AC 2010-1246: THE ROLE OF STRUCTURAL ENGINEERING IN MULTI-DISCIPLINARY FRESHMAN PROJECTS

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The Role of Structural Engineering in Multi-Disciplinary Freshman Projects

Abstract

Channeling the excitement of young engineers in a first year introductory course offers many challenges for instructors. A common first year experience for freshmen engineers is now the norm, with many universities having a second common year. During the introductory courses it is essential to provide the students a broad view of engineering while engaging them to the fullest, such that their excitement is allowed to flourish in an active learning environment.

This paper presents an overview of half-semester multidisciplinary projects introduced into Villanova University's 2009 – 2010 engineering freshmen curriculum and details two successful projects that incorporate structural engineering as a means for providing a hands-on, active learning experience. Both projects combine the disciplines of civil, mechanical, and electrical engineering. One project uses a structural engineering system as the main thrust area, with modeling techniques from mechanical engineering and data acquisition applications from electrical engineering highlighted. The second project involves acoustic technologies. In this project, electrical and mechanical engineering applications are investigated and elements of non-destructive examination and concrete material behavior are included. Students non-destructively or destructively evaluate the behavior of structural elements, construct/apply data acquisition systems, collect data, and synthesize the data to compare experimental results to theoretical predictions. Finally, students report their findings in written, graphical, and oral form.

The projects highlighted provide civil, mechanical, and electrical engineering faculty members the necessary building blocks that can be applied to development of substantial educational experiences that fully engage young engineers. Data on the course outcomes and student evaluations for all projects will be presented.

Introduction

Villanova University is an independent coeducational institution of higher learning founded by the Augustinian Order of the Roman Catholic Church. A medium-sized Catholic institution and comprehensive university, Villanova emphasizes undergraduate instruction and is committed to a strong liberal arts component in each of its undergraduate programs, including engineering.

The College of Engineering at Villanova University (CoEVU) is comprised of four departments, Civil and Environmental (CEE), Chemical (ChemE), Electrical and Computer (ECE), and Mechanical (ME) and three Centers, the Center for Advanced Communications (CAC), the Center for Nonlinear Dynamics and Control (CENDAC), and the Villanova Center for the Advancement of Sustainability in Engineering (VCASE). There are a total of 68 full-time faculty members that teach in the CoEVU, 58 of which are tenured or tenure-track. The CoEVU is committed to an educational program that emphasizes technical excellence and a liberal education within the framework of the University's Augustinian and Catholic traditions.

Engineering programs throughout the country continue to modify their curriculums in an effort to be more innovative, integrated and inclusive of “real world” hands-on experiences and examples[1-5]. Engineering colleges are taking varied approaches in presenting material in new formats and the CoEVU is no different in this regard. The CoEVU, as part of their continuous improvement program, has undertaken the task of revitalizing its required freshmen engineering two course sequence[6]. The goals associated with this curriculum change were to excite freshmen about their chosen field of study and demonstrate the multidisciplinary nature of engineering by introducing hands-on experiences. Although the current freshmen retention rate of engineers is over 89 percent, it is hoped that this new course will aid in increasing retention. Additional information on the new two course sequence is provided in Reference 6.

Background

In 2007, the CoEVU conducted a SWOT (Strengths, Weaknesses, Opportunities, and Threats) analysis of the undergraduate program. The analysis collected data from the following CoEVU constituents: faculty, staff, administration (deans and chairmen), undergraduate students, graduate students that matriculated from VU, and other alumni. The SWOT also considered input from university faculty members and administrators outside of the CoEVU, advisory boards, and peer schools. An outcome of this thorough analysis was that while the existing two course freshman engineering experience had improved in recent years there existed significant opportunities for improvement. Faculty and undergraduate students agreed that the current format and content should be improved.

A committee was formed to investigate modifications of the existing two course sequence. The committee decided to split the current two course sequence into four parts of equal length, 7 weeks each. Part 1 was to include an introduction to engineering and include hands-on mini-labs[6]. The content and implementation of part 1 is described in detail in References 6. Parts 2 and 3 were to be multi-disciplinary projects, referred to herein as mini-projects. Part 4 was an introductory course in each of the four departments.

In the spring semester of 2008 the CoEVU administration and committee requested proposals from all engineering faculty for multi-disciplinary mini-projects to be implemented in the 2009 – 2010 academic year. Criteria in the request for proposals included a number of key educational elements (similar to standard ABET requirements), a minimum of a faculty member from two different departments, the ability to accommodate 25 students per section, and a maximum of budget of $20,000 to cover the costs of course development over the summer and all necessary equipment and supplies to complete the project.

Twenty-five proposals were received and evaluated based on relevance, quality, key educational elements contained, extent of multidisciplinary nature, likelihood of being successfully developed, and the ability to grow or morph in the future. Six mini-projects were funded; including the two co-developed by the authors that incorporated structural engineering as the CEE component. Each project included components from ECE and ME as well. The projects titles were the “Analytical and Experimental Evaluation of a SMARTBEAM®”, and “Applications of Acoustic Technologies”. This manuscript provides a description of these two projects with a focus on the structural engineering elements.

Course Format

The mini-project element of the course commenced at the mid-point of the 2009 fall semester and was offered again at the beginning of the 2010 spring semester. Each mini-project had two assigned instructors, although each project was developed by a team of five faculty members. Both mini-projects were actually taught by a team of three (*not the two official instructors*), one faculty member from each department (CEE, ECE, and ME). The courses met two times a week for 75 minutes per meeting. For the fall semester the 8 weeks of class translated into 15 individual meetings. There were two sections of each mini-project with section sizes ranging between 21 and 25 students. The detailed class meeting schedule for the two mini-projects is provided in Table 1. Faculty member responsibility is shown in parenthesis. Approximately half of the classes involved hands-on active learning experiences.

Final grades for the mini-projects described herein were determined based on a combination of attendance and participation, homework, quizzes, poster presentation, and technical report. Rigorous format requirements on homework were established for both projects. The grading of the other four mini-projects varied, as poster presentations and technical reports were not a uniform requirement in all mini-projects. Modification of the grading format will be investigated prior to the second offering of this course. The student grade was determined as the average of their grades from the first and second halves of the semester. Grades for the mini-projects were normalized based on a comparison of the individual mini-project averages.

Description of Analytical and Experimental Evaluation of a SMARTBEAM®

Relevance of Structural Engineering Component

A SMARTBEAM® is the manufacturer's name for either a cellular or castellated beam. Cellular beams are expanded steel sections with circular holes, and castellated beams are beams with expanded sections containing hexagonal openings as shown in Figure 1. The SMARTBEAM® is produced by cutting a standard wide flange beam, of depth d, in half longitudinally and welding the staggered two halves back together. The SMARTBEAM® has either circular or hexagonal openings and weighs the same as the original root beam, but is 50% deeper ($d_{SMART} = 1.5d$) and 50% more stiff than the original beam and is ideal for long span applications.

These structural members are marketed as a *sustainable solution* in the building industry, as it is comprised of between 90 – 100 recycled materials. The authors have conducted research on these beams continuously for a decade. Theses structural elements are widely used in Europe, and have recently gained in popularity in the United States. The American Institute of Steel Construction will be releasing a design guide for these beams within the next year; therefore, it is expected that their use in the United States will greatly expand.

Figure 1: The two configurations of SMARTBEAMs®

Table 1: Summary of mini-project schedules.

Meeting	SMARTBEAM®	Acoustic
1	Introduction to SMARTBEAM®, manufacturing and applications (CEE)	Introduction to vibration and frequency (All)
2	Linear-elastic beam behavior, stiffness, moment of inertia (CEE)	Non-destructive examination (NDE) and concrete mix and beam design (CEE)
3	Deflection analysis and introduction to the finite element (FE) method (CEE, ME)	Fundamentals of signal generation, measurement, and processing (ME, ECE)
4	FE modeling of a loaded plate with and without a hole (ME)	Vibrations and ultrasonic NDE, ME applications (ME)
5	FE modeling of a SMARTBEAM®, assumptions, boundary conditions, material properties, and loading (ME)	Measuring the elastic modulus of materials using ultrasound – lab (ME)
6	Measurement systems and measuring strain (ECE)	Ultrasound pulse-echo method to detect flaws – lab (ECE)
7	Wiring circuitry for a measurement system – lab (ECE)	Formwork construction and concrete beam and cylinder pouring (CEE)[SS]
8	Measuring strain on bench top cantilevered beam, use of Ohm and Volt meters (ECE)	Acoustic equipment training and impedance matching (ECE)[SS]
9	Review of experimental results of root beam and SMARTBEAM® (⬡ openings) (CEE)	Destructive testing of cylinders and beams reinforced with steel and GRFP (CEE)[SS]
10	Laboratory basics, identification of testing equipment, measurements of beam (CEE)	Data measurement and processing (ECE)[SS]
11	Experimental testing of a SMARTBEAM® (○ openings) (CEE)	Ultrasonic and vibration testing of cracked and uncracked concrete beams (ECE)
12	Technical presentations via PowerPoint and poster (CEE)[CP]	
13	Technical report writing and data presentation (CEE)[CP]	
14	Recap of learning outcomes, presentation preparation and course evaluation (All)	Recap of learning outcomes, presentation preparation and course evaluation (All)
15	Poster presentation (All)[CP]	

SS – Split session: the class was divided in half and went to two separate locations, then switched for the following class period
CP – Combined projects: SMARTBEAM® and Acoustic classes met as one large section

Multidisciplinary Elements

This project includes substantial elements of civil engineering, mechanical engineering, and electrical engineering. The civil engineering components are structural analysis/design and large scale experimental testing. The electrical engineering portion of the project includes the design and construction of a data acquisition system. The mechanical engineering element focused on the modeling of the structural system using finite element analysis and the material characterization of the steel. The sequence of these topics is outlined in the following section.

Student Experience

Students learned about structural building elements and the basics of load and displacement of a beam and material behavior over a period of two and a half classes. Homework problems reinforced these concepts. As noted in Figure 1, following this introduction to beam bending, students were exposed to and conducted FE modeling. Following the presentation of the basics, the students spent one period creating a model in ABAQUS of an axially loaded plate with and without a hole. Students were able to identify change of the stress and strain distributions due to the presence of the hole. Students then spent the next period working on developing the two dimensional model of a cellular beam loaded at mid-span. They were tasked for homework to determine the load displacement plot and the maximum displacement of the beam when it was subjected to its service load. A typical model developed by the students is shown in Figure 2.

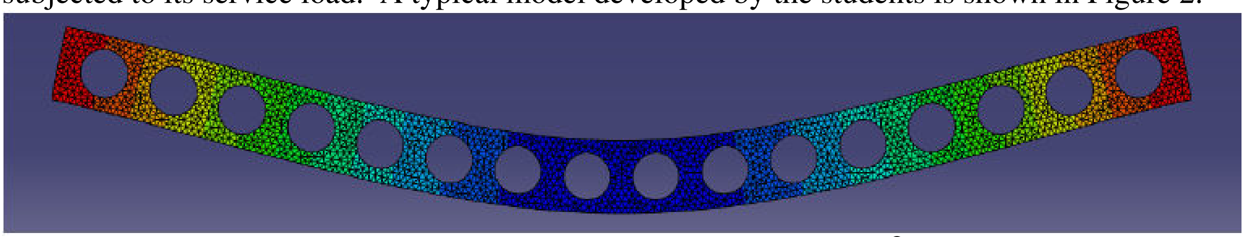


Figure 2. FE model of the displacement of a cellular SMARTBEAM® loaded at mid-span

The students then moved into the ECE labs to gain some insight about data acquisition systems. They worked in small groups to construct a simple data acquisition system to read strain. Using a bench top assembly that included a cantilever beam with a strain gage attached the students experimented on how different variables affected their strain readings. They documented the relationship between load and strain. A photo of test setup is shown in Figure 3.

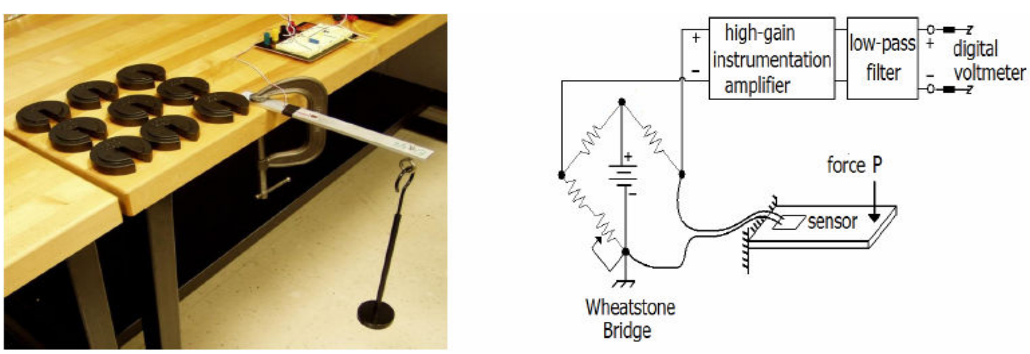


Figure 3. Cantilever beam setup and diagram of required circuitry

The students then worked in the structural engineering laboratory for the next class meetings where they learned about the equipment used to test a full-scale beam. They viewed the load frame, lateral bracing system, hydraulic cylinders, load cells, strain gages, and the multi-channel data acquisition system (a full size commercial version of what they had previously constructed). The test setup is shown in Figure 4.

Figure 4. Test frame used for mini-project

Students were provided with the experimental data collected from full-scale testing (to failure) of a root beam and a castellated SMARTBEAM®, and were shown how to analyze the data. These tests were conducted prior to the class by graduate students. The students then conducted their own full-scale test and evaluated the linear-elastic bending behavior of a cellular SMARTBEAM®. Students were able to record the load-deflection behavior of the cellular beam and compare it to that of the root beam and castellated beam. Additionally they were able to compare their experimental results to those predicted by their FE model. A plot comparing the load displacement behavior of the root beam and a SMARTBEAM® is shown in Figure 5.

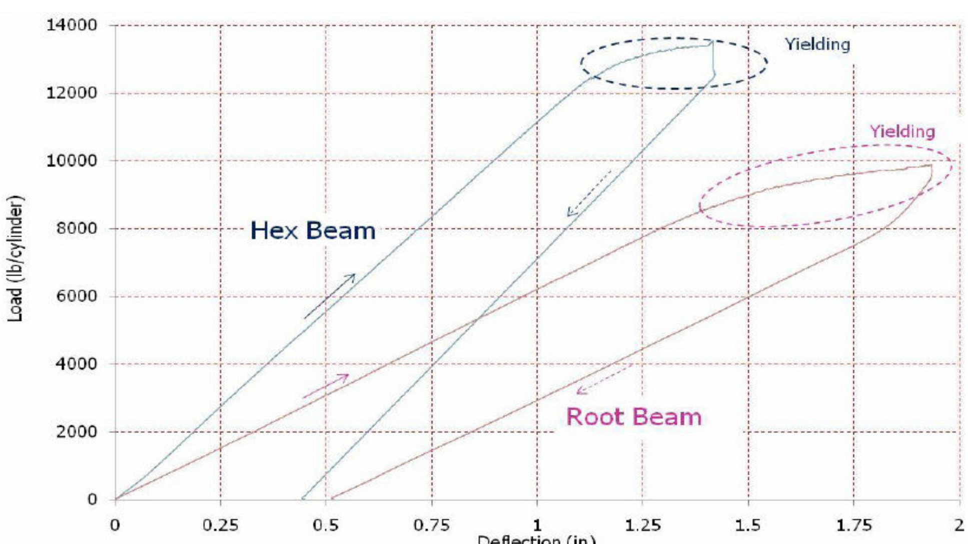


Figure 5. Load – displacement plots of the root and castellated SMARTBEAM®.

Description of Applications of Acoustic Technologies

Relevance of Structural Engineering Component

America's infrastructure continues to degrade and has once again earned a grade of "D" by the American Society of Civil Engineers[7]. The concrete elements of our infrastructure continue to degrade as well. Corrosion of traditional steel reinforcement has long been known to be a problem in the bridge industry. A potential replacement of reinforcing steel is glass fiber reinforced polymers (GFRP); however, due to the difference in material properties (stiffness and ductility) it has not been readily adopted for structural beams. The authors have conducted research on GFRP reinforced beams for over 10 years. The use of NDE techniques is essential to quantify the actual performance of structures and to identify critical flaws and material degradation. Acoustic techniques are becoming increasingly necessary and popular.

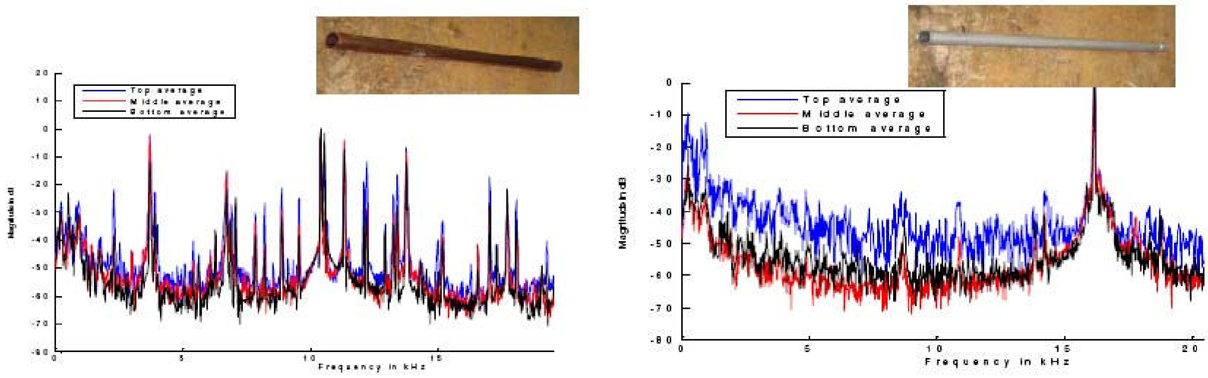
Multidisciplinary Elements

This project also includes substantial elements of civil engineering, mechanical engineering, and electrical engineering. The CEE components are concrete material properties and the design and behavior of conventional and GFRP reinforced concrete beams. The ECE portion of the project includes application of acoustic and vibration technologies for non-destructive evaluation of materials and structures, while the ME element focused on flaw detection and determination of material properties using acoustic and vibration techniques.

Student Experience

The mini-project started with an introduction of the project and a discussion of the basics of waveforms and definition of frequency. The following period was initiated with a photographic tour of the state of the US infrastructure. To reinforce the state of our concrete infrastructure students were required to visit specific structures on or near campus and visually inspect them and document their observations for homework. The students were exposed to the basics of a concrete mix design, alternative reinforcements, and the general behavior of concrete beams subjected to bending. For homework they were required to determine the cracking load of a beam of given cross-section subjected to a point load at mid-span. Additionally, they were required to determine the mid-span deflection at the cracking load.

The students then investigated signal generation, measurement, and processing using a signal generator, an oscilloscope, their laptops, and Matlab and provided files. Two additional classes were spent looking at applications to ME. These classes involved material studies and determination of the elastic modulus for various materials, including steel and GFRP reinforcing bars used in the upcoming beam construction. Short lab write ups were required for these in-class activities. Figure 6 shows the characterization of identical pipes made from different materials.



Copper Aluminum

Figure 6. Characterization of copper and aluminum pipes

The class was divided in half to reduce the group size (~12), as designated by the SS (split section) in Table 1. Additional lab and lecture time was focused on acoustic signal processing; specifically, equalization and source separation. Students again used their laptops and Matlab programs (provided by the instructor) to experiment with different numbers of sources and microphones to examine the acoustic signals. All freshmen are supplied laptops upon entrance to Villanova University. Simultaneously, the other half of the class was constructing the formwork for two concrete beams. Groups of 5 or 6 were formed, such that one group constructed the beam reinforced with steel and the other group constructed the GFRP beam.

All wood and rebar, No. 4 bars, were precut to the required dimensions and the students were required to assemble the pieces. The cement, fine and coarse aggregates, and water were weighed prior to the lab to proportion the required amount of material for the two beams and four concrete cylinders. The students used a 9 cubic foot mixer to prepare the concrete mixture. They conducted a slump test, and then poured and vibrated the beams, and prepared cylinders. The students were also showed the test setup they would be using the following week for destructive evaluation of their beams. For homework they had to develop a formula to determine the cracking load for their beam based on the test setup loading as a function of the concrete strength, f'_c. The beam size was kept small, 5 feet long with a 5.75 in depth and 1.5 in width, to facilitate moving the beams by hand.

The following week the students tested their four cylinders to determine the concrete strength, f'_c. They could then predict the cracking load of their beams using the equation developed for homework and the corresponding expected displacement. The beams were prepared with a chalk lined grid, and placed in the load frame, as shown in Figure 7. The hydraulic system used to load the beam included a hand pump and a pressure transducer with LED that displayed load to the nearest 10 lbs. A digital dial gage was used to measure displacements at mid-span. Students took readings at 250-500 lb intervals. A comparison of the load-displacement behavior for the two beams prepared by one group is shown in Figure 8.

Figure 7. Students mapping cracks during the destructive testing of a concrete beam

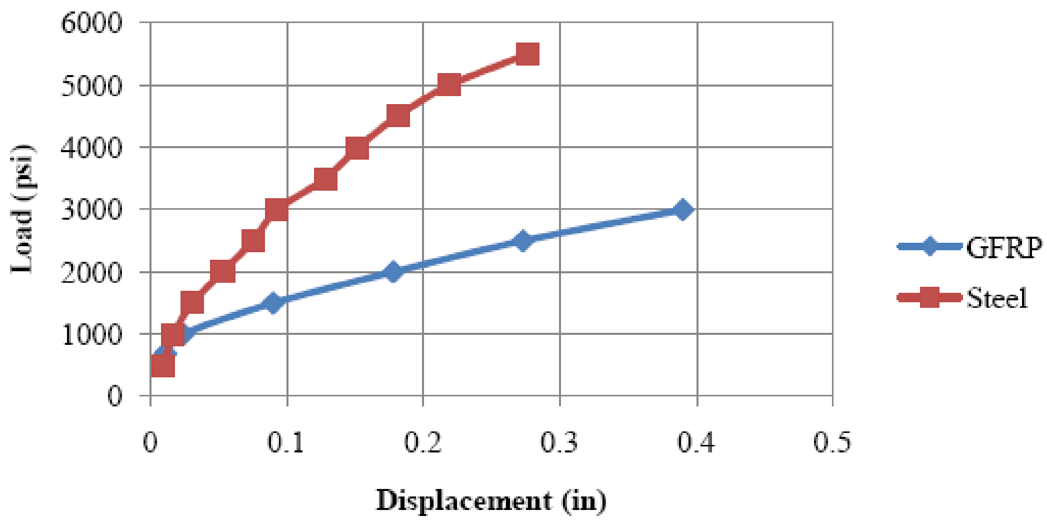


Figure 8. Load – displacement comparison of steel and GFRP concrete beams

During the testing of the beams, students were responsible for visually inspecting the bottom of the beam for cracking. When cracks were identified, the loading was paused and crack locations were mapped and the magnitude of load at the time of sighting was noted. Additionally, using a crack width gage, students recorded the width of the cracks. This process continued for each loading interval. Figure 9 presents the cracking pattern for one set of beams.

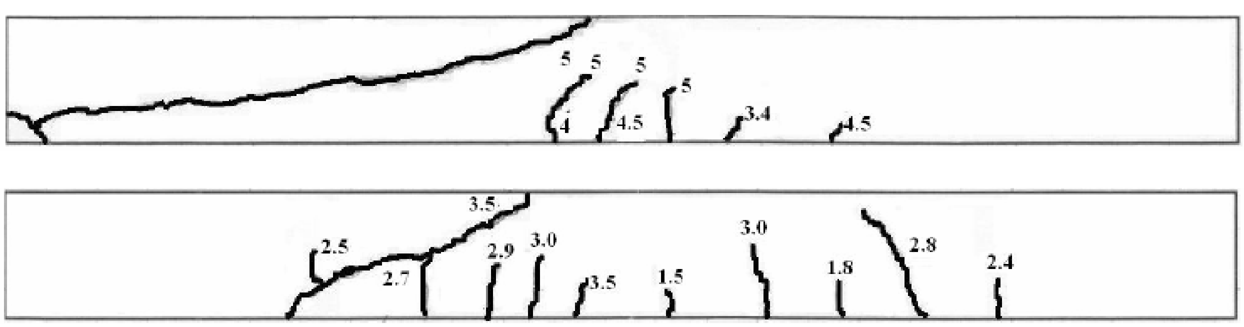


Figure 9. Concrete beam mapped cracks (steel on the top, GFRP on the bottom)

In the class that followed the destructive testing, the students were given what appeared to be four identical beams that matched those that they had constructed. Two beams were reinforced with steel and two with GFRP. One of each set of beams had been cracked, but the cracks were not readily visible with the naked eye. These beams were constructed and cracked by graduate students. Using knowledge they had acquired on stiffness and natural frequency, the students used acoustic and vibration techniques to determine which of the beams were cracked. The recorded waveforms and Fourier transforms for one test of an uncracked and cracked steel reinforced beam are presented in Figure 10. The students, with some guidance, could identify the loss of stiffness and the resulting lower natural frequency of the cracked beam. They had more difficulty determining the very slight differences between the uncracked steel and GFRP beams.

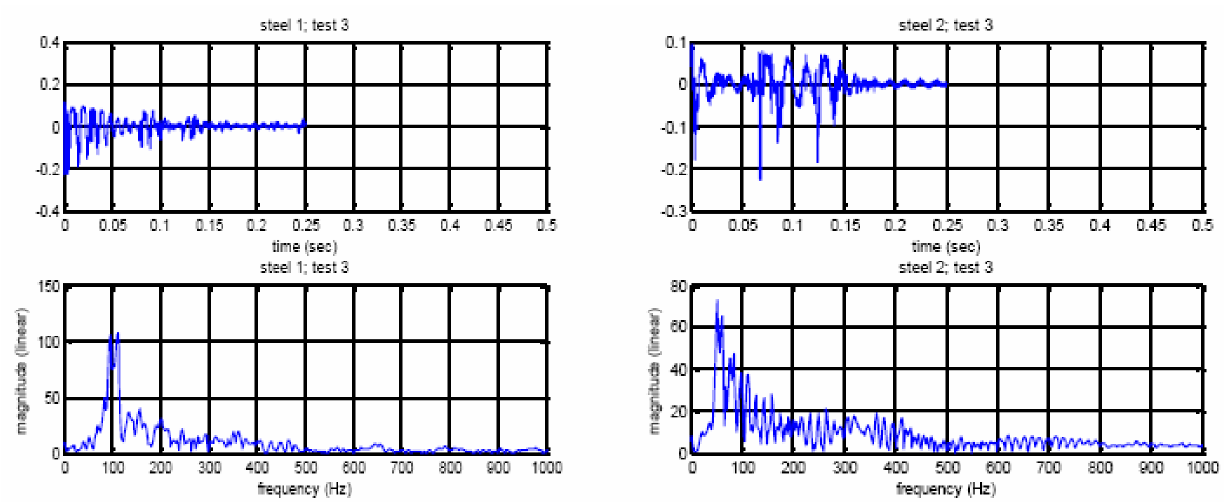


Figure 10. Waveform and Fourier transforms for an uncracked (left) and cracked (right) beam

Professional Technical Communication

One of the prioritized learning outcomes for these mini-projects was the development of technical communication skills. As noted in Table 1 in meetings 12 and 13 (CP – combined projects), the students in the two projects were combined to discuss effective technical communication. The first class focused on presentation skills using PowerPoint and effective use of a poster to present technical data. The students were required to attend a combined poster session of the two mini-projects and present their findings to faculty, staff, graduate students, and upperclassmen. Over one hundred people attended these poster sessions. An example of a SMARTBEAM® poster and an acoustic poster is presented in Figures 11 and 12 respectively.

The follow-up lecture was on the writing of technical reports and the nuances of presenting technical data effectively. The students were also responsible for submitting a final group report. Specific format requirements on par with those used for technical journals were given. Additionally, technical requirements were provided on sections (abstract, theory, experimental results, conclusions, etc.) for each mini-project. A minimum or maximum page length was not specified, but students were told to be concise in their write-ups. Report lengths varied slightly, but were generally around 25 pages in length.

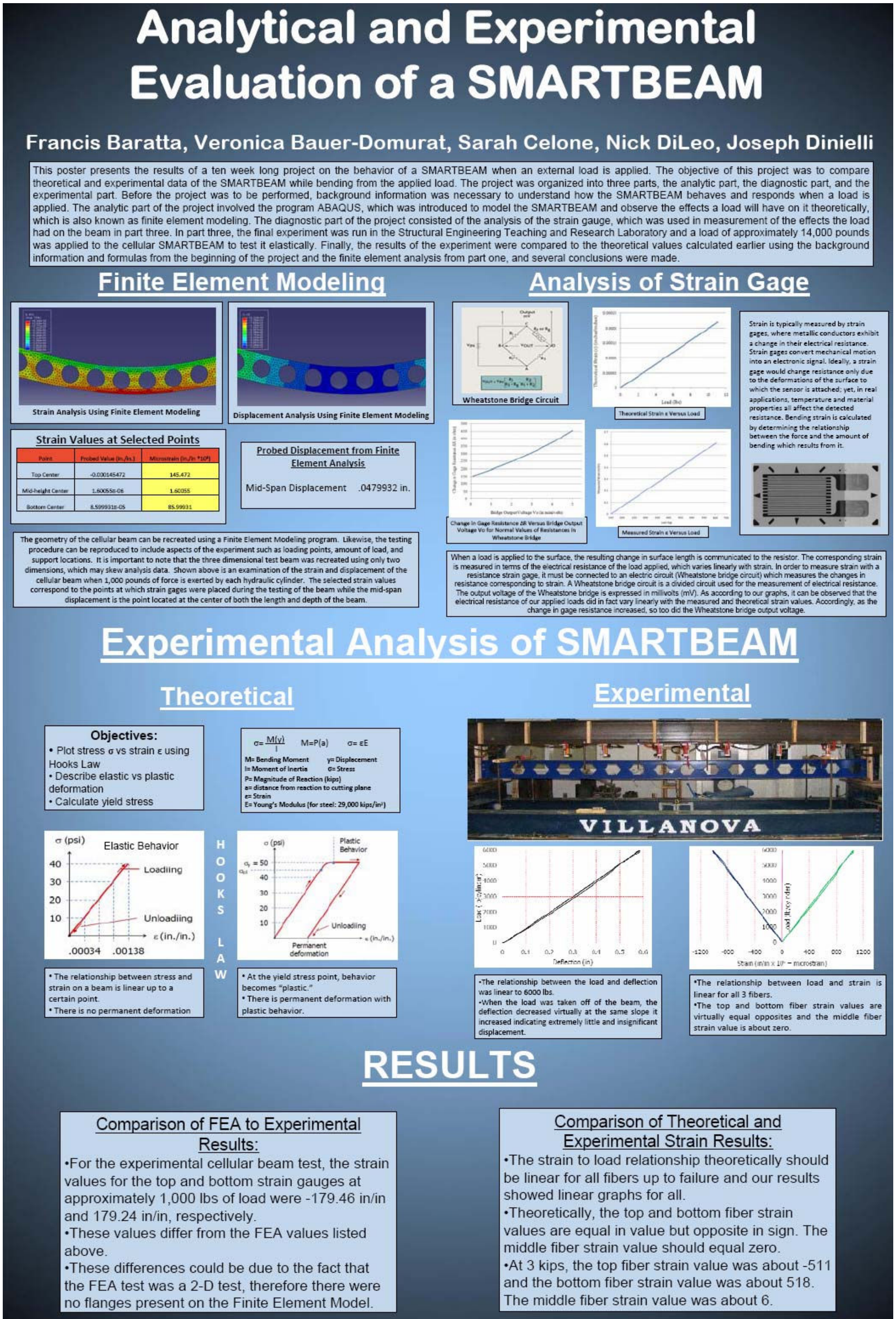


Figure 11. Example of a student poster from the SMARTBEAM® mini-project

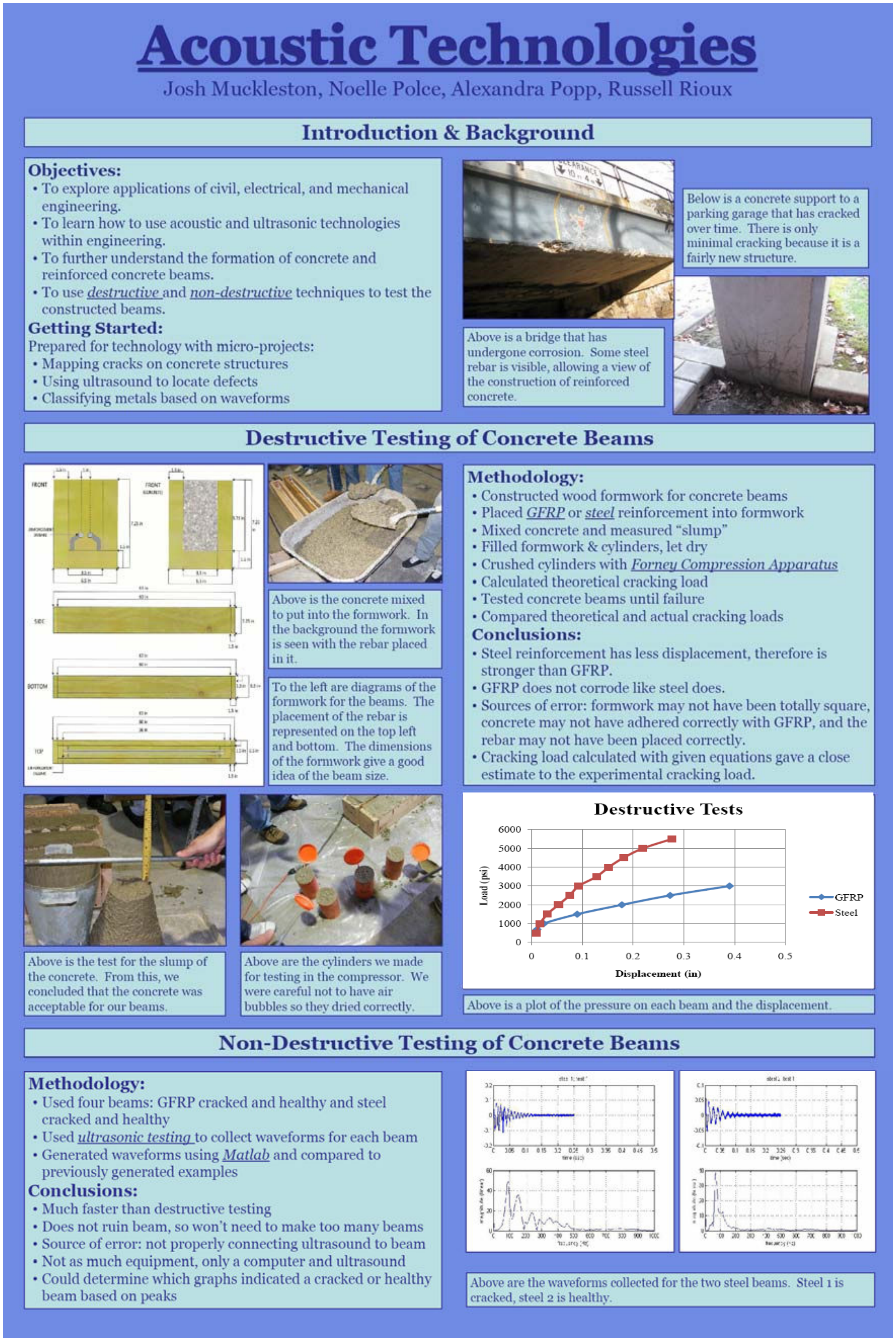


Figure 12. Example of a student poster from the acoustic mini-project

Assessment

Course Assessment and Teaching Surveys (CATS) are given at the conclusion of each course at Villanova University. The CATS ask 23 pointed questions pertaining to the quality of instruction, time utilization, organization, clarity of goals, level of cheating observed, etc. and ask the students to rate them from 1 (poor) to 5 (excellent). Each section of the course completes CATS for all professors involved with the course. Tables 2 and 3 present the mean values of four questions for the SMARTBEAM and Acoustic projects, respectively, and compare the scores to the other four mini-projects. The percentage difference of the evaluations is also presented. The evaluations clearly show that the amount of work required to get a good grade in the mini-projects with a structural engineering component was perceived to be significantly higher than that of the other mini-projects. The SMARTBEAM evaluations were nominally higher for all questions, while the Acoustic project evaluations were within -3 and +2 percent of the other mini-projects.

Table 2. Comparison of CATS data for SMARTBEAM and non-structural mini-projects

Question	SMARTBEAM®	Other Mini-Projects	Difference (%)
Hard work is required to get a good grade	4.55	4.05	12
I found the course intellectually stimulating	4.35	4.22	3
I learned a great deal in this course	4.37	4.08	7
Rate overall value of this course	4.27	4.11	4

Table 3. Comparison of CATS data for ACOUSTIC and non-structural mini-projects

Question	Acoustic	Other Mini-Projects	Difference (%)
Hard work is required to get a good grade	4.48	4.05	11
I found the course intellectually stimulating	4.20	4.22	0
I learned a great deal in this course	4.15	4.08	2
Rate overall value of this course	4.00	4.11	-3

One of the impetuses for modification of the freshman course sequence was the CATS data that showed that the freshman courses were not achieving the mean level of other engineering courses, typically 4.0 or higher. Table 4 presents the comparison of the average CATS data for the fall freshman engineering courses in 2008 and 2009 to the data for all of the mini-projects. The improvement in scores for the four important questions was remarkable, as it ranged from 16 to 20.

Table 4. Comparison of CATS data for 2008 and 2009 course to 2010 mini-projects

Question	All Mini-Projects	'08 and '09 Course	Difference (%)
Hard work is required to get a good grade	4.27	3.66	17
I found the course intellectually stimulating	4.25	3.55	20
I learned a great deal in this course	4.18	3.60	16
Rate overall value of this course	4.13	3.55	16

Table 5 compares the mean CATS scores for all mini-projects to the mean of all courses taught in the CoEVU. The evaluations of the mini-projects compare favorably to other engineering courses, with the mini-projects being rated as more intellectually stimulating.

Table 5. Comparison of CATS data for mini-projects and other engineering courses

Question	All Mini-Projects	All Engineering	Difference (%)
Hard work is required to get a good grade	4.27	4.30	-1
I found the course intellectually stimulating	4.25	4.10	4
I learned a great deal in this course	4.18	4.10	2
Rate overall value of this course	4.13	4.10	1

Written comments echo the numerical CATS data. General trends include comments on superior organization of the material, an enthusiasm of the instructors, the level of learning achieved and the high standards and corresponding hard work required. The CATS provide a mechanism for assessing the mini-projects and comparing them to previous freshman offerings and other courses; however, other means of assessment should be developed. As with any course that has multiple sections and instructors, scores can vary greatly. Scores ranged for different categories within the same mini-project by +/- 1.0 for some questions, depending on the instructor.

College administrators, center directors, faculty, graduate students, and upperclassmen were in attendance at the poster session. Visitors were asked to evaluate the posters and presentations on a scale of one (low) to five (high). All posters received average scores of 4 or higher from all reviewers (~100). Verbal comments from faculty indicated that they were shocked at the quality of the technical content and the knowledge and confidence displayed by the students. Graduate students and upperclassmen unanimously expressed that they wished that these projects were part of their freshmen experience. The success of the poster session has prompted the CoEVU to require it for all mini-projects that did not have a concluding competition in the next course offering.

Review of the technical reports by the instructors showed that these first semester freshmen had prepared documents that met all expectations and in many cases exceeded the requirements established by the instructors. There is little question that they were able to produce a document that would have surpassed what many of our upperclassmen could develop. The students had satisfactorily achieved the outcomes related to technical communication.

Conclusions

As part of a new two-course sequence for freshmen, two half-semester multi-disciplinary mini-projects were developed. Structural engineering components served as a central theme for both of the mini-projects. Students were exposed to how civil, electrical, and mechanical engineers work together on a common problem. Active learning was utilizing to engage the students in many different laboratory environments. Technical communication skills were emphasized and rigorous standards were set and enforced for homework, poster presentations, and the final technical reports. The CATS assessment clearly shows that this new offering was a significant improvement of previous versions of the course and that the mini-projects with structural engineering components required more than the other mini-projects. Written and verbal feedback from the students and evaluators showed that the mini-projects were a resounding success. The authors encourage their colleagues to develop similar freshmen experiences, as we have found great joy in preparing and participating in these mini-projects.

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