Research Experiences for Undergraduate Students in Structural Engineering

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1. Introduction

This paper describes the experiences provided in a five-year Site for undergraduate research in "Structural Engineering" with a special focus on techniques to study the *"Development of Enhanced Materials, Structural Components and Structural Assemblages Used for Seismic Performance Evaluation Studies."* The Site was offered at the School of Civil Engineering and Environmental Science, University of Oklahoma (OU) during 1999 and 2000, and then at the Department of Civil and Environmental Engineering (CEE) at University of Cincinnati (UC) during 2001 to 2003. This Research Experiences for Undergraduates (REU) Site was funded by the National Science Foundation (NSF). The purpose of this REU Site was to encourage talented undergraduates to enroll in graduate school by exposing them to research, and to increase their interest in graduate research. In this paper, first the basic approach adopted to plan the REU Site is presented, followed by a description of how it was administered each year. Then a detailed description of the projects executed in different years is presented. In the end the evaluation process used, and the outcomes from the whole experience are summarized. Hopefully, this documentation will help others in planning similar experiences for engineering undergraduates.

Enhanced analytical and computational capabilities and higher strength materials have led to lighter, larger and more complex and unconventional civil structures. To design such structures, one must be able to evaluate their overall behavior under both static and dynamic (seismic) heavy overloads, both in laboratory and field environments. The inherent non-linearities in describing the material behavior and the interaction between the components of a structure, makes simply using analytical tools for studying the response inadequate. This can only be done by experimental testing. Research projects for the REU Site are designed to introduce undergraduate students from diverse engineering backgrounds to structural engineering research. The “hands-on” laboratory and field research experiences included in these projects would help in recruiting and retaining them in civil engineering programs. The need for cultivating learning environments for stimulating student’s learning in undergraduate engineering is well established.

2. Basic Approach Used To Provide Undergraduate Research Experience

The basic approach used in this REU Site 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.

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, 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[2]. To address similar issues, health-monitoring (HM) concept is used in many engineering disciplines in various contexts, but is not yet exploited fully in CE practice. While most civil engineers recognize forensic engineering, HM and its system-identification are yet outside the realm of applications in this profession.

Given these 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 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 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.

3. General Description And Administration Of The REU Site

The REU Site was administered each year for eight weeks during the summer. Each year nine undergraduate students were recruited, who were divided into three teams, with three students in each, and each team pursued a unique project for the two summer months under the direct supervision of a Faculty Mentor and a Graduate Lab Assistant. The author served as the Project Director and managed and led the entire project. Recruitment was targeted from: 1) comprehensive universities in the neighboring states; 2) universities which have a high undergraduate minority enrollment; 3) institutions which have a very well reputed undergraduate CE program but no graduate program; and 4) a few selected institutions which had a strong undergraduate and graduate program in CE. Each year, an attempt was made to select two-third of the students from institutions other than the host institute, with one-third being women and/or minorities.

To prepare the students for the research topic, reading material was sent four weeks prior to their arrival. This material included an overview of the project, relevant literature, prior results available, plan of study, descriptions of the appropriate test procedures and equipment, and the weekly activities. Each participant was also be informed of the name, phone, e-mail address of their team partners.

During the Site the Project Director, along with the Faculty Mentors (if different than Project Director) and the Lab Assistants, guided the students on a regular basis. In each REU team, one student was made the team leader on a weekly rotating basis, and was responsible for entering the daily activities in a logbook. Every alternative morning the Project Director and the Lab Assistants held a meeting of the three teams in which the team leaders presented the work planned for the next two days and any problems encountered. All queries were ironed out, and it was made sure that the students were on track. Students, who were constructing some of their experiment materials, components or equipment, were given complete freedom to try different combinations and configurations, so that their creativity and curiosity were challenged. However, the Lab Assistants and technician kept a close watch so that they did not stray from their objectives and waste valuable time. Every attempt was made to create a work environment in which the students were made to think and identify their needs. This approach leads them to become more independent early on.

On the first day of the project, the Project Director discussed with all teams collectively the nature and scope of their project, make them aware of the lab safety rules, show them the lab facilities and ongoing research projects, and introduce them to other graduate students and faculty members. Students were asked to research in detail the pertinent literature. On the third day each team was required to present in their own words the goals and objectives, research tasks, and time schedule for their project. The second through seventh weeks were primarily devoted to: developing materials, components, structural assemblages, and test equipment; testing; test data synthesis; and interim report presentations. Every alternate Friday afternoon was devoted to student presentations. Each team submitted a written report and gave an oral Power Point presentation in which each participant participated in some capacity. This approach promoted teamwork, and provided an opportunity to each student to lead the discussion and respond to queries. When the goals of a project were nearing completion, the students were assisted in writing the work as a Technical Report and prepare a Display Poster. On the last day, each team was required to give a one-hour Power Point presentation, which along with the Technical Report and Poster was judged by an invited panel of external judges consisting of three professional civil engineers and a Fine Arts faculty member who had the expertise to judge visual aspects of the presentation. The judges selected the “Best Project” considering both the report and presentations. This activity fostered a spirit of competition among the three REU teams. The student researchers were encouraged to present their findings in state meetings, national conferences or student paper competitions. Students were helped in condensing their reports into technical papers and funds from the project were provided for them to travel to these meetings. Thus, the REU Site provided a "total" experience to the participants--learning, research, report writing and presentation.

During alternate weeks on Friday (when student presentations were not scheduled) a guest speaker was invited to give a presentation or the students were taken on a field trip. Each year the first invited lecturer was on the use of photography and visual media to enhance quality of presentations; this was in the form of a two-day "hands-on" workshop. The second invited lecture was on the use of statistical software packages available for student use. The third lecture was from a researcher working in the area of the projects selected for a particular year. The weekly presentations were followed by a social hour in which refreshments were served to cultivate student/faculty interaction. Two field trips were organized each year. In the last three years the first trip was to THP Ltd., a major CE and architecture design, restoration and construction company in Cincinnati. The students visited their design production center, and were taken to a building construction site. The second field trip was planned to include a visit to a bridge or highway construction project under execution by Ohio Department of Transportation. Not only these field trips enhanced the students' background knowledge, but also they provided an opportunity for them to interact with other professionals. Each team, in rotation, prepared a write-up of the special events (seminar or field trip), which was put on the REU Website.

4. Description Of The Research Projects Undertaken

4.1 Design of Improved Building Systems

4.1.1 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.

The test set up used by the students consisted of two major components--an actuator connected to an end of the beam specimen selected to apply a cyclic (moving up and down) load, and a reaction frame supporting the actuator and the column specimen selected. The beam and column specimens were connected using the desired connection. The beam specimen was adequately braced to prevent any out-of-plane deflections. The instrumentation consisted of two Linear Variable Displacement Transducers (LVDTs) mounted at the level of the top beam flanges to measure connection local rotation, one wire potentiometer attached to the bottom flange of the beam near the actuator attachment point to compute connection global rotation, strain gauged bolts used to connect the beam-end to the column flange to measure bolt force variation, and a load cell and displacement transducer mounted on the actuator to measure the load and displacement applied, respectively, at any instant. Each of these electronic measuring devices were connected to a unique channel of a data acquisition system, and application of the cyclic loading history, data collection, processing and display in real time was automated. The cyclic load was applied to follow a predefined (SAC loading) displacement history. The initial stiffness of the connection was computed using the first few load cycles. All tests were conducted until failure occurred due to either excessive rotation or bolt fracture.

The moment-rotation hysteresis loops for each connection were recorded and transferred to a spreadsheet program. From the data recorded, the initial stiffness, ultimate moment, ultimate rotation, and moment-rotation plots were obtained. The test results were used to develop a family of mathematical models, with varying degrees of sophistication, that idealize the observed moment-rotation behavior of the typical connection being studied, and which can be later incorporated in a frame analysis computer program. Moment-rotation hysteresis models for the following four types of idealizations were developed by the REU groups: elasto-plastic (most simple to implement), bilinear (an improvement over the previous, but more complex to implement), Ramberg-Osgood function (most complex to implement, but most accurate), and modified bilinear Ramberg-Osgood (similar to implement as bilinear, but may be more accurate).

From the aforementioned studies it was observed that PRC have their own shortcomings including low initial rotational stiffness and pinched hysteresis behavior due to slip. The above two shortcomings of PRC have precluded their widespread acceptance as moment resistance connections in multi-story steel frame structures. The REU project was extended to investigate if elastomeric bearing pads can be used at the interfaces where the connection plate elements (e.g., the T-flange and T-stem of a T-stub connection) are connected to the column and beam flanges to overcome this shortcoming of PRC connections. This novel connection is expected to produce: stable hysteresis loops, as typically demonstrated by fully restrained welded connections; high rotational stiffness; no fracture failure; and more ductility without loss in moment capacity. Two separate projects were conducted using this strategy, one for top and seat angle connections (both types), and the second for T-stub connections. Only limited tests were conducted, and results are being used to develop a more comprehensive research study for external funding.

A photograph showing the test set-up used by the REU students for a steel connection is presented in Figure 1.

4.1.2 Improved Coupled Wall Systems

Individual wall piers (shear walls) are coupled together to resist large lateral loads that typically occur during an earthquake. They provide a huge amount of lateral stiffness and strength. Under individual action they would tend to transfer the loads through flexure. 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. Coupling beams can be reinforced concrete beams, structural steel beams or hybrid beams. 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. No matter what type of material is used, in the past coupling beams have been designed to be significantly strong and stiff, but yield before the wall piers, which increases the energy dissipation characteristics of the walls.

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. These pads were placed between the splice plates and the fuse beam, both on the web and the flanges. The motivation for using neoprene elastomeric pads is their excellent energy absorption and damping capabilities. These properties may help to increase the efficiency of the fuse beam in the shear wall system, which was explored. 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 2.

4.2 Design of Improved of Bridge Systems

4.2.1 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 tested were installed as part of Project 100, an initiative in Ohio to install 100 FRP bridge decks. The bridges studied were on Five Mile Road in Anderson Township in Hamilton County in Cincinnati. This county replaced three fifty year-old reinforced concrete bridge decks with the FRP deck. The bridges are supported by prestressed concrete I-beams. Two of the bridges still use the original fifty year-old beams, while the third bridge had its beams replaced with new prestressed concrete I-beams. The bridges' performance was evaluated by analyzing data collected from field-testing. Since the two bridges with the old beams are functionally identical. The project was concerned with only analyzing the composite action of the bridge, since additional analysis is dependent on this result. The new bridge deck consists of several FRP panels across the width. If there is composite action, the sharing of the load between them as vehicles traverse may be unequal. It is important to know the extent to which this is happening, for future designs and to plan precautionary measures to decrease the distress it may be causing. The abutment support conditions, which are unknown, may also cause this problem.

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 was 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. The strain measurements were taken by strain gages mounted on the beams and deck at both mid-span and quarter-point; 24 gages were used. Five LVDTs were used to measure displacement of the deck: two to measure deck panel displacement relative to one another, two to measure the displacement of the deck relative to one beam, and one to measure deflection of the deck relative to both of the instrumented beams. Two wire potentiometers were mounted at mid-span and measured deflection of the entire bridge relative to the ground. All of the instruments were read and processed by a data acquisition system, and stored in a laptop computer.

A photograph showing field testing of one of the bridges is presented in Figure 3.

4.2.2 Use of Fiber Reinforced Polymer Composite to Strengthen Reinforced Concrete Bridge Beams

A fiber-reinforced polymer (FRP) is a rigid material composite consisting of resin and fibers. The fiber type can be aramid, glass, or carbon. This material has been used recently in civil engineering to retrofit old and deteriorating structures, such as bridges. Although FRP is weak in compression, it is very strong in resisting tensile forces. Because of this property, in bridges FRP plates can be bonded at the bottom of concrete beams to increase their flexural strength. This in-turn increases the weight resistance capacity of the bridge deck without increasing the dead load of the bridge. Before such usage, one problem that needs to be investigated is the effectiveness of the bonding technique used to attach the FRP to the concrete beam surface. When the flexural capacity is reached, the FRP can debond from the concrete and fail catastrophically. 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. If mechanical anchors are used to connect the FRP plate to the concrete surface, then such holes will need to be drilled into the FRP plate. Under a tensile load will the hole made in a FRP plate result is stress concentration and loss in tensile capacity, needs to be determined. 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. Six specimens were prepared for each of the three different hole diameters (1/8 in., 1/4 in., and 3/8 in.) investigated. The plates were cut into 10 in. x 1 in. coupons, and 2 in. x 1 in. fiberglass tabs were attached with epoxy on each end of the coupons. The students prepared the FRP plates and grip tabs by cleaning both surfaces with acetone. Structural epoxy was applied to the tabs and the plates with a 1/8 in. V-notched trowel. Clothespins were attached to the ends to secure the tabs in place.

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. The blocks were 6 in. x 6 in. x 10 in., and the bonding area was 8 in. in the center of the block. The mechanical anchors were put 3 in. from the top of the FRP bond, and 2 in. from the bottom.

A photograph showing shear test set-up designed by this group is presented in Figure 4.

4.2.3 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.

This group first performed a detailed literary review and documented the findings. The full project, which was funded by the National Cooperative Highway Research Program (NCHRP), called for the testing of four specimens. Specimen 1 consisted of a 1/2 in. bent strand connection. Specimen 2 consisted of 5/8 in. bent bar connection. Specimen 3 consisted of the bent strand connection with the girders embedded 6 in. into the diaphragm. Specimen 4 consisted of the bent bar connection with the girders embedded 6 in. into the diaphragm (Specimen 1 and Specimen 2). Students tested Specimens 1 and 2, which were made available to them when they arrived, and casted Specimens 3 and 4. The students also started the testing of Specimen 4, which was later completed by the graduate students assigned to the project. Thus, the students got an exposure to both the construction techniques and the testing of the specimens. In particular, they understood both technologies, one in which the girders are directly connected using bent bars or bet strand, and the second in which the girders are connected through the use of diaphragm.

Specimen construction and testing took place at Prestress Services Inc. (PSI), in Northern Kentucky. The construction was a cooperative effort of PSI employees and the REU students working on the project. Formwork for each specimen had to be built by 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 M_{cr}, the moment at which the joint would crack if it were completely rigid, and then live loads were applied in a cyclic pattern, i.e., $M_{cr} \pm M_{live\ load}$. Specimen 1 failed after 16, 000 cycles by pullout of the bent strands in the diaphragm. Specimen 2 failed after 29,000 cycles after the bent bars in the connections had yielded and fractured. The connection in Specimen 2, a bent bar connection, was found to be stiffer than the bent strand connection in Specimen 2, and was subject to less beam rotation and crack opening than the connection in Specimen 2.

A photograph showing students working on the project at the field-testing site is presented in Figure 5.

Tensile Testing of High Performance Steel Plate Material Used for Bridges

Traditionally grade 36 and 50 steels have been used for structural application in bridges. Stronger steels could not be effectively used in bridge construction because the method used to create stronger steels compromised ductility and weldability. However, the recent development of High Performance Steel (HPS) has remedied this problem. High Performance Steel was originally manufactured using the Quenching and Tempering Process, which limited its plate length to fifty feet. A new process, Thermo-Mechanical Controlled Process (TMCP), allows for production of steel in much longer sheets. However, HPS produced in this manner has not been thoroughly tested, and thus is not yet included in ASTM specifications. This REU project was concerned with determining the material behavior of HPS.

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 grade 70W steel. The objective of the REU project 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, which included reading background information about HPS-70W, it’s weathering and mechanical characteristics and weldability, as well as its current use in bridges, including its use in hybrid bridge design. The cost saving associated with the use of HPS-70W was also a subject of literature review. A review of the ASTM testing specifications found in E8 and A370 was also undertaken. Another important element included for review was a study of steel basics including welding, weathering steels, and common steels (A36, A572-50, and A588).

Students then conducted tensile coupon tests on a large number of specimens; a few were fabricated by them, whereas the remaining were manufactured to precision by a local steel fabricator. The MTS 312 load test frame was used for testing the tensile specimens. The project results showed that the average values for yield stress and ultimate strength were lower than the mill certified values. Specifically noted were the values of yield stress; these values were, on average, lower than the minimum 70 ksi yield stress prescribed by ASTM specifications. The average yield stress of the specimens from the 7/8 in. plate was higher than that of the specimens from the 2 in. plate, while the ultimate strength and percent elongation were lower. This could be as a result of the difficulty in maintaining the precise temperature necessary throughout the plate when rolling the thicker sheet using the Thermo-Mechanical Controlled Process. Further research into the TMCP process and the resulting mechanical properties of steel produced using this process is necessary in order to obtain more conclusive results. It was also noted that coupons transverse to the direction of loading had higher yield stress and ultimate strength than those parallel to the direction of rolling. The variation in yield strength from side to side was only 2%. The variation in yield strength averages only 1.2% over the entire 7/8 in. plate and 4.4% over the 2 in. plate. This small variation over the plate is typical for all properties and indicates consistency through the TMCP plate. Testing of more specimens throughout the plate is necessary in order to obtain more precise trends across the TMCP plate. The overall results of this project showed that HSP-70W TMCP has the anticipated mechanical properties and, therefore, it is a promising grade of steel for application in bridge design.

A photograph showing a REU participant milling relief in HPC test coupons is presented in Figure 6.

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

4.3.1 Development of Small-Scale Reinforced Concrete Model Materials and Components

Small-scale modeling of structures can be an invaluable tool, allowing engineers to test the soundness of a prototype design without prohibitive expense. Ideally, the models should replicate the material properties and strengths of the prototype, and should exhibit similar behavior under the loadings considered. Unfortunately, due to different scaling factors for various properties and due to the fact that some of the parameters cannot be scaled down, it is very difficult to exactly replicate the strength and behavior of the prototype in all respects. Two key parameters needed for realistic small-scale models of reinforced concrete structures are the materials used to simulate concrete and reinforcing steel. Even if a small-scale model is not relied upon to predict localized failures such as cracking, spalling, and loss of bond to reinforcing steel, any improved simulation of these behaviors enhances the prediction of global structural response. The current material of choice for model concrete, microconcrete, is a mixture of water, Portland cement, graded sand, and sometimes plasticizing admixtures. Deformed spring steel wire is currently the best model reinforcing bar material. The different projects undertaken dealt with the design of a workable microconcrete of desired strength and model reinforcing bar with desired bond characteristics. The projects pursued by the REU groups are described in the paragraphs that follow.

*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, Duracem 100, was added. If superplastizer was needed, two dosages were considered to investigate the effect of superplastizer on mix strength. The graded sand, Type III Portland cement and tap water was used to prepare the different microconcrete mixes. The group followed a standardized procedure to mix these three ingredients in any desired proportions. 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 in a Universal Testing Machine connected to a microcomputer controlled data acquisition system. The specimens were cured in a water filled tank with lime added and temperature maintained at 100^0 F. Full strength was achieved at 14 days by curing at this elevated temperature, and this made it possible to conduct all the desired tests in the first six weeks of the project period. The groups were able to develop a standardized procedure to cast the cylinder specimens by pouring concrete in three layers and hand tamping each layer a certain number of times. The cylinder specimens for compressive and split cylinder tests were tested at 3, 5, 7, 10, 14 and 28 days to verify the gain in strength with curing time. The strength results obtained for the 2x4 in. cylinders were compared to the respective day strength of the 3x6 in cylinders to investigate if the specimen size had any effect on the strength obtained. The MOR beams were only tested after 14 and 28 days of curing. The groups working on this project were able to produce a variety of microconcrete mixes in which the compressive strength, and the tensile strength was less than 10% of this value.

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. Additionally, this study researched the effects of superplastizer and elevated-temperature accelerated curing on the strengths of microconcrete (model concrete mix). 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. Pullout test results enabled the number of variables tested in subsequent Texas bond beam and lap splice test to be reduced. The Texas bond beam and lap splice tests achieved similar failure modes and crack patterns as the prototype tests, but bond strength values, although decreased, remained higher than the prototype. The lap splice tests were more successful, resulting in bond values slightly lower than those in the prototype. The results were regressed to develop empirical formulas to predict bond stress in small-scale reinforced concrete beams.

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. These two properties of the model strands selected are usually determined from simple tension tests conducted on the strands. Traditionally, a tension test is done on a Universal Testing Machine, and a load cell can be used to measure the load applied and an extensometer can be used to measure the strand elongation. It was very difficult to fix an extensometer to the very small hard strands. The students tried different methods to prevent slippage of the extensometer and the slippage at the anchorages. Finally, they devised a 16 ft long horizontal bed to test the specimens with load cells to measure the strand tension and Linear Variable Deformation Transducers (LVDTs) to measure the extensions at any load level. 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 Fears Structural Engineering Laboratory at OU. 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. The following four strand conditions were tested: normal, acid etched, coated with saline and coated with WD-40. Based on the results obtained from the simple pullout and tensioned pull-out tests, it was found that both the 7x7 galvanized helical cable and spring steel wire under normal surface conditions had bond characteristics similar to that of the prototype. The students in this group were only able to do two beam tests to estimate bond strength in flexure. In summary, this group had laid down foundations on which future researchers can work.

A photograph showing the reinforcement cages manufactured by the REU participants for the small-scale model bond beam tests is presented in Figure 7.

4.3.2 Development of Small-Scale Building Models Fitted with Aseismic Devices

Modern aseismic design methods include the use of various energy absorbing devices, which are not permanently deformed when activated by earthquake motions. These include specialized sway braces used to increase the damping in each story, and base isolators which significantly de-couple the building from the damaging horizontal components of the earthquake motions, thus reducing the earthquake forces on the structure and hopefully enabling most of the structural members to remain elastic. Analytical prediction of the response of these highly nonlinear systems to earthquake motions requires significant idealizations of the material, component, and structural behavior, and is not fully developed for all structural systems. Thus, in order to understand and evaluate the global behavior of structural systems with these aseismic devices, one needs to do physical testing. Because of the size limitations and expense of seismic simulators available and the need to test complete structures, small-scale models are often the only choice for testing. It is generally agreed that testing of larger scale models (1/3 size) gives better information about localized behavior such as member cracking, however much of the same global behavior can be obtained at a much lower expense by testing much smaller models (1/24 size). The expense reduction due to the use of small-scale models is due to lower specimen production and instrumentation costs and drastically lower simulator costs. 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 the following three types of dampers was explored:

viscous, friction and beam yielding. The first three experiments dealt with free vibration motion characteristics of one- and two-story models with and without dampers. The next three series of experiments involved mounting a one- and two-story model on a shake table, and subjecting it to a harmonic base motion. For these three tests, using the knowledge gained by the first three series of tests, students designed the models with a known fundamental natural frequency. Each test was repeated for three different base motion frequencies--lower, about equal and greater than the model fundamental frequency. In the first experiment, the response (displacement, velocity and acceleration) of the bare model was measured, and in the second experiment the three damping devices were mounted on the model, one-by-one, and the response for each will be recorded and compared to that obtained for the undamped model. Each experiment with a damping device was repeated with three levels of damping. Finally, the device, which was found to be the most effective in decreasing the amplitude of the displacements, was identified.

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. Cylindrical rubber mounts are commonly used as supports in mechanical machinery, and different size mounts are commercially available. So, these could be used as base isolators for small-scale models. One of the more common designs of base isolators is a stack of rubber layers laminated with a series of horizontal very thin steel plates. The steel plates distributed among the rubber layers retain the lateral bulging of the rubber, thus increasing the vertical stiffness and strength. At the same time, the steel plates interfere very little with shear deformation of the rubber layers, giving relatively low shear stiffness. A common method of adding damping to the horizontal motion of these isolators is to insert a cylindrical lead plug through a hole in the center of the bearing, so that the lead plug is yielded when the isolator is displaced in shear. This REU project evaluated the use of these two types 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. The students did six experiments on one- and two-story small-scale building models. The first three experiments were identically same as the previous project described in the last paragraph. The next three series of experiments were also similar to the previous one, except this time the one- and two-story frames were fitted with the three types of base isolators (commercially available rubber mounts, the in-house fabricated elastomeric base isolators laminated with steel plates, and the latter with lead plug) instead of the damping devices. The response obtained for frame with each type of base isolator was recorded and compared to that obtained for the undamped model. 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 and 2) 5 layers of very thin steel plates, and 3) optimum of 1) and 2) with a central lead plug.

A photograph showing a two-story frame model mounted on the shake table and used for this REU project is presented in Figure 8.

5. Project Evaluation Procedures Used

The primary goal of the REU program was to introduce undergraduate students to, and encourage them to pursue, careers in research. Both traditional and innovative methods were used to access this goal. A REU homepage (http://www.eng.uc.edu/dept_cee/undergrad/research/ucreu/) was developed to inform students outside UC about the program, to present summaries of research projects completed, and elicit communication from REU alumni. All past REU students were asked to fill every year, up to next five 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 presentation competitions and peer-reviewed conferences and journals. The attitudes and opinions of undergraduate 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 herself/himself as a researcher, or about the role or research in improving quality of life. It was 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 senior graduate students and faculty members. In the past two REU Sites the author has used these questionnaires (see REU Website). Another real measure of the REU program success, which was tracked, was the number of participants who enroll in graduate school at the UC or at other graduate institutions, as compared to the enrollment rate of non-REU students at CEE. A third measure of success, which will be tracked over an extended period, will be 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, which was submitted 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 us an overall picture of their perception of the REU experience. A direct measure of the effectiveness of the whole REU Site was obtained from the judges. The judges filled out a scoring form (see past REU Website) 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 (see REU Website) 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 asked to give suggestions for improving the overall project activities.

The assessment plan was conducted during the academic year following the execution of each REU Site. The formative and summative evaluation activities provided 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 was non-REU students. Information for these questions was gathered from the aforementioned student questionnaires, tracking form, and judge's evaluation forms.

6. Project Outcomes

Forty-five students have participated from ten institutions, including eleven women (one African American), and eight minority male (one Native American, four African American, and three Hispanic), three Asian American male, and 23 white male students. Seventeen students are pursuing their MS degree program, and 18 are still pursuing their BS degree program, and many of them have plans to pursue graduate studies. The author has presented six ASEE Conference papers.

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.

7. Acknowledgment

The author would like to acknowledge the financial support provided by NSF for this REU Site (Award No.EEC-0196371), and cost sharing provided by OU and UC.

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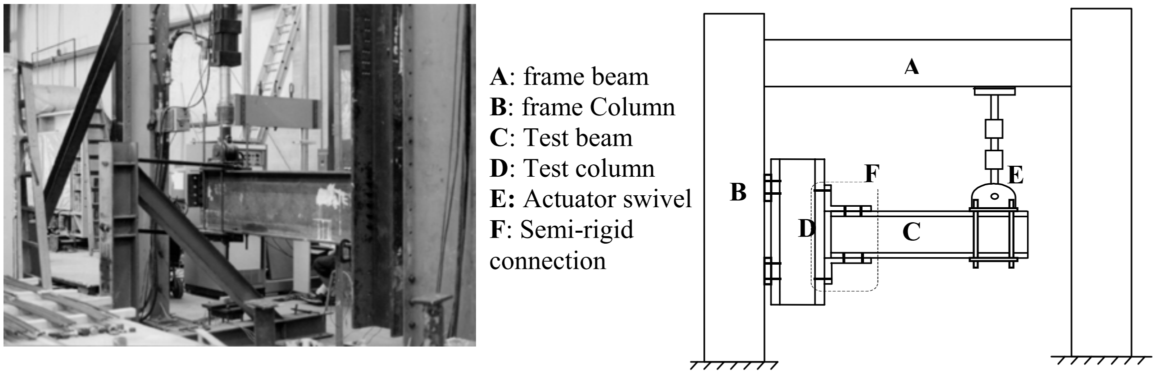

(a) Photograph of Test Set-Up

(b) Schematic Test Set-UP

Figure 1 Test Set-Up Used for Testing a Steel Connection

Figure 2. A View of the Test Set-Up Used for the Fuse Beam Testing

Figure 3. Positioning the Trucks on the Bridge Deck for Testing

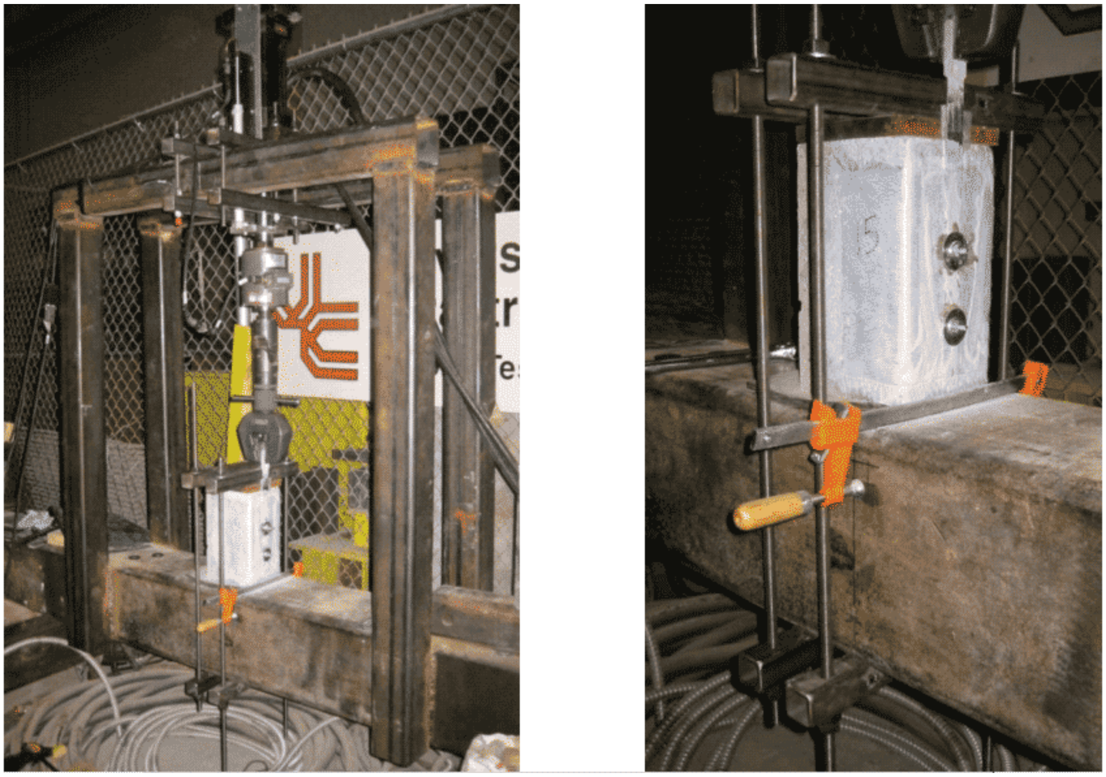

Figure 4. Shear Test Set-Up Designed by the Fiber Reinforced Polymer Group

Figure 5. Prestressed Concrete Girder REU Participants Preparing for Testing

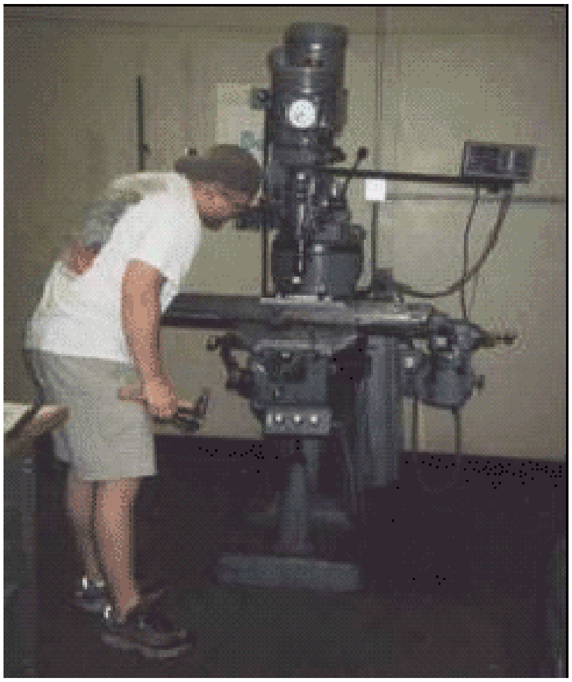

Figure 6. High Performance Steel Group Participant Milling Relief in Test Coupons

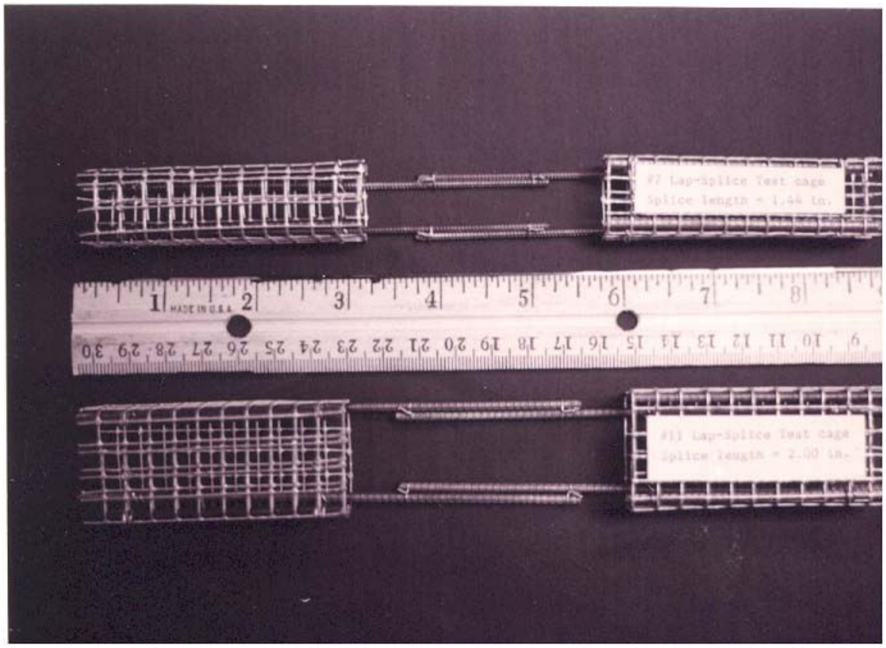

Figure 7. Reinforcement Cages Fabricated for the Small-Scale Bond Beam Tests

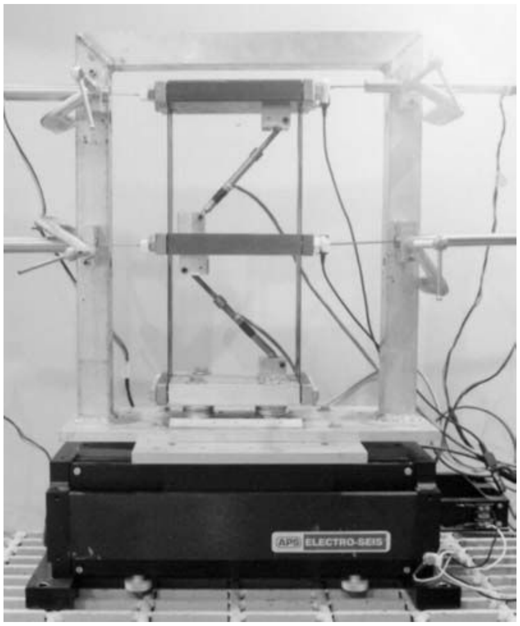

Figure 8. Two Story Frame Model with Dampers Mounted on the Shake Table