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A Summer Research Experience for Undergraduate Students in Civil Engineering

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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 Site grant sponsored by the National Science Foundation, and administered in the Department of Civil and Environmental Engineering at the University of Cincinnati during the Summer of 2001. The research experience provided was in the area of structural engineering. Nine students were selected to participate in the Site; four students selected were from institutions outside Cincinnati, and five were selected from UC. These included three women, one Native American male, one Hispanic male, one African American male, and three white American male students, and each group worked on a separate project during the two summer months. Each group were supervised by the Project Director (author) and a Faculty Mentor, one Graduate Student Mentor (Research Assistant), and a Lab Technician during the complete duration of the REU Site. The paper presents how the whole research program was planned and conducted, the details of the projects selected for the students, and procedures used to evaluate the impact of the project. This paper will help others in planning similar experiences for engineering undergraduate students.

I. Introduction

This paper describes the experiences provided in a Site for undergraduate research in "Structural Engineering" in the Department of Civil and Environmental Engineering at the University of Cincinnati (UC), Cincinnati, Ohio. 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 and associated activities are presented in this section, followed by a detailed description of the projects executed. In the end, evaluation procedures used, the lessons learned, and the outcomes from the whole experience are summarized.

Hopefully, this documentation will help others in planning similar experiences for engineering undergraduate students.

The REU Site was successfully administered from June 11 through August 3, 2001. Nine students were selected to participate in the Site; four students selected were from institutions outside Cincinnati, and five were selected from UC. The REU participants included three women, one Native American male, one Hispanic male, one African American male, and three white American male students. Three of these students were sophomores, five were juniors, and one was a second-year junior (from UC where the undergraduate program is a five-year co-op integrated program); and eight were pursuing an undergraduate degree in Civil Engineering, and one in Mechanical Engineering. All students came from Ph.D. granting institutions. These students were divided into three groups with three students in each, and each group worked on a separate project. The three projects selected for this REU Site included an ongoing research project on prestressed concrete beam girders, a new research project planned to be executed on steel building connections, and an outreach project demonstrating seismic performance of small-scale building models. The exact titles of the projects were:

1. Project #1: "Connections Between Simple Span Precast Concrete Girders Made Continuous."
2. Project # 2: "Service Load Prying of Tension Bolts in T-Stub Connections."
3. Project # 3: "Using Small-Scale Models to Demonstrate Earthquake Aseismic Design Procedures."

The basic approach used in this REU Site was discovery through actual construction, experimental testing, observing and recording, synthesizing the data collected, and generalizations. In general, projects were chosen in which students had to organize an experimental study program by varying the pertinent variables impacting the response being investigated, and then using the test results to generalize their findings. This approach provided an opportunity for individual growth and challenge to the young and inquisitive mind.

The selection of the students was based on GPA, two recommendation letters, and an essay on why they would like to participate in this REU Site and how it relates to their career goals. In total 32 applications were received for the nine positions. All applicants had excellent scholastic qualifications, and satisfied the requirements for selection if resources permitted their support. An effort was made to recruit at least three under-represented and/or minority students, with particular effort to recruit a Native American. This goal was exceeded since six (i.e., 67%) of the nine students selected satisfied the under-represented and/or minority status, and one Native American student was recruited from Oklahoma. The participants were paired such that a more experienced student interacted with a lesser experienced student, as far as their scholastic standing was concerned. All students had indicated that they may consider graduate studies after completing their B.S. degree program, but had not decided at this point. Each student was given a monthly stipend of $1,000/month for 2 months, and board, lodging and travel expenditures.

Each REU project team worked closely under the supervision of the Project Director (author), a Faculty Mentor, a Graduate Student Mentor (Research Assistant), and a Lab Technician during the complete duration of the REU Site. A Secretary assisted in the mailing of the REU Site Announcement Flier, coordinating the correspondence with the applicants, making the travel and housing arrangements for the applicants selected, and organizing the refreshments for the social meetings.

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 partners, and were encouraged to contact each other.

Two field trips were organized for the REU participants, one to Prestress Services Inc. in Melbourne, Kentucky during the second week, and the second to Champion Bridge Co. in Wilmington, Ohio during the third week. Since two of the projects were in the area of prestressed concrete and steel structures, so these field trips fitted well into the theme for this year's work. At Prestress Services Inc. the students saw the complete process of pretensioning of cables and casting of prestressed concrete bridge girders, and cutting of cables after the beams had hardened and were cured. The students also visited the design office at the plant and the shipping yard, which handled the delivery of finished products to the job sites. Champion Bridge Co. is a mid sized structural steel fabricator in South-West Ohio. While the tour was being conducted, workers in the shop were assembling trusses from light W sections to be used in the roof system of a secondary school. The trusses served as a sample project for the day. The students were shown the contractor's drawings for the project, how an estimate is prepared, how shop drawings are produced, how the steel is ordered, how it is cut to length once it is received, how it is cambered or straightened, how connections are made, how the finished products are painted and shipped, and how erection drawings are prepared.

Three seminars were also included in the REU Site. The first seminar, which was held on the first day, was designed to provide an orientation to the students on the expectations from the REU Site and discussed issues related to "Lab Safety." The second seminar was a "hands-on" seminar on "Equipment Usage," and was conducted separately for each group. A third seminar on "Regression Analysis and the Use of Microsoft software Excel" was given during the third week of the Site. The third seminar was essential because students needed to perform statistical analysis of test results to generalize their findings in all three projects selected.

The Project Director, and the three Graduate Student Mentors appointed on the project had a short meeting with the three groups every alternative day at 8:00 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 their assigned Graduate Student Mentor 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 refreshments were 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 structural engineering laboratories. The bi-weekly reports were promptly critiqued by the Project Director and returned. A suggested outline and detailed instruction for preparing the final report was given to the students at the end of the third week of the project. Using the bi-weekly reports and this outline, the students prepared the final project Technical Report.

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 range of different structural engineering research projects. 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

Project #1: Connections Between Simple Span Precast Concrete Girders Made Continuous

This group 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 4.6 m (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 was also evaluated. Due to time constraints only tests for two specimens were completed, one bent bar and one bent strand connection. Testing of a bent bar connection specimen with girders embedded was initiated, but completed soon after the REU site ended. As a result, the effect of embedding girders in the diaphragm could not be completely evaluated during the project duration, but initial assessment of performance was reported.

Prestressed concrete bridge girders are fabricated by stretching steel cable strands to a tension of approximately 200 ksi. Concrete is then poured around the stressed strands and when the concrete reaches the specified strength, the steel cable strands are cut at each end of the girder. The strands inside the girder acts like a rubber band and attempt to snap. However, since the strands are bonded to the concrete, the concrete prevents the strand from snapping back to its full potential. This causes the girder to camber up. The girder is therefore placed in a state of compression (prestress) and the application of any load relieves the compression stresses instead of causing potentially damaging tensile stresses in the concrete. This group first performed a detailed literary review and documented the findings. It focused on the following past research projects: PCA Research[1], Missouri Reports[2,3,4,5] , NCHRP Report [6], and Indiana Report[7].

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.

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., $M_{cr} \pm M_{live\ load}$. The cracking moment, M_{cr}, was equal to 241 kip-ft, and the positive and negative live load moments were +95 kip-ft and –385 kip-ft, respectively.

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) was also preformed by the REU students. Results were reported for Specimen 1 (bent strand connection, not embedded) and Specimen 2 (bent bar connection, not embedded). 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. Unfortunately, results of the bent bar specimen with the end diaphragm constructed by REU students (Specimen 4) could not be included as testing was delayed until the last few days of the REU experience. The students started the test, which was finished by the participating graduate students the day the REU students were giving their final project presentations. So, they were not able to incorporate the results of this tests in their final report.

Strain gauge data indicated that during early stages of testing Specimen 1, most of the load was transferred through the slab and barely through the diaphragm. However, as testing proceeded, the load was also partially transferred to lower regions of the beam. Moment-rotation data also showed that stiffness of the connection decreased with increasing fatigue testing. This resulted in larger crack opening and more beam rotation. Failure occurred by a gradual pullout of the bent strands at 16,000 cycles.

Specimen 2 failed after 29,000 cycles due to yielding and actual fracture of all five bars in the bent bar connection. As for Specimen 1, beam rotation and crack opening increased during the process in testing, and implied a loss in connection stiffness under fatigue.

Judging from the moment-rotation data, Specimen 2 proved to be stiffer than Specimen 1 both during the initial stiffness test and the cyclic fatigue loading. The rotation of Specimen 2 was recorded to be less than the rotation of Specimen 1 when identical loads were applied. This was also found to be true for the crack opening between the diaphragm and the beam: the crack opening experienced by Specimen 2 was less than the crack opening experienced by Specimen 1 when the same loads were applied.

While Specimen 2 failed later than Specimen 1 and exhibited greater stiffness, its failure was more drastic. In Specimen 1, the bent strands were merely pulled out of the diaphragm. However, in Specimen 2, the bents bars actually fractured. Therefore, this type of failure caused greater structural damage to the connection.

As mentioned erilier, tests on specimens with the girders embedded into the diaphragm were not completed before the end of the REU project. However, preliminary initial stiffness tests of one of these connections showed that these types of connections are stiffer than their non-embedded counterparts. But, the merits and details of this observation still remained to be proven.

The group successfully completed the research within the scope identified by them. The participants of the group prepared a 95 page detailed Technical Report. A photograph showing students working on the project at the field testing site is shown in Figure 1.

Project # 2: Service Load Prying of Tension Bolts in T-Stub Connections

The goal of this project was to analyze service load prying in tension bolts in T-stub connections used as steel building connections. The first objective of this group was to analyze data from previous T-stub tests available from Georgia Institute of Technology. This data was compared to existing models, and to a new model proposed by the REU group. The second objective of this group was to prepare the necessary equipment and test specimen configurations for the actual testing of T-stubs to be conducted during 2001-2002. This required planning of the testing procedure, identification of the equipment to be used, preparing a detailed fabrication drawing of the test set-up, ordering of the parts to be fabricated, instrumenting the bolts to be used, and preparing tension test coupons from the steel material selected to be used for the fabrication of the T-stub connections. A literature review of T-stubs and other related topics was done first. In the T-stub tests the bolts as well as the T-stub needed to be strain gauged. Strain gauge theory and installation was reviewed, since this was a new topic for the REU participants. Different types of strain gauges were used, ones that go inside the bolt shank, and ones that are applied to the face of the steel. The group investigated both types.

The Data Acquisition System (DAS) to be used in the T-stub tests was identified. The use of this system was investigated by conducting tension tests on bolts, and the students demonstrated and documented its versatility, set-up procedures, and how to use it. Students used the DAS to study the load-deformation behavior of different types of tension bolts used in steel construction, and compared the results to those available in the literature. The sample bolts were tested to failure in the Tinius-Olsen hydraulic press to which the DAS was connected to record, process, and display the results in real-time. This data was analyzed and the students identified the bolts to be used for the T-stub tests. The average strength of these bolts was found to be 145 ksi, whereas ASTM specifies that these bolts must be at least 120 ksi. For the tests conducted, different threading types were examined, and it was found that when the bolt had a maximum amount of threads it deforms more.

Each bolt to be used for the T-stub tests had to be strain gauged and calibrated, and some had to be tested to failure to plot the stress-strain behavior of the bolt material and define its failure strength. The REU students developed the equipment for the bolt calibration and material testing. They drilled holes in each bolt, and meticulously installed miniature strain gages in each bolt hole. They checked the functioning of each strain gage installed, and conducted tests to find the calibration factor of each strain gaged bolt. The reason for calibrating the connection bolts is two fold: first, each bolt in the T-stub connection to be tested has to be pretensioned to a known amount by using a torque wrench before any external load is applied to the connection, and, second, the load-deformation history of each bolt during the connection testing has to be recorded till the connection fails. Thus, the strain gaged bolts act as transducers measuring the deformation, and then by using the calibration factor one can determine the force in it. To conduct the calibration and load-deformation tests to failure on some selected bolts, the REU group proposed the design of a bolt extensometer setup. Such tests could not be conducted using directly the fixture to hold the bolt in the Tinius-Olsen machine because the elongation measured would not represent the elongation of the bolt shank, but would include the deformation of the components of the fixture in which the bolt is mounted. The special extensometer designed by the REU students included use of other deformation measurement transducers (LVDTs) to separately measure the deformation of the fixture component, thus enabling the exact computation of the bolt elongation as the test was being conducted.

The stress-strain behavior and material properties of the steel used in the T-stub test had to be determined. This was done by conducting the standard tension test using tension coupons cut out from the parent material and shaped precisely according to the ASTM Specifications. The REU group used different machines to cut the coupons. Some of them included the band saw, lathe, end mill, and micrometer. The students got the valuable training from the Lab Technician on the use of these equipment and the training for precision machining needed to prepare the specimens. The project required preparation of a large number of test coupons, and took significant time.

One of the conclusions of this study was that the prying models used at Georgia Institute of Technology for ultimate loads can, with some accuracy, be used to model service load prying forces of tension bolts in T-stub connections. The predicting capabilities of a modified model proposed by the REU group was also evaluated. For some selected Georgia Institute of Technology test data it was seen that this model predicted the bolt forces better. The group recommended that this model needs to be explored in detail when the T-stub tests are conducted during 2001-2002. The group successfully completed the research within the scope identified by them. The participants of the group prepared a 33 page detailed Technical Report. Figure 2 illustrates the test setup proposed and designed for the testing by this group.

Project # 3: Using Small-Scale Models to Demonstrate Earthquake Aseismic Design Procedures

The main goal of this research project was the construction of simple, portable demonstrations for Kindergarten through twelfth grade (K-12) students to teach and spark interest in aseismic design. In order to design these demonstrations, an understanding of basic vibration principles was needed along with knowledge on how some general pieces of equipment commonly used for structural testing work. The REU participants did not have much prior knowledge in this area.

This project was begun with the learning of basic vibration principles through literature that was provided to the students, and the help given by the two Faculty Mentors. The topic of strain gages was also discussed, as they play an important part in many of the measurement devices that were to be used by the participants. With this knowledge, the group began learning how to use the different pieces of equipment needed for the project. The first piece was the P-3500 Strain Indicator Box that is used to measure the voltage change in the strain gage, which is related to the strain produced and displayed. To gain the experience in the use of the strain indicator box, they conducted a simple static strain experiment involving a cantilever bar with a varied point load applied at the free end. Strain gages were longitudinally attached to the top and bottom surfaces of the bar at a little distance away from the fixed end, and the leads of the strain gages were connected to the strain indicator box in quarter and half bridge connections. Known amounts of weight were then applied at the free end of the bar and the corresponding strain was recorded. When plotted, this showed that there was a linear relationship between weight applied and resulting strain.

The group also learned how to use a Hewlett Packard 35660A Dynamic Signal Analyzer. Its use was demonstrated with another simple experiment to determine the natural frequency of a cantilever bar. As in the previous experiment, there were strain gages longitudinally mounted on a cantilever bar and connected to a strain indicator box. The strain indicator box was connected to the dynamic signal analyzer and used to perform a fast Fourier transform as the cantilever bar was struck with a heavy object. This produced a graph with distinct peaks that could be paused and read. The reading from each peak represented a different natural frequency for the cantilever bar. Knowing these frequencies the bar could be excited to any desired frequency using a LDS Barrel Exciter to observe the mode shape corresponding to this frequency. In this experiment the dynamic signal analyzer also operated as a function generator and was used as a source to produce sine waves for the barrel exciter. The sine waves produced were not very strong and were therefore amplified before reaching the exciter. By positioning the barrel exciter beneath and close to the fixed end of the cantilever bar, it was then excited at several of its predetermined natural frequencies and the various nodes (points along the bar which experience no vertical displacement) of vibration were observed. Thus, this experiment provided an opportunity to the students to observe various modes of vibration of a continuum.

An extensive amount of time was also committed to the understanding of a Data Acquisition System (DAS). The DAS consisted of BNC 2080 and SC-2043- collection boards that were externally wired for their protection. The data could then be analyzed on the computer software Virtual Bench. The group also learned how to use an Electro-Seis Model 113 Shaker. This shaker was used in the 2000 REU Site[8] for the testing of one- and two-story small-scale building model structures, and used in this REU Site for the conceptualization and design of the K-12 demonstrations. The shaker was designed to subject structures mounted on its table top to base motion with different sinusoidal frequencies. The sinusoidal frequencies were supplied by the dynamic signal analyzer and amplified. A PCB Accelerometer was used in many of the demonstrations to measure different natural frequencies with the aid of the dynamic signal analyzer.

The extensive research conducted by the 2000 REU Site[8] involving 1/24-scale models was first reviewed and analyzed by this group. These experiments demonstrated that column height, damping devices, and base isolators changed the stiffness and vibration characteristics of the model. The models used consisted of four spring steel columns that were attached to rigid floor masses to give fixed connections. The floor masses consisted of steel and the base mass of aluminum. The effectiveness of the following three types of dampers was explored by the participants: viscous, friction, and beam yielding. The dampers were tested under both free and forced base motion vibration conditions. The models were mounted over a shake table, which subjected the base mass of the model to a horizontal motion, simulating ground motion during an earthquake. The models were also mounted to the shake table with and without base isolators to compare the effect of decoupling of the model from the seismic motion source. All the data was collected by a DAS and analyzed in real time.

The experiment conducted to determine the stiffness of a model showed that if all variables are fixed and only the column height is changed, the stiffness decreases with an increase in height. The free vibration experiment then showed that the natural frequency of the structure decreased as the stiffness decreased. The addition of dampers to the model had varying effects on the characteristics of the free vibration of the model. The friction dampers had increasing damping properties as more friction was applied by the damping devices. Both the friction and viscous dampers had relatively little effect on the natural frequency of the frame model. This was attributed to the fact that they only resisted motion of the model without adding stiffness. The beam yielding dampers had dramatic effects on the damping properties of the frame model. Since the beam yielding dampers increased the stiffness of the frame model they also shifted the natural frequency of the model to become higher.

Using this knowledge, the REU participants of this group then developed and constructed three distinct demonstrations for K-12 students. They actually did not demonstrate it to a select group of K-12 students, but simply developed the models to be used later by the faculty advisors and other students for demonstrations. These demonstrations included lumped mass models, a fluid tank model, and a portable shake table. The lumped mass model basically consisted of a steel/aluminum cylindrical solid mass piece screwed to one end of a 1/8 in. diameter rod, and the other end of rod was rigidly connected to a wood block. This model represents a one-story building; the rod represents the building columns, and the cylindrical mass represents the rigid top floor. Students also fabricated similar two-story lumped mass models. The lumped mass models were designed to mount to the top of a shake table, where they would be excited by different sinusoidal base frequencies. These lumped mass models were an additional simplification of the 1/24-scale models used by the 2000 REU Site[8], but were intended for physical observation only. The models consisted of threaded metal rods to which metal weights could be attached. There were three distinct lumped mass model demonstrations developed, which included variable mass model, variable stiffness model, and a model in which the number of stories could be varied.

For each lumped mass demonstration, the natural frequency was measured using an accelerometer and dynamic signal analyzer, and then subjected to a base motion whose frequency was less, equal, and greater than the pre-determined natural frequency of the lumped mass model. When subjected to a base motion with the same frequency as the natural frequency of the model, it was observed that resonance developed and vigorous vibration occurred. When the structure was excited at frequencies other than its natural frequency, there was relatively little movement. The variable mass model consisted of three different mass weights, all mounted at the same height. It demonstrated that by varying the floor mass, the natural frequency of a structure can be altered. The variable stiffness model consisted of three identical weights, mounted at three different heights. This model demonstrated that by varying the column height, the natural frequency of a structure can be altered. The model in which the number of stories could be varied consisted of a structure with one mass at the mid level and another at the top (two stories) and a separate structure at an intermediate height. This model demonstrated the effects that an additional lumped mass can have on a system. The two-story model showed two natural frequencies, as opposed to the single natural frequency of all other models.

The fluid tank model was also mounted on the shake table and excited at varying frequencies to give a visual representation of ground motion profile during an earthquake. For K-12 demonstrations a portable shake table which was much lighter and easier to transport than the shake table that was commercially available (Seis Model 113 shaker), was designed and fabricated in-house. Both the lumped mass and fluid tank were to be used on this portable shake table.

The REU group also correlated the measured frequencies for the lumped mass model to those obtained from theory which assumes the column's top end to be fixed to a rigid floor mass and the bottom end to be fixed to the rigid foundation. Since at the top end of the lumped mass model a steel/aluminum mass was attached, it experienced some end rotation during vibration. To account for this different boundary condition at the top end of the column, the group developed a scaling factor between the model and theoretical results, and showed that it predicted acceptable results for different lumped mass and column height (i.e., different column stiffness) values. Thus, they learnt how models can be calibrated to represent the real system.

This REU group strongly felt that with the constant threat that earthquakes provide and the limited academic courses offered on this subject, there should be an increased emphasis on education in this area. By introducing and exciting students of all ages into the area of seismic studies, they might be encouraged to pursue this area of study further at a university level. The need for more research and study in this area is evident with the massive destruction that continues to follow earthquakes all over the world. Important research contributions have been made in this area and are evident in the associated lower loss of human life in the event of such catastrophes, but many critical structures, such as hospitals and vital roadway structures, are still being severely damaged. By sparking interest in seismic design to students at an early age, it will ensure that solutions to the problems created by earthquakes will be solved.

The group successfully completed the research within the scope identified by them. The participants of the group prepared a 118 page detailed Technical Report. Photograph showing the portable shake table designed by this group with lumped mass models mounted on it is shown in Figure 3.

III. Evaluations Conducted and Results

On 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 presentation, in which scanned photographs and video clips of the experimental set ups, behavior, and failure modes were incorporated. The judges consisted of two practicing structural engineers, and an administrator in the College of Engineering at UC who runs a REU program for Women in the College of Engineering, funded by the university. The judges included: Mr. Bill Schrudde, Structural Engineer at KZF Incorporated, Cincinnati, Ohio, Mr. Frank Monastra, Structural Engineer, THP Limited Inc., and Dr. Roy Eckart, Associate Dean for Academic Affairs, College of Engineering, UC. Both the professional engineers had a graduate degree, and one of them had participated in a NSF REU (supplement) program as an undergraduate student at the University of Illinois at Urbana-Champaign. 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. These evaluation forms were developed by the author, and had evolved over the three REU Sites supervised since 1994 and the input received by the judges. The evaluations results provided by the judges are averaged and presented in Table 1. 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, video clips, 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. Each participant was also awarded a certificate showing their participation in this NSF REU Site.

Each student participant was asked to submit a written narrative evaluation of their experience 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. All students made a presentation at their institution in one of the student chapter meeting of a professional organization, e.g., American Society of Civil Engineers.

IV. Summary Comments

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) 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.

In each of the three projects conducted in this REU Site unique contributions were made by each group. Based on preliminary initial stiffness tests the Prestressed Concrete Girder group had ascertained that girders embedded into the diaphragm are stiffer than their non-embedded counterparts. This has since been verified and found to be true as more tests have been completed. The Steel Connection group conceptualized and designed the test set-up for T-stub connections, which is being currently fabricated, and incorporates the following unique features: measurement of bolt force history until the connection fails; and an extensometer to measure the bolt elongation, bolt force, and its stress-strain behavior until failure. This group also suggested a modified model to predict the bolt forces in a Tee-stub connection, and validated it using limited test results made available to them. The Dynamics Model group designed and fabricated demonstrations for K-12 students to illustrate the following: wave profiles generated by ground motion; lumped mass one- and two-story models and procedures to find their natural frequency, and its relationship to the frequency of the ground motion of the earthquake and the resulting damage; lumped mass one- and two-story models to illustrate how the natural frequency of a structure is impacted by changing story height (or column stiffness) and story mass; and a hand operated light weight shake table to simulate ground motion.

After the REU experience all the five UC students have been recruited by the faculty members to work on existing externally funded research grants. All the students made a presentation at their home institution and submitted a letter from a faculty member documenting it's success. Based on their presentation, enquiries have been received from undergraduate students desiring to participate in the Summer 2002 REU Site. It was most rewarding to receive the following comment from one of the participants from the University of Oklahoma: " My junior year has just begun and has already proven to be very challenging. This semester I started my first real lab course; Solid Mechanics and the lab section that comes along with it. As you know, technical writing is involved in writing the lab reports. I'm sure you remember grading my section of the technical paper submitted for the REU dynamics group. I think I was the student in the greatest need of technical writing skills. This was also reflected in the shear amount of red ink that was necessary to grade my paper. Well I'm writing you to let you know that it didn't go to waste. When writing my first lab report I referred back to my graded report from this summer. To get to the point, I earned an A on my first lab report for the Solid Mechanics lab. I'd like to thank you for putting forth the effort involved in grading my papers and showing me how to write technically."

VI. Acknowledgment

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Table 1. Judges Evaluations

Group	Attitude	Organization of Presentation and Emphasis	Clarity of Presentation	Use and Quality of Visual Aids	Response to Questions from Audience
Project # 1	3.78/5.00	3.44/5.00	3.56/5.00	4.11/5.00	3.78/5.00
Project # 2	3.67/5.00	3.56/5.00	3.67/5.00	4.00/5.00	3.89/5.00
Project # 3	4.00/5.00	3.78/5.00	3.89/5.00	4.00/5.00	4.00/5.00
COMMENTS					
Project # 1	Participant # 1: 1. Well spoken and confident. 2. Good voice for communicating, little nervous, good job. 3. Good overall presentation, positive responses to questions. Participant # 2: 1. Well spoken but quiet. 2. Good eye contact and explanations, good luck with future classes. 3. Very clean presentation, makes his points very well. Response to questions well thought out and insightful. Participant # 3: 1. Speaks well but doesn't visually engage. 2. Good eye contact and use of laser pointer. 3. Reasonable presentation, but not clear how the tests he describes relates to the overall goal of the span connections.				
Project # 2	Participant # 1: 1. Good Job, nerve racking for a sophomore. 2. Very uncertain, hesitant presentation, knows the subject but not used to presentations. 3. Nervous and quiet at first, better by end. Participant # 2: 1. Good eye contact and use of laser pointer 2. Very nice presentation-poised, presents ideas well. Somewhat rigid presentation, but will improve with experience. 3. Well spoken and confident. Answered group questions first. Participant # 3: 1. Good use of show and tell samples. Good presentation. 2. Very good presentation, clear concepts. 3. Well spoken, quieter at times, thought out response to question - good attitude.				
Project # 3	Participant # 1: 1. Very clean presentation, well done, clearly presented background material and concepts. 2. Good use of show and tell items, nice intro of presentation. 3. Well spoken, but needs more eye contact. Good hand held demo. Participant # 2: 1. He is a well poised presenter, speaks clearly and presents the basic ideas very well. Participant # 3: 1. Very nice presentation, well spoken, presents results, demonstrates very well, technical difficulties were overcome during his presentation. 2. Good use of show and tell items. 3. Well spoken, needed to focus discussion more (nervous).				

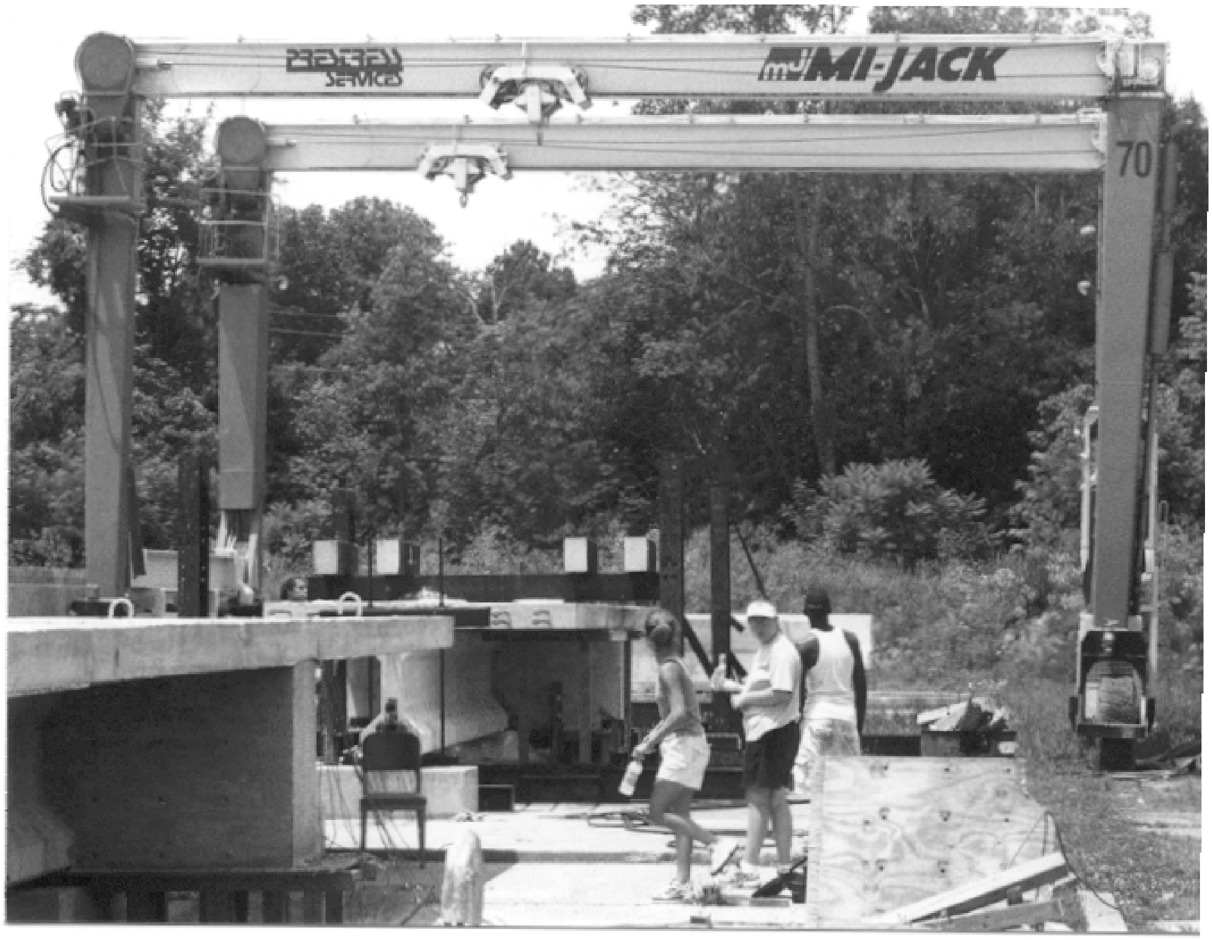

Figure 1. Prestressed Concrete Group Preparing for Testing

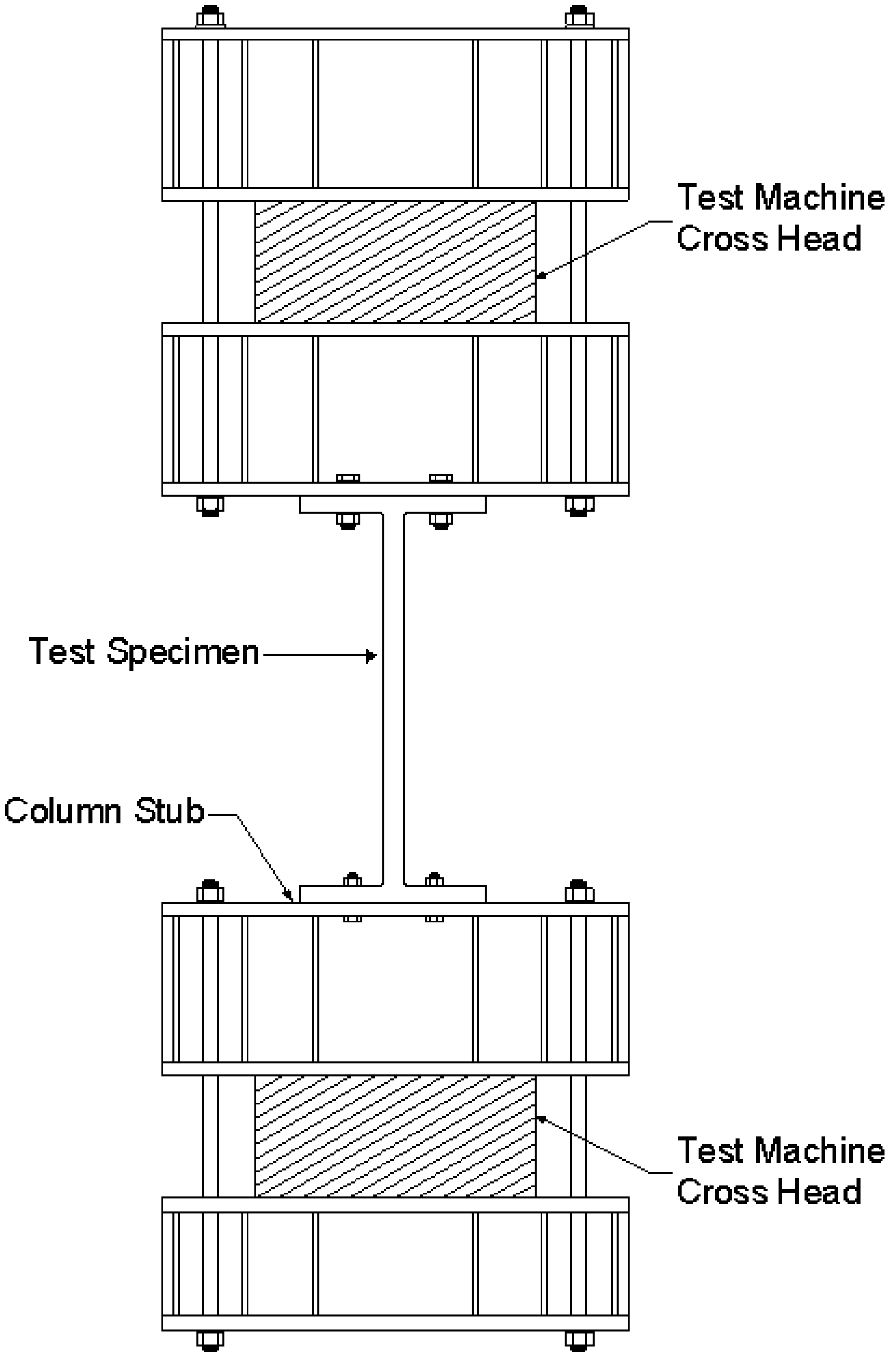

Figure 2. Test Setup Designed by the Steel Connection Group for the Tee Stub

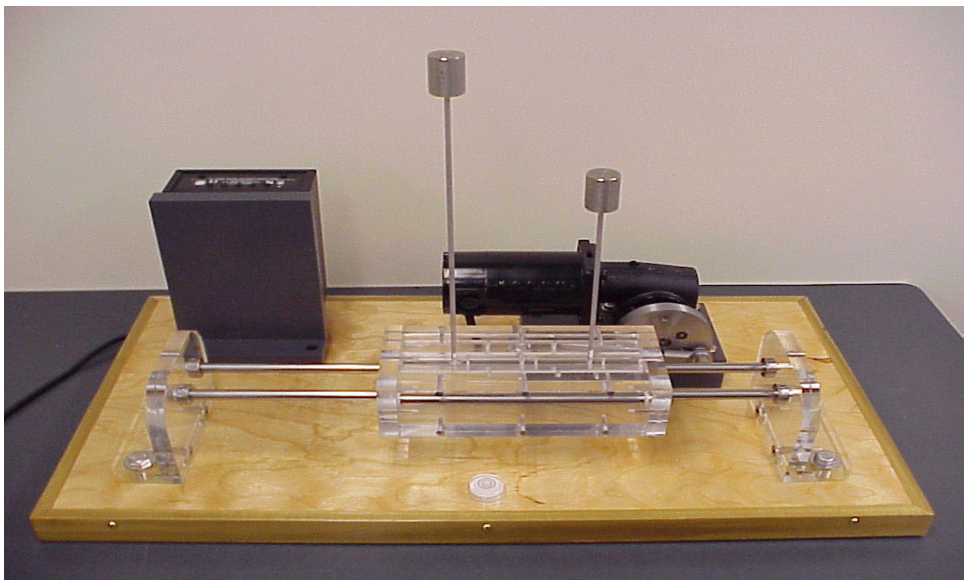

Figure 3. Photograph of the Model Shake Table Designed by the Dynamics Model Group with Lumped Mass Models Mounted on it