

An Open-Ended Research Project for Undergraduate Students

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Abstract

This paper describes a project conducted to provide research experience to engineering undergraduate students involving discovery through actual construction, experimental testing, observing and recording, synthesizing the data collected, and generalizations. The project was part of a Research for Undergraduates (REU) Site grant sponsored by the National Science Foundation, and administered in the School of Civil Engineering and Environmental Science at the University of Oklahoma (OU) during the Summer of 2000. The research experience provided was in the area of structural engineering with a special focus on the development of enhanced materials, structural components and testing procedures for small-scale modeling in seismic performance evaluation studies. Nine students were selected to participate in the Site; six students selected were from institutions outside Oklahoma, two students selected were from OU, and one student selected was from another institution in Oklahoma. These included one woman, one Hispanic male student, and seven white American male students. These students were divided into three groups with three students in each, and each group worked on a separate project during the two summer months. Each group were supervised by the Professor In-Charge of the project (author) and a Graduate Research Assistant. The paper presents how the whole research program was planned and conducted, the details of the projects selected for the students, procedures used to evaluate the impact of the project, and what were the outcomes of the program. This paper will help others in planning similar experiences for engineering undergraduates.

I. Introduction

This paper describes the experiences provided in a Site for undergraduate research in "Structural Engineering" with a special focus on techniques to study the *"Development of Enhanced Materials and Structural Assemblages Used for Seismic Performance Evaluation Studies"* in the School of Civil Engineering and Environmental Science (CEES) at University of Oklahoma (OU), Norman, Oklahoma. This Research Experiences for Undergraduates (REU) Site was funded by the National Science Foundation (NSF) and matching funds were provided by OU. 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 in this section, followed by a detailed description of the projects executed, and other activities planned. In the end evaluation of the Site's impact, the lessons learned, and the outcomes from the whole experience are summarized. Hopefully, this documentation will help others in planning similar experiences for engineering undergraduates.

The basic approach used in this REU Site was discovery through actual construction, experimental testing, observing and recording, synthesizing the data collected, and generalizations. This

approach provided an opportunity for individual growth and challenge to the young and inquisitive mind. Projects were chosen to separate the intuitive part from formalism. When intuition itself did not suffice, as usually expected, formalism was introduced to interpret the intuitive ideas through the formal mathematical framework used to analyze the problem. This approach provided an opportunity for interplay between intuition and formalism.

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. The three projects selected for this REU Site were concerned with the design and manufacture of small-scale model materials and components for seismic studies. These included the following projects:

1. Project 1: development of high strength microconcrete for small-scale models. This project was concerned with the manufacture of model concrete to construct 1:12 scale models.
2. Project 2: behavior of steel connections for low-rise building frames under seismic loads. This project investigated the use of 1:2 scale models to investigate a novel technique to enhance the energy dissipating capability of semi-rigid connections used in low rise buildings.
3. Project 3: testing and evaluation of modern aseismic systems utilizing small-scale models. This project investigated the performance of various types of damping and base isolation devices for buildings using 1:24 scale models.

Thus, the whole REU Site provided an insight to the participants on the issues and concerns with design, manufacture, testing and data synthesis of a wide range of different scale models used in seismic research. The work accomplished by the participants in each of these projects is described next in this paper.

II. Description of the Research Projects Executed in the REU Site

In **Project No. 1** the students studied the designing, mixing and testing of various high performance microconcrete mixes with compressive strengths ranging from 4 to 8 ksi and with tensile strength limited to 6% to 10% of compressive strength. 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 were chosen in which the amounts of sand particles passing through sieve sizes #12, #16, #20, #30 and #35 were varied between a low of 10% to a high of 35%. Four sand to cement ratios were considered, which were 2.5, 3.0, 3.5 and 4.0. Three water to cement ratios were considered, which were 0.4, 0.6 and 0.8. All combinations of these sand gradations (three), sand to cement ratios (four) and water to cement ratios (three) were considered, which gave twelve different mixes for each sand gradation or a total of 36 different mixes. When the workability of a mix (i.e., when the mix was too dry to take any shape) was found to be less 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 superplastizer was added to most mixes with a water to cement ratio of 0.4.

To obtain the required amounts of sand for the three gradations a sieve analysis was done. The sand was first sieved thorough #8 sieve, and the material that passed through it was sieved, one-by-one, thorough the #12, #16, #20, #30 and #35 sieves and separated. Sand that passed thorough #35 sieve was discarded. To speed the sieve analysis process, a novel sieving apparatus was designed and fabricated, which consisted of a three foot long wire mesh (with opening size corresponding to a particular sieve size #) drum set on a slight slope with a turn crank to rotate it and a funnel continually feeding sand into the drum. A view of the sieving apparatus used is shown in Figure 1. The sand that was retained was caught in a bucket at the end of the drum, and the remaining sand which passed through was collected in large trays placed below the drum. A separate drum was fabricated for each sieve size #. This way, the needed amount of sand was separated and stored in bins corresponding to each sieve size #. 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 type 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.), 3 in. diameter and 6 in. height (3x6 in.), and 4 in. diameter and 8 in. height (4x8 in.) cylindrical specimens were cast and tested by applying an axial compression load until failure occurred. The test was conducted in a Forney Testing Machine connected to a microcomputer controlled data acquisition system. An extensometer was also mounted on the specimen to determine the axial change in length at each load level. The compressive strength was determined by dividing the failure load by specimen cross-sectional area, and the extensometer readings were used to plot the stress-strain diagram and determine the modulus of elasticity of the microconcrete. The specimens were cured in a water filled tank with lime added and temperature maintained at 100⁰ F (43⁰ C). 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 group was 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 2x4 in. cylinder specimens were tested at 3, 5, 7, 10, 14 and 28 days to verify the gain in strength with curing time; three specimens were prepared for each mix for each test day to estimate the average strength. The 3x6 in. and 4x8 in. cylinder specimens were only tested at 14 and 28 days; two specimens were prepared for each mix for each test day to estimate the average strength. The strength results obtained for the 2x4 in. cylinders were compared to the respective day strength of the 3x6 in. and 4x8 in. cylinders to investigate if the specimen size had any effect on the compressive strength obtained.

The split cylinder test was conducted to determine the tensile strength of the microconcrete mix. This test involves the application of a diametral compressive line load on a cylindrical specimen with its axis horizontal between the platens of a Forney Testing Machine. For each microconcrete mix three 2x4 in., two 3x6 in., and two 4x8 in. cylinder specimens were cast for this test, and were tested on the same days as the compressive strength cylinders. Most of the specimens failed

in a columnar fashion. The failure load was used to determine the split cylinder tensile strength.

The MOR test is used to determine the flexural tensile strength of the microconcrete mix. For this test a special fixture was fabricated which applies two equal concentrated loads at one-third points on a simply supported beam specimen, 2 in. square and 7 in. long (2x2x7 in.), until it failed. Such beams were tested at 28 days of curing. Three specimens were prepared for each mix for each test day to estimate the average strength. The test was conducted in the Forney Testing Machine. The failure load is used to calculate the flexural tensile strength.

This group was able to produce a variety of high performance microconcrete mixes in which the compressive strength ranged from 2.5 ksi to slightly more than 7 ksi, and the tensile strength was less than 10% of this value. The strength test results indicated that overall the mixes gained full compressive strength by the 14th curing day. The compressive strength of the 2x4 in. cylinders generally was slightly higher than the 3x6 in. and 4x8 in. cylinders for the same curing day; but not significantly different statistically. For the compressive, tensile split cylinder and MOR tests it was found that in general the superplastizer had little or no effect on strength.

This group regressed the strength results to develop prediction equations (empirical) for compressive strength, split cylinder tensile strength, modulus of elasticity, and MOR flexural tensile strength in terms of the following variables: water to cement ratio (x_1), sand to cement ratio (x_2), percentage of coarse sand (#12 and #16 sieve sizes) (x_3), percentage of fine sand (#20 and #30 sieve sizes) (x_4), and percentage of very fine sand (#35 sieve size) (x_5). They discarded all data if it fell outside the +20% and -20% error band, and obtained excellent relationships, with R^2 greater than 0.9 for compressive strength and split cylinder tensile strength, and $R^2 = 0.88$ for modulus of elasticity. However, that was not the case for the MOR flexural tensile strength; the data did not produce a reliable prediction equation. The group then conducted a sensitivity study for the three good prediction equations, in which they varied one variable at a time and observed whether the equations predicted the trend similar to that observed from test results. Finally, this group developed an iterative, but deterministic mix design methodology using the prediction equations obtained. In this method, first x_2 (sand to cement ratio), x_3 (percentage of coarse sand), x_4 (percentage of fine sand) and x_5 (percentage of very fine sand) are assumed, and the compressive strength equation is used to find the water to cement ratio (x_1) for a given compressive strength. Next, the values of x_1 through x_5 are substituted in the prediction equation for the tensile strength, and this strength is evaluated. If this value is greater than 10% of the compressive strength, then the whole procedure is repeated by assuming new values for x_2 through x_5 . A computer program automating the whole procedure was developed for a PC to obtain different mix proportions which will give the desired strengths, and one can select the mix which has the desired workability.

Thus, this group was able to complete all the objectives of their project. During this study, the students used digital data acquisition systems, the Forney Testing Machine, loading and deformation measuring transducers, spreadsheets, word processors, regression tools, electric saws, drills, and sanders. The students spent lot of time in preparing a large number of mixes and testing specimens. They had to carefully plan their casting and testing schedule so that they could complete all the testing in the first six weeks. The group prepared a detailed schedule for specimen casting and testing, and presented it on the third day of the project. This exercise guided

them to stay on the schedule as much as possible, with the objective that the last two weeks of the project will be devoted to test data synthesis and final presentation preparation and report writing. The students prepared a 315-page Technical Report.

In **Project No. 2** experimental research was conducted to investigate the moment-rotation behavior of double web angle and top and seat angle connections when subjected to cyclic loads, which simulated earthquake conditions. The double web angle connection consisted of two angles, one leg of each was bolted on either side of the web of a beam, and the other leg of each was bolted to the flange of a column. The top and seat angle connection also consisted of two angles, one leg of each was bolted to the two flanges (top and bottom) of a beam, and the other leg of each was bolted to the flange of a column. This project was an extension of an earlier REU project, and the group also conducted pilot tests to evaluate the feasibility of using neoprene rubber pads as dampers for these two types of connections. This was the first time this novel technique was explored. Current codes design these type of connections to transfer shear force, and no significant moment is assumed to be transferred by the beam-end into the column flange. However, limited test results available in the literature indicates that this design assumption is sometimes unconservative because under cyclic loading it is seen that there is indeed a significant moment transfer to the column. Development of moment in a connection of a steel frame can have positive as well as negative effects on the performance of the frame. The positive effect of moment is to contribute to lateral strength and stiffness of the frame, and the negative effect is to cause extra moment in the column, which in combination with the axial force can cause a plastic hinge to form in the column — a highly undesirable feature which may result in system instability. Therefore, to perform a realistic dynamic response analysis of steel frames with top and seat angle connections, inclusion of realistic hysteresis characteristics of connections, similar to those observed from experimental testing, is very essential. This was the motivation behind this project. The primary task assigned to the group were two: (1) to develop a family of mathematical models, with varying degrees of sophistication, that idealize the experimentally observed moment-rotation behavior of double web angle and top and seat angle beam-to-column steel frame connections considered, and which can be later incorporated in a dynamic frame analysis computer program; and (2) to compare the behavior of the connection with and without rubber pads as far as the energy dissipating capability is concerned. Moment-rotation hysteresis models for the following three types of idealizations were recommended to be developed: elasto-plastic (most simple to implement), bilinear (an improvement over the elasto-plastic, but more complex to implement), and modified bilinear Ramberg-Osgood (same level of simplicity to implement as bilinear, but it may be more accurate). The third model, the modified bilinear model, uses the Ramberg-Osgood function to define the coordinates of the bifurcation point between the two linear segments.

The participants of this group, first established a procedure to judiciously select four connection geometric configurations to be tested, two for double web angle and two for top and seat angle connections, in which the main variables that effect the connection hysteretic behavior are varied within the wide range currently used by the steel design and fabrication industry. Each of these four connections were to be tested with a ½ in. thick neoprene rubber pads, and without. It was decided to limit the testing program to eight connections, and to reuse the same beam (W21x65) and two different column specimen (W14x159 and W24x68) for all tests, because of the limited time available to finish the project, and due to project budget constraints. A significant amount of literature is available on the moment-rotation behavior characterization and design procedures for

double web angle and top and seat angle connections when subjected to monotonic (static) loads. Also, previous REU groups and other research projects executed at the Fears Engineering Laboratory at the University of Oklahoma have conducted cyclic load tests, which were made available to the participants. The students used this information to select two connection geometries of each type of connection in which the initial elastic stiffness and ultimate moment capacity (the two main parameters that effect the performance of a connection) varied from a low to high value, thus considering a very ductile to stiff connection, and a low strength capacity to a high strength capacity connection. The participants fabricated all the test specimens using the band saw to cut the angles, beam and column specimens to correct length, and the drilling machine to make precision holes in them. All welding was done by the lab technician, who also taught the participants the welding process.

The test set up used consisted of two major components: (1) an actuator connected to an end of the beam specimen to apply a cyclic (moving up and down) load, and (2) a reaction frame supporting the actuator and the column specimen. A schematic view of the experimental setup is shown in Figure 2, and a photograph of it is shown in Figure 3. The beam and column specimens were connected using the angle specimens and A325 type-SC (slip critical) bolts. The instrumentation used included the following: two Linear Variable Displacement Transducers (LVDTs), one mounted just above the top beam flange and one just below the bottom beam flange; one wire potentiometer attached to the bottom flange of the beam near the actuator attachment point; two to three strain gaged bolts used to connect one angle leg to the column flange; 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 was 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 connection rotation was obtained two ways to check the accuracy of measurements: local rotation was obtained by dividing the difference between the two LVDT readings by the vertical distance that separated them, and global rotation was obtained by dividing the wire potentiometer reading by the beam span. The moment applied to the connection at any instant was computed by multiplying the actuator load by the beam span. In this phase of the research, the participants learned: to install strain gages in the bolts; the function and operation of the different electronic data measurement equipment used; procedure to calibrate and install these equipment in the test set up; and the use of the computer software and data acquisition system to conduct the test, and to record and display the moment-rotation behavior and bolt force variations until the connection failed. Three types of failure modes were observed: excessive rotation due to significant yielding of the angle material, beam web bearing failure in double web angle connections (occurred when angles with large leg thickness were used), and excessive yielding of the bolt shank ultimately resulting in bolt fracture (results in excessive pinching of the hysteresis loops and decrease in the energy dissipation capability). All tests were completed by the sixth week into the project.

The moment-rotation behavior data recorded for the four tests and results available from previous tests conducted at the Fears Engineering laboratory 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. In developing some of these prediction equations, in addition to the connection variables the angle material yield strength, obtained from the tensile strength test conducted on a coupon cut from the angle leg, was also considered as a variable. In this phase of the research, the students learned the theory of regression analysis, and the use of the Microsoft Excel spreadsheet software to conduct the regression analyses and obtain the required graphical plots. The students conducted the regression analyses, model development and validation during the last two weeks of the project.

Comparison between the energy dissipating capability of each type of connection tested with and without rubber pads were made by comparing the area under the last loop of the hysteresis graphs. The rubber pads were found to decrease the energy dissipating capability of the double web angle connection. However, they increased the energy dissipating capability of top and seat angle connection, indicating that the use of rubber pads may be useful for stiffer connections. In such connections, the rubber pads increase the ductility of the connection without much loss in the moment carrying capacity. The prying force in the connection increases, which decreases the plastic deformation in the bolts, thereby resulting in reduced pinching in the moment-rotation loops. The group concluded that more research needs to be conducted on what type of rubber pad to use, possibly including rubber pads with wire mesh to increase initial stiffness. Thus, the group successfully completed the research within the scope identified by them. The participants of the group prepared a 189-page detailed Technical Report.

In **Project No. 3** the students 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 and base isolation techniques to improve the capabilities of the model to better withstand seismic loading 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. Cylindrical rubber mounts are commonly used as supports in mechanical machinery to reduce the damage caused by vibration, and different size mounts are commercially available. To study the use of such mounts as base isolators for aseismic design, experiments were conducted with three different size diameter rubber mounts installed under each column of the model frame so that the model is decoupled from the shake table over which it is mounted. The shake table is forced to move horizontally simulating the ground motion caused during an earthquake. To conduct these experiments, an assortment of pre-fabricated parts of models representing different story heights, different types of damping devices and commercially available base isolators were made available to the students. In all the experiments, data collection, processing and display of results in real time was automated using a computerized data acquisition system and the *Global Lab* software.

The first task assigned to the three students was to learn to use the data acquisition system and software. This took about two weeks. After completing this task, they started with the experiments. The first three experiments dealt with free vibration motion characteristics of one-

and two-story models with and without dampers.

In the first experiment the students conducted static load tests to determine the stiffness of a one-story model, conducted free vibration tests to experimentally determine the natural frequency of vibration of this model, and then compared their results to those obtained from theory to investigate how good their model performed.

The second experiment was similar to the first one except a two-story model was used. The stiffness of each story was computed by deflecting each story one at a time and holding the other one fixed, and the two frequencies of the structure were obtained by deflecting the floor masses to correspond to the theoretically computed first and second mode shapes. The students used two electromagnets to pull the floor masses by a known displacement and to release both the floor masses simultaneously using one electric switch. This was a challenging task, and they were successful within reasonable error limits.

In the third experiment, different type of dampers were installed, one by one, in the one- and two-story models of the first and second experiments. A view of a two-story model with viscous dampers and instrumentation installed is shown in Figure 4. The damping coefficient for the frame was determined, and the effect of different damping devices on frequency and response was compared to that obtained for the undamped model. The amount of damping in each device was varied to investigate its effect on the response, for example in the viscous damper following three different fluids were filled in the damping device: water, ordinary cooking oil and motor oil. All results obtained for these three experiments were compared to those obtained from theory, and they compared very well (about 10% difference). It was found that though the friction damper and beam yielding damper reduced the motion the most, but the viscous damper produced a more smooth reduction in the displacement response. The beam yielding damper increased the natural frequency of the model, since it acted as a structural element and thus increased the model stiffness.

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. The tests were repeated for different base motion frequencies. In the first experiment, the response 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 was recorded and compared to that obtained for the undamped model. The beam yielding damper was found to be the most effective in decreasing the amplitude of the displacements, whereas the viscous damper had a lesser, but smoother effect. The friction damper behaved very differently, at a base motion frequency which was much different than the natural frequency of the model, the friction damper did not let the model displace relative to the shake table because of the large static frictional force created, but as the two frequencies were made to approach each other (i.e., when resonance occurred) the model vibrated randomly by intermittently stopping and then starting with a jerking motion.

In the third experiment of the second series of tests, the one- and two-story model was tested on the shake table with and without base isolators. As stated earlier, three different diameter cylindrical rubber mounts were used, each having the same height. The largest size base isolators had very large vertical and horizontal (i.e., shear) stiffness, and so produced a response very

similar to the model with the fixed base. The smallest size base isolators, on the other hand, produced a rocking motion, indicating that they had low vertical stiffness. The mid-size base isolators performed the best, they possessed high enough vertical stiffness to limit rocking, and adequate horizontal flexibility to effectively dissipate the energy of the base motion and to reduce the top-story horizontal displacements. Overall, the performance of the base isolators was better than the dampers.

During this study, the students used digital data acquisition system and the vibration analysis software *Global Lab*, a small-scale reaction table with reaction frame, and loading, deformation, velocity and acceleration measuring transducers, electronic magnets to displace the floor masses by a desired amount, shake table with function generator and power supply, frequency analyzer, spreadsheets, word processors, regression tools, electric saws, drills, and sanders. The group successfully completed the research within the scope identified by them. The participants of the group have prepared a 244-page detailed Technical Report.

III. Description of Other Activities Planned for the REU Site

Reading material was mailed to the students four weeks prior to their arrival. This included a brief description of the project assigned, test equipment and testing procedures to be used, copies of selected reference papers, the Site administration, and expected deliverables. Each participant was also informed of the name, phone, e-mail address of their group partner, and were encouraged to contact each other.

Two field trips were organized for the REU participants, one to W&W Steel Company in Oklahoma City during the second week, and the second to Holnam, Inc. in Ada, Oklahoma during the third week. W&W Steel Company is the largest structural steel fabricator in central Oklahoma specializing in fabricating components for steel buildings and bridges. During this field trip the students observed warehousing of structural steel shapes, sawing, computer controlled drilling and coping, detail material cutting and punching, fit-up process, welding, blast cleaning, and painting of structural steel. Holnam, Inc. is a Portland cement manufacturing plant. In this field trip the students observed the complete manufacturing process. This included a visit to the quarry site, where they observed the blasting, collection and delivery operations of the raw material, and the testing lab, where quality assurance testing is conducted.

Two seminars were also included in the REU Site experience. One seminar on “photography for documenting experimental testing” was given by a professor from the Photography and Audio-Visual Media Department at OU during the first week of the Site. The professor also visited the students mid-way through the project, to critique their photographic work and to give suggestions to improve their quality. A seminar on “Regression Analysis and the Use of Microsoft software Excel” was given by the Graduate Research Assistants working in the project during the fourth week of the Site.

The Professor In-Charge and the three Graduate Research Assistants appointed on the project had a short meeting with the three groups daily at 8:30 a.m. One member of each group was appointed as the group leader for a week, and this appointment was rotated. During the daily meeting the group leaders presented orally the progress of the work, the plan for the present and

next day, and asked questions. The group leaders also kept a daily log, which was reviewed by one of the Research Assistants at this meeting and signed.

Each group gave bi-weekly presentations and submitted typed reports of their progress. Each group member participated in the oral presentations. These presentations were followed by a social hour, during which food was served. This provided an opportunity for the students to socialize not only with the REU project team, but with other graduate students, staff, and faculty members working in the Fears Engineering Laboratory on other research projects. The bi-weekly reports were promptly critiqued and returned. A suggested outline and detailed instruction for preparing the final report was given to the students at the end of the second week of the project. Using the bi-weekly reports and this outline, the students prepared the final project Technical Report.

IV. Evaluations Conducted and Results

One day before the last day of the Site each group gave a one hour presentation (45 minute presentation and 15 minute questions and answers) to a panel of external judges, who evaluated the presentations as well as their project reports. All groups made a Power Point/multi-media based presentation. The judges consisted of the following three local practicing structural engineers: Dr. Greg Allen, Bridge Engineer, Oklahoma Department of Transportation, Oklahoma City; Mr. Larry Curtis, Senior Structural Engineer, Frankfurt Short Bruza Associates, Oklahoma City; and Dr. Greg Fitter, Principal, Fitter Consulting, Norman, Oklahoma. In addition, the use of visual aids and photographs in project presentation and report were judged by Mr. Andrew Sprout, Associate Professor and Associate Director, Photography and Audio-Visual Media Department, University of Oklahoma. After each presentation, the judges filled-out two separate evaluation forms, one to evaluate each participant's presentation and the second to evaluate the overall performance of the group. The judge who evaluated the use of visual aids and photography provided comments. The evaluations provided by the judges are tabulated in Tables 1, 2 and 3. The judges were very impressed with the high quality of work done in the limited time period (two months). They were also impressed by the way the students presented their work using computer multi-media graphics with animation, and scanned photographs. They decided the Dynamic Models group (Project # 3) to be the winner of the "Best Project." Each member of this group was given a plaque. The Dynamic Models group (Project # 3) was also declared the winner for the best use of visual aids and photographs in their report and presentation. Each member of this group was given a special prize. Each participant was also awarded a certificate showing their participation in this NSF REU Site. The corrected final reports were returned to the students soon after their presentations. The corrections were implemented, and the final reports were submitted on the last day of the Site.

Each student participant was asked to give a written narrative evaluation of their experience, and turn it on the last day. Besides the narrative evaluation, a separate questionnaire was filled out by each participant on the first day and the last day of the REU Site to assess the success of the REU experience provided. In general, all students expressed great satisfaction with the experience and commented that they would highly recommend a similar experience to their friends. The participants were given instructions on the work expected of them after they return to their home institutions.

V. Summary Comments

In general all students expressed great satisfaction with the experience and commented that they would highly recommend a similar experience to their friends. The universal lessons learned by each group included the following:

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. Team work and collaborative learning (between participant and participant, participant and graduate assistant, and participant and faculty mentor).
10. To visual aids in communicating the test responses.
11. Writing and presentation of technical reports.

In each of the three “research-oriented” projects conducted in this REU Site unique contributions were made by each group. The microconcrete group developed prediction equations (empirical) for compressive strength, split cylinder tensile strength, modulus of elasticity, and MOR flexural tensile strength, and a mix design methodology for high strength concrete. The use of neoprene pads as dampers in bolted moment connections demonstrated by the steel connection group is an innovative technique, which needs to be further researched.

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 participants impressed their peers and superiors by the high quality of their presentations, and the confidence they showed in presenting their work. The judges found the judging difficult since all the groups did nearly equally good work. The Technical Reports prepared by each group and a Project Summary Report prepared by the Professor In-Charge were submitted to NSF soon after the Site was completed. Upon returning to their home institutions the participants made a presentation at their ASCE Student Chapter Meeting, and are preparing papers for presentation at student paper competitions and seminars.

It is well accepted that the capstone experience needs to allow for collaborative effort whenever appropriate to the discipline, so that undergraduate students can be better prepared for participation in the team projects they will encounter in professional as well as private life. It should be conducted under the mentorship of a seasoned scholar-teacher who understands the joys and frustrations of a major project. It should allow the student to understand their potential for serious work and develop the aspiration to do it well. In addition, this experience could also be designed to provide a bridge to graduate education for the holders of research university

baccalaureate degrees who immediately enter graduate school. The type of open-ended projects presented in this paper make the undergraduates become an active part of the audience for research. The projects were designed to provide learning based on discovery by mentoring rather than on transmission of information. Inherent in this inquiry-based learning was an element of reciprocity: faculty learned from students as students were learning from faculty. Undergraduate students in fact provided a “lubricant” that broke down intellectual barriers between the faculty member and graduate students. It was found that when students at all level, baccalaureate, masters, and doctoral, join with faculty in common inquiry, the opportunities for “collision of ideas” are optimized.

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Figure 1. Sieving Apparatus used for the Microconcrete Project

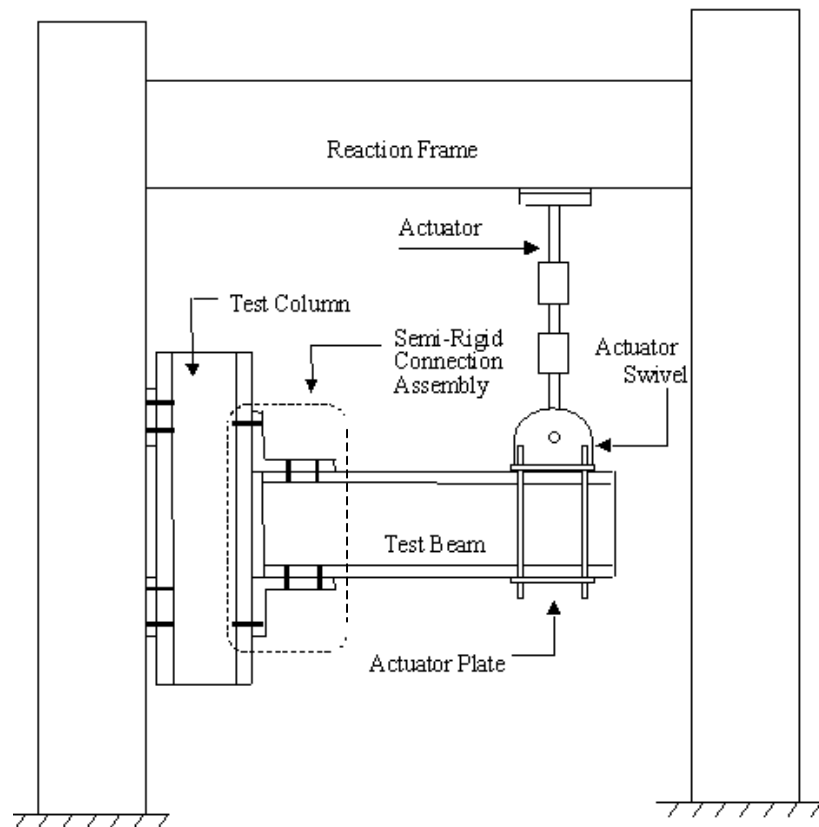


Figure 2. General Experimental Setup for Top and Seat Angle Connection



Figure 3. A View of the Test Setup for the Steel Connection Project

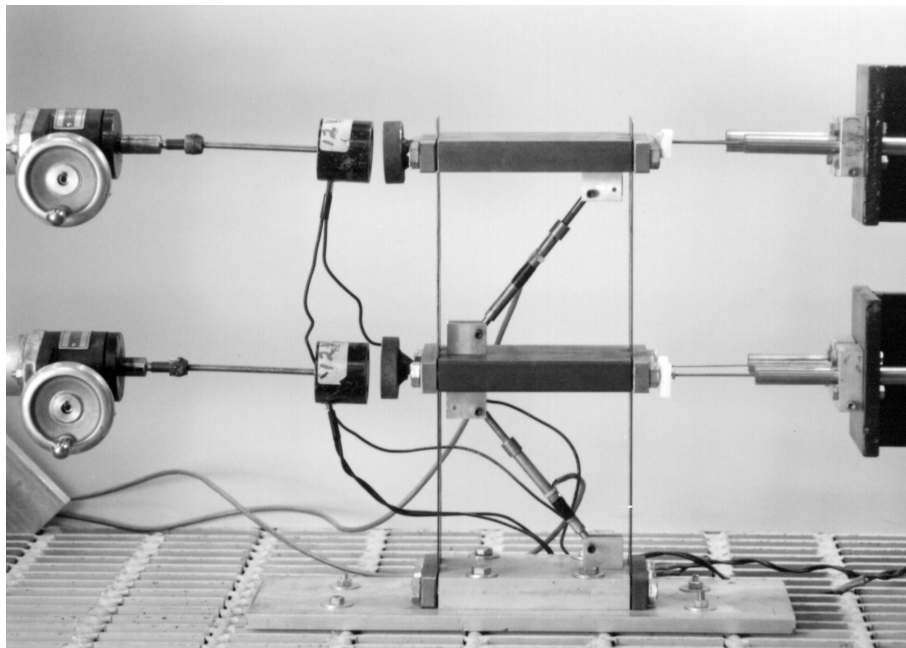


Figure 4. Two-Story Building Frame Model with Viscous Dampers Used for Free Vibration Test

Table 1. Evaluation of Written Project Reports by the Judges
(5 = Excellent 4 = Very good 3 = Good 2 = Fair 1 = Unsatisfactory)

Group	Attitude	Organization of Presentation & Emphasis	Clarity of Presentation	Use & Quality of Visual Aids	Response to Questions from the Audience
Microconcrete	4.33	4.00	4.33	4.00	4.33
Steel Connection	3.75	4.50	3.75	3.75	3.75
Dynamic Models	4.00	4.00	4.50	4.00	4.00
Comments					
Microconcrete	<ol style="list-style-type: none"> 1. Excellent! Recommendations should include future research to include effects of admixtures, other cementitious materials, slag, fly-ash, pozzolons, and steam curing etc. Perhaps 10 ksi and higher strengths could be looked at. Again, a good piece of work. 2. Regression analysis seems appropriate for studying the effects of various variables on experimental results. Also, it saves a lot of time. Sometimes, it is more appropriate to base prediction equations on engineering mechanics that is then verified by experimental results. 				
Steel Connection	<ol style="list-style-type: none"> 1. You might consider that not only will the column stiffness effect the behavior, but the beam to column stiffness ratio might as well. Well done. 2. For this application of including prediction equations in computer analysis software, aggression analysis seems appropriate, for other applications, it might be more appropriate to derive equation based on engineering mechanics and then experimentally verified. 3. Perhaps connection-to-column stiffness ratios and connection-to-beam stiffness ratios should also be investigated in teams of frame analysis. 4. Not only should different types of rubber be investigated, but material properties like shear modulus, elastic modulus, durometer (hardness) and geometric properties, such as, shape factor and thickness should be included in future investigated. Different locations of neopreme pads should also be looked at in future. 5. Reconsider recommendation on double angle connection for stiffer pad. 				
Dynamic Models	<ol style="list-style-type: none"> 1. This is pretty good presentation of a large amount of data. Personally, I would have placed all sections concerning "Testing Procedures" in the appendices. Overall, a good job considering the scope. 2. The section on "Recommendations" seems a little wordy. The 2nd paragraph refers to "a number of recommendations that can be made." Expand on exactly what the recommendations are. 3. Again, a pretty good job considering the large scope and limited time. 				

Table 2. Evaluation of Individual Presentations by the Judges
(5 = Excellent 4 = Very good 3 = Good 2 = Fair 1 = Unsatisfactory)

Group	Attitude	Organization of Presentation & Emphasis	Clarity of Presentation	Use & Quality of Visual Aids	Response to Questions from the Audience
Microconcrete	4.56	4.22	4.11	4.33	3.56
Steel Connection	3.78	4.78	4.00	3.56	3.33
Dynamic Models	4.67	4.67	4.33	4.00	3.78
Comments					
Microconcrete	<p>For Participant No. 1:</p> <ul style="list-style-type: none"> Seemed to gain confidence as presentation progressed. <p>For Participant No. 2:</p> <ul style="list-style-type: none"> Allow just a little more time on chart review to allow viewer acclamation. Very good tone & deliveries, don't be afraid to speak up. <p>For Participant No. 3:</p> <ul style="list-style-type: none"> A little more explanation of sensitivity analysis graphs would be good - good job! Good job on probably the toughest portion of the presentation. 				
Steel Connection	<p>For Participant No. 1:</p> <ul style="list-style-type: none"> All peers (engineers) will know what a "kip" is. There's probably no need to define it during your presentation. Know your audience. You were on a team. You might consider allowing them to answer questions. Take more time before you answer question. Try to reduce the "up and down" of presenters. <p>For Participant No. 2:</p> <ul style="list-style-type: none"> Coupon test pictures could be clearer provide spacing between slider. Try to reduce the "up and down" of presenters. <p>For Participant No. 3:</p> <ul style="list-style-type: none"> Could have done without video, I think would have spent more time presented by powerpoint. Good explanation on Regression Procedure. Try to reduce the "up and down" of presenters. 				
Dynamic Models	<p>For Participant Nos. 1, 2 & 3 (same comments):</p> <ul style="list-style-type: none"> Excellent speaking. Each kept the momentum going, and maintained continuity. Good job. Great visuals and organization. 				

**Table 3. Comments Given by the Judge Who Evaluated
Use of Visual Aids and Photography**

Group	Comments
Microconcrete	<ol style="list-style-type: none"> 1. Oral presentations were smooth and cohesive. Participant No. 1 took a few minutes to get to comfortable level, but appeared confident and knowledgeable about project. Participants 2 and 3 picked up with a smooth transition. Question responded to with confidence but no evidence of overstating their understanding. 2. Caution the overuse of animation and special effects in power-point, it distracts from importance and transmission of information.
Steel Connections	<ol style="list-style-type: none"> 1. I found the frequent change of presenter to be distracting but explanation was logical and reasonable. Considering the newness of topic research, the team appeared to comprehend theoretical basis and experimental experience. 2. I caution the overuse of power-point animation and special effects. It distracts from import of material use of emphasis to draw attention. 3. The use of arrows and "boxes" to compare loops was useful addition.
Dynamics Models	<ol style="list-style-type: none"> 1. Organization and documentation enhanced the presentation quality and viewers understanding. All presenters were confident, knowledgeable and informed. Material was straight forward but substantial. Use of video clips and motion to demonstrate need for studies and the goals provided insight. 2. The overuse of animation and special effects in power-point distracts from its use as a tool. Consider how this may impact on retention and understanding as apposed to visual appeal.