop provides a practical overview of key factors involved in being a successful entrepreneur. Topics included are: Myths and truths about being an entrepreneur, evaluating the commercial potential of an idea/technology, importance of realistic expectations and focus, necessity of developing a written business plan, essential elements of a business plan, how to find funding for early stage ventures, importance of intellectual property and forms of protection, getting the right people involved and key drivers for success. The final topic for discussion focuses on getting started and working the plan.

4. **Graduate Education Opportunities and Application Process.** A general overview of graduate studies, covering motivation for pursuing graduate education, selection of a university and an advisor, and the application process and timetables are presented. The presentation is designed to help students clarify their future goals by addressing concerns rather than simply trying to convince them to attend graduate school. A suggested timetable for the application process as well as general suggestions for enhancing applications and obtaining reference letters is provided.

Each year research projects for the REU Site are designed to introduce undergraduates from diverse engineering and science backgrounds to “hands-on” structural engineering laboratory, field, and computer simulation research experiences. Six to nine engineering and science undergraduates are recruited through a national application process annually, with a special focus on women and underrepresented ethnic minorities. Teams of two or three students are guided on a research project by faculty member(s) and a graduate research assistant (GRA). In each team, one student acts as the team leader on a weekly rotating basis, who is responsible for reflecting on the daily activities, which is reviewed by the GRA. Weekly summary reports of these are conveyed by each GRA to the Project Director (PD). Any concerns are promptly discussed by the PD with the respective faculty mentor.

Each student team is required to give a PowerPoint presentation summarizing the goals, objectives, tasks, and time schedule to complete the tasks for their project on the third day. This may appear as an ambitious goal, but based on input from REU participants this has been effective in instilling a need to identify the research process early and make modifications on need basis as the research progressed. As the REU students are guided, each group is required to prepare a one page abstract of their research project, and a technical written report and oral presentation on literature review or background information, goals, objectives, scope, and time line for their project by the end of the second week as their first bi-weekly report.

Part of the second week and third to seventh weeks are primarily devoted to: developing test materials, components, structural assemblages, and test equipment; testing; test data synthesis; and interim report presentations. A digital camera with video recorder is provided to record experiments. Every alternate Friday afternoon is devoted to student presentations. Each team submits a bi-weekly written report and gives an oral PowerPoint presentation in which each team member is required to participate in some capacity. This approach promotes team work and provides an opportunity to each student to lead the discussion and address questions.
When the projects are nearing completion, using the bi-weekly reports, each student team is assisted by the faculty mentors(s) and the GRA in writing a Technical Paper and preparing a display Poster. The deadline for the final Technical Paper is two days before the last day. Each team gives a final half-hour PowerPoint presentation, which along with the Technical Paper and Poster is judged by an invited panel of three local area external professional judges (see Figures 3 and 4). The Technical Paper is hand delivered to the judges two days before the presentation. The judges select the “Best Project” considering both the report and presentations.

![Judges Viewing REU Group Poster](image1)

**Figure 3. Judges Viewing REU Group Poster**

![REU Group Making a Power Point Presentation](image2)

**Figure 4. REU Group Making a Power Point Presentation**

After the REU Site, the faculty mentors(s) help students to condense their technical paper for publishing and presentation in conferences, journals, or student paper competitions (at least one). Funds from the project were provided for them to travel to these meetings. After returning to their home institution, each REU participant is required to make at least one presentation at their
in an appropriate forum, for example the ASCE Student Chapter Meeting. A report
documenting this presentation is required to be submitted by their home-school faculty advisor,
who also submits a recommendation letter as part of the student’s application.

**Field Trips.** Two to three field trips, connected with the research projects, are organized each
year. These field trips enhance the students' background knowledge and also provide an
opportunity for them to interact with professional engineers.

**Social Enrichment Events.** All biweekly presentations are followed by a social hour with food
and refreshments. The final-day starts with a continental breakfast with judges and other invitees
followed by a lunch after presentations and judging.

**Research Projects Selected**

**Context.** Recently enhanced analytical and computational capabilities and higher strength
materials have led to lighter, larger and more complex structures. To design them, the engineer
must be able to evaluate their overall behavior, including their performance under possible heavy
overloads of both static and dynamic (seismic, wind, blast) environments. Because of the
inherent nonlinearities and the complexities in describing the material behavior and the
interaction between the components of a structure, to simply use analytical tools for studying the
response is not adequate by itself. There is no substitute for understanding how the material and
the structure respond to a full range of loading which may cause failure. This can only be done
by experimental testing. Testing full-scale structural systems and/or components is time
consuming, requires high capacity and expensive equipment, and is limited by economic
constraints. Thus, utilizing small-scale models is becoming a viable approach to solve many
complicated problems.

Given the above challenges, four logical research topics to solve infrastructure problems are: (i)
full-scale testing of structures and/or subassemblies to understand their behavior under adverse
loadings and implement novel strategies to enhance performance; (ii) developing improved
materials and testing procedures for small-scale models which are cost effective; (iii) field
studies on health monitoring and retrofitting techniques to preserve and upgrade our aging
structures; and (iv) 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. Design of improved building systems.
2. Design of improved bridge systems.
3. Manufacturing and testing structural components used for small-scale models in seismic
   performance evaluation studies.

The research projects executed in the 14 REU Sites offered during 1992 to 2008 both at
University of Oklahoma (OU) and University of Cincinnati (UC) are presented in Table 1. One
research project in each category is presented next, as a sample.

**Design of Improved Building Systems:** Moment-Rotation Behavior of Steel Frame Bolted
Connections. In this topical area the REU Site projects were selected to: (i) understand the
<table>
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<tr>
<th>Year</th>
<th>Research Project</th>
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| 1992 OU | 1. Improvement of Microconcrete for Small-Scale Structural Models  
2. Quantification of Bond Between Microconcrete and Model Reinforcing Bars  
3. Development of Model Base Isolator Devices |
| 1994 OU | 1. Development of Small-Scale Reinforced Concrete Materials  
2. Performance Evaluation of Moment Rotation Behavior of Endplate Steel Connections  
3. Testing and Evaluation of Modern Aseismic Structural Systems Utilizing Small-Scale Models |
| 1995 OU | 1. Development of Small-Scale Reinforced Concrete Model Materials and Components  
2. Development of Small-Scale Prestressed Concrete Model Materials and Components  
3. Testing and Evaluation of Structural Dynamic Systems Using Small-Scale Models |
| 1966 OU | 1. Development of High Strength Microconcrete for Small-Scale Models  
2. Development of a Novel Steel Frame Moment Connection Protected by a Steel Shear Link  
3. Development of a Novel Steel Frame Moment Connection Protected by an Aluminum Shear Link |
| 1997 OU | 1. Cyclic Performance of Semi-Rigid Steel Frame Connections  
2. Static Performance of Stiffened Eight-Bolt End-Plate Connection  
3. Cyclic Performance of Stiffened Eight-Bolt End-Plate Connection |
| 1998 OU | 1. Cyclic Performance of Double Web Angle Connections Bolted to Column Flange Welded to Beam Web  
2. Cyclic Performance of Extended Four-Bolt End-Plate Beam-to-Column Connections |
| 1999 OU | 1. Cyclic Performance of Double Web Angle Connections Bolted to Column Flange and Welded to the Beam Web  
2. Study Behavior of High Performance Concrete Under Three-Dimensional Loading  
3. Study Micromechanics of High Performance Concrete |
| 2000 OU | 1. Development of High Strength Microconcrete for Small-Scale Models  
2. Behavior of Steel Connections for Low-Rise Building Frames Under Seismic Loads  
3. Testing and Evaluation of Modern Aseismic Systems Utilizing Small-Scale Models |
| 2001 UC | 1. Connections Between Simple Span Precast Concrete Girders Made Continuous  
2. Service Load Prying of Tension Bolts in T-Stub Connections  
3. Using Small-Scale Models to Demonstrate Earthquake Aseismic Design Procedures |
| 2002 UC | 1. Testing of Fiber Reinforced Polymer Bridge Deck  
2. Tensile Testing of HPS-70W TMPC Steel Plate Material  
3. Use of Fiber Reinforced Polymer Composite for Strengthening of Reinforced Concrete Structures |
| 2003 UC | 1. Mathematical Modeling of Monotonic and Cyclic Behavior of T-stub Steel Connections  
2. Novel Steel Frame Connection With Damping Capability  
3. Energy Dissipating in Steel Coupling Beams Involving Splice Joint Coupled with Elastomers |
| 2006 UC | 1. Large-Scale, Hybrid Pseudo-Dynamic Testing of a Steel Concentrically Braced Frame under Earthquake Loading  
2. Investigation of the Properties of Innovative Materials for Structural Engineering Applications  
| 2007 UC | 1. Innovative Approaches to the Retrofit of Steel Braced Structures  
2. Testing and Evaluation of the Resistance Factor for Fully Threaded High Strength Bolts  
3. On the Behavior of Slip and Bearing in Slip-Critical Connections |
| 2008 UC | 1. Study of the Ductility and Deformation of High Strength in Tension  
3. Parametric Flexural Evaluation of Concrete Members Reinforced with High-Strength Reinforcement |
behavior of steel building frame connections, when subjected to cyclic loads expected during a severe earthquake; and (ii) 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 versus 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. The moment-rotation behavior data recorded from tests and results available from previous tests were used to develop the procedure to mathematically construct the moment-rotation hysteresis loops for the elasto-plastic, bilinear, and modified bilinear Ramberg-Osgood models for each type of connection. First, the parameters characterizing each model were identified, second, the test results were regressed to develop prediction equations (analytical expressions) for these parameters which best fitted the test data, third, a parametric sensitivity study was conducted for each prediction equation to demonstrate its level of acceptability, fourth, the step-by-step procedure to use these prediction equations to geometrically plot the moment-rotation hysteresis loops was outlined for each model, and finally, fifth, the level of accuracy in predicting results by each idealized model was demonstrated by comparing model predicted results with experimental recorded data. A photograph showing one of the beam-to-column test set-up used at University of Oklahoma for the REU project is presented in Figure 5.

![Test Set-Up Used for the Beam-To-Column Connection Testing](image.jpg)

**Figure 5. Test Set-Up Used for the Beam-To-Column Connection Testing**

**Design of Improved 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 conducted field monitoring tests and added to the data bank. The bridges studied were on Five Mile Road in Anderson Township in Hamilton County in Cincinnati, Ohio. 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 6.

![Figure 6. Truck on the Bridge Deck for Testing](image)

**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 and base isolator 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: (i) 3 layers, (ii) 5 layers of very thin steel plates, and (iii) optimum of (i) and (ii) 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 7.

![Elastomeric Bearing Casting Molds](image1)

![Two Story Frame Model with Dampers on Shake Table](image2)

**Figure 7. Small-Scale Models for Seismic Studies**

**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 is developed to inform students outside UC about the program, to present summaries of research projects completed, and elicit communication from REU alumni. A sample for past REU Site can be viewed at [http://www.eng.uc.edu/dept_cee/research/reu/](http://www.eng.uc.edu/dept_cee/research/reu/). All past REU students are asked to fill a Web-based *Tracking Form* every year up to next five years. Measures of success for REU include changes in attitudes and opinions about graduate school and research, increased enrollment in graduate school, and submission of research papers to competitions and peer-reviewed conferences and journals. The attitudes and opinions of students are evaluated through surveys before and after participation in the REU program. Questions probe 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. These should become more positive as students conduct research activities, view themselves as successful participants in larger projects, and build mentoring relationships with graduate students and faculty members. Another real measure is the number of participants who enroll in graduate school at UC or at other graduate institutions, as compared to the enrollment rate of non-REU students in the College of Engineering. A third
measure of success is the number of peer-reviewed papers submitted by faculty and students, both individually and jointly.

Internal and external evaluation is provided by participants and judges. The students complete two surveys on the last day with specific questions to assess their satisfaction with the Site. A direct measure of the effectiveness of the whole REU Site is also obtained from the judges. The judges fill out a scoring form evaluating each team’s technical paper: their organization, method of analysis, critical path followed, reporting and synthesis of test data, goal achievement, and comments. Also they fill out a scoring form evaluating each student’s presentation skills: their organization and emphasis, clarity, use and quality of visual aids, and response to questions, and poster presentation. The judges are also asked to give suggestions for improving the overall project activities.

The assessment plan is conducted during the academic year following the REU Site each year. The evaluation activities provide answers to:

1. Formative Evaluation: (i) Is this REU Site working as anticipated? (ii) Are any significant changes needed?
2. Summative Evaluation: (i) Can REU students work on an open-ended research problem and articulate their findings to others? (ii) Do REU students become more interested in CE programs? (iii) Do REU students become interested in continuing their education in graduate programs? The control group is the non-REU students.

Information for these questions were gathered from the aforementioned student questionnaires, tracking form, and judge’s evaluation forms each year.

Outcomes

Number of Participants

- Total REU participants = 113.
- Gender distribution = 82 men (73%) and 31 women (27%). The men consisted of 60 white men (53%) and 22 minority men (20%). The women consisted of 10 minority women (9%) and 21 white women (19%).
- Total ethnicity distribution = 81 white (72%) and 32 minorities (28%).
- Total underrepresented participants = 53 (47%).
- Figure 8 shows the growth of the REU program from 1992 to 2008.

Number of Participating Institutions

- Total number of institutes from where the REU participants were recruited = 44
- PhD Granting Institutions = 38 (87%)
- Undergraduate Institutes with Engineering Degree Programs = 1 (2%)
- Institutes with No Engineering Programs and Four-Year Colleges = 5 (11%)

Educational Placement of REU Participants

- Degrees finished
  - Bachelors = 94 (83%)
  - Masters = 55 (49%)
  - PhD = 2 (2%)
Figure 8. Cumulative Growth of the REU Sites Administered During 1992 to 2008

- Still in School = 32 (28%)
  - Undergraduate = 19 (17%)
  - Masters degree program = 6 (5%)
  - PhD degree program = 10 (9%)

- Figure 9 shows the cumulative educational placement of the REU participants. As can be seen from this figure, from 1992 to 2003 all students who participated in the REU program finished their undergraduate degree and 68.3% (average) of them pursued a graduate degree. During 2006 to 2008 still 5% to 17% (average = 10.6%) are pursuing their undergraduate degree, and out of the 83% to 95% (average = 89.3%) who graduated with a Bachelor’s degree, 64% to 73% (average = 68.7%) are pursuing a graduate degree.

The College of Engineering at University of Cincinnati conducts a survey of its seniors. Of the 260 graduating seniors in the Spring Quarter of 2007, 100 responded and returned the survey and 30% of them indicated that they are planning on attending graduate school. No such data was available for University of Oklahoma at the time of writing this paper. Comparing the data available for UC College of Engineering, it is concluded that the success rate of the REU Sites presented in this paper is more than double that for the majority students in the control group as far as motivating students to pursue graduate studies is concerned.

Professional Placement of the REU Participants
- Teaching and academics = 5
Figure 9. Cumulative Growth of the by the REU Participants who have Completed Degrees and/or Still in the Process of Completing

- Government organizations = 6 (out these 3 are in senior executive positions)
- REU participants who are working or have worked in jobs in industrial organizations = 73 (out these 14 are in senior management positions, 1 is a President and 1 is a Partner of a company)

Publications
- By REU participants:
  - Total = 57.
  - Number of student papers which won awards = 10. Six students/groups won national/regional students paper competitions, and 4 students/groups won judged institutional paper presentation competitions.
- By PI: Total = 15.

REU Judge Evaluation of Presentations

Figure 10 shows the average scores given by the judges for the REU group presentations during 2000 at University of Oklahoma and from 2001 to 2008 at University of Cincinnati. The data for these years was available. As can be seen in Figure 10, the judges have evaluated the overall performance of the REU participants to be between “Excellent” to “Very Good” in all years, except 2001.
**Figure 10. Judge Evaluation of REU Presentations**

(5 = Excellent; 4 = Very good; 3 = Good; 2 = Fair; and 1 = Unsatisfactory)

**Reflective Feedback on Impact of REU Projects on Participants**

Sample responses, one from each year, obtained to the question, “Describe how the REU Program has helped you in your Professional Development,” in the REU Tracking Form are presented below:

“I believe that this experience allowed me to have more confidence in pursuing my MS and PhD degrees.” (REU 1992; BS, MS, and PhD Civil Engineering; Assistant Professor at a major comprehensive university)

“The REU project was the template used in all of my subsequent project work during the course of my studies.” (REU 1994; BS, MS, and PhD Industrial Engineering; Adjunct Assistant Professor at a major comprehensive university and Software Engineer for a major aerospace organization)

“It helped me decide to attend graduate school and prepared me for the research I was to perform.” (REU 1995; BS and MS Civil Engineering; Project Engineer at a private industrial organization)

“The REU provided amazing exposure to graduate level research. It also helped me make a more informed decision to attend graduate school to further my career in engineering. Having the REU on my resume was certainly a big factor in gaining admission to Masters degree programs... I know that these schools thought highly of the fact that I already had research experience as a result of the REU program.” (REU 1996; BS and MS Civil Engineering; MBA; Director of a healthcare organization)
“REU was my first true experience in team work in the academic regime. As a Process Engineer at Dallas Semiconductor, my ability to work effectively within the small group and organizing the team effort is probably the most critical part of my job today.” (REU 1997; BS Physics; MS Electrical Engineering; Process Engineer)

“The most rewarding experience – it changed my life as far as self confidence on my capabilities was concerned. Immediately introduced me to the pace, problems, and insight research provides for the engineering profession.” (REU 1998; BS and MS Civil Engineering; Structural Engineer at a private industrial organization)

“The REU experience laid the foundation for my graduate education. I would credit it for making it possible for me to get admission into the prestigious graduate program at MIT.” (REU 1999; BS Civil Engineering; M Eng. Structural Engineering; Design Engineer at a private industrial organization)

“The REU gave me great insight into the process of research in general. How to write technically, speak in front of an audience of peers, and schedule and complete a research project. It undoubtedly contributed to the path I have taken to … I will return to Colorado State University (where I got my Master's) this fall [2005] to pursue a doctoral degree…” (REU 2000; BS, MS and PhD Civil Engineering; Assistant Professor at a major comprehensive university)

“This dynamic learning environment mimicked real world situations and aided in developing critical thinking skills. This combination of presentation skills, technical writing skills, and critical thinking skills equipped me with the tools needed during my interviews to convey my ideas clearly to someone who wasn’t an expert, be able to respond to questions that I wasn’t prepared for, and be able to think on my feet.” (REU 2001; BS and MS Mechanical Engineering; Mechanical Engineer at a private industrial organization)

“The REU program gave me a head start in my graduate studies by better preparing me for what to expect. It helped give me an idea of the time and effort required to be successful within a graduate program. I am very thankful to Dr. Kukreti for recommending me for the NSF Graduate Fellowship.” (REU 2002; BS and PhD Civil Engineering; working in a Research and Development Division for a major oil company)

“I was able to travel to two conferences and present the findings of the research project. This helped me increase my confidence in public speaking, to explain the goals/results of the project to different audiences, and to consider aesthetic aspects of presenting.” (REU 2003; BS Civil Engineering; Masters of Community Planning (MCP) Program; Project Manager for a landscape architecture/planning firm)

“The REU has given me research experience, which helped me discover my interest in research and encouraged me in my pursuit of a graduate degree. It also gave me experience with group projects and mentoring younger students, as
well as with giving oral presentations and writing technical papers.” (REU 2006; BS Civil Engineering; pursuing PhD Civil Engineering)

“REU helped me realize that research is the field into which I want to go. I had suspected that I would end up in research prior to REU, but REU confirmed it.” (REU 2007; pursuing BS Civil Engineering)

“The REU program has first, and foremost, given me the opportunity to understand what engineering is about beyond the classroom. I prefer best: working in a laboratory, conducting experiments. However, it has also helped me to learn how to research properly, and has made me expand my horizons in the sense of where I would like to work. As a sophomore, I'm not yet sure how much of an impact this has made on my Professional Development, but the REU program has certainly allowed me the chance to learn and grow as an engineer, and given me a better idea of what I might be doing in the future.” (REU 2008; pursuing BS Chemical and Materials Engineering)

**Concluding Remarks**

Universal lessons learned by each team participating in the REU Site each year were that for a research problem assigned to them they were able to:

1. Identify important parameters for the problem and the appropriate testing procedures to study their impact.
2. Identify the range of variation of these parameters within practical design and fabrication practices followed.
3. Identify appropriate parameter combinations to study the effects of significant parameters one at a time.
4. Choose appropriate procedures to manufacture the test specimens using the available fabrication equipment.
5. Design and fabricate testing apparatus, if not commercially available.
6. Recognize the importance of testing and data recording procedures for the research study.
7. Identify the data synthesis procedures for the research study.
8. Use regression analysis procedures to develop prediction equations using the test data obtained.
9. Recognize the importance of teamwork and collaborative learning (between participant and participant, participant and graduate assistant, and participant and faculty mentor).
10. Use visual aids to communicate their test results and respond to questions asked.
11. Write the technical results and conclusions of the study and present these using PowerPoint presentations and posters.

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. The biggest challenge was to keep up with all the programs and be on schedule. This was to a great extent accomplished by giving to each constituent a detailed daily calendar with expected deliverables included. This was updated periodically if any changes had to be made.
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Bibliography


