
AC 2011-1201: AN INTEGRATED FRESHMAN PROJECT COURSE COMBINING FINITE ELEMENT MODELING, ENGINEERING ANALYSIS AND EXPERIMENTAL INVESTIGATION

Ani Ural, Villanova University

Ani Ural is an assistant professor in the Department of Mechanical Engineering at Villanova University. She received her B.S. degree in 1997 from Bogazici University, M.S. and Ph.D. degrees in 1999 and 2004 from Cornell University. She was a postdoctoral research associate in the Department of Biomedical Engineering at Rensselaer Polytechnic Institute between 2004 and 2007. She held a Visiting Assistant Professor position at Stony Brook University in Spring 2007. She joined Villanova University in Fall 2007. Her research interests include computational biomechanics, fracture mechanics, and solid mechanics.

Joseph Robert Yost, Villanova University

Joseph Robert Yost is an Associate Professor of Civil and Environmental Engineering at Villanova University, where he teaches undergraduate and graduate courses in structural engineering mechanics and design.

David W Dinehart, Villanova University

Professor Assistant Chairman, Department of Civil and Environmental Engineering

Shawn P Gross, Villanova University

Shawn Gross is an Associate Professor of Civil and Environmental Engineering at Villanova University, where he teaches undergraduate and graduate courses in structural engineering and engineering mechanics.

An Integrated Freshman Project Course Combining Finite Element Modeling, Engineering Analysis and Experimental Investigation

Abstract

The freshman engineering curriculum at Villanova University is in a state of transition. In fall 2009 the College of Engineering introduced a new two semester course sequence that is required for all freshman students. An integral part of this new course is an interdisciplinary project-based experience. Six projects are offered and students must choose two; one in the second half of the fall semester, and a second in the first half of the spring semester. This paper describes one of these interdisciplinary freshman projects. The project, known as Analytical and Experimental Evaluation of a SMARTBEAM, combines elements of civil, mechanical and electrical engineering in the study of flexural behavior of expanded wide flange steel beams known as cellular beams. The project combines finite element analysis, flexural stress concepts, strain gauge instrumentation and experimental investigation into a unified experience. Details related to course development and structure, lecture content, method of delivery, outcomes, and learning assessment are presented.

1. Introduction

Engineering analysis, design and research investigation must rely on theory, computational analysis and experimental evaluation. In order to effectively prepare undergraduate students for engineering practice and advanced study in graduate school, it is necessary to build knowledge in these areas throughout the engineering curriculum, starting from the first year. However, in a typical civil or mechanical undergraduate engineering curriculum, students are not exposed to basic stress analysis and force-deformation concepts until the second semester of the sophomore year. In addition, experimental techniques and finite element modeling are mostly covered in the junior and senior years. Interestingly, the fundamental concepts central to much of this course work are understood much earlier in the students' education. That is, students understand from observation and common experience the meaning of concepts central to engineering mechanics and physical force-deformation behavior. Examples include an intuitive understanding of tension and compression, axial deformation and bending deformation, buckling, twisting, and elastic and plastic behavior. The value of this basic level understanding is that it can be elevated beyond intuition and connected in a mathematical and experimental sense to a higher level understanding of engineering analysis, design and experimental investigation.

Development of creative instructional tools that integrate theory and experimental investigation in a project-based course structure have been shown to be effective in improving learning in freshman as well as upper level courses¹⁻⁷. In addition, incorporating computational methods such as finite element modeling throughout the engineering curriculum have been successful in reinforcing the students' understanding⁸⁻¹¹. The previous work in project-based, hands-on learning experiences shows that restructuring of the freshman year can allow for education of the

freshman students so that engineering modeling and analysis become quantitative tools to study what is already understood in a qualitative sense.

The objective of introducing advanced topics in engineering mechanics and analysis was a central component in the development of a new project-based freshman engineering course at Villanova University (VU). First delivered in fall 2009, the new project-based freshman engineering course represents two parts of a four part sequence that is continuous over the freshman fall and spring semesters. In the fall semester freshmen take a 7-week core course, followed by a 7-week project-based course. The core course is the same for all students and covers basic topics that relate to all engineering disciplines offered at VU¹². Following the core course students select one of six multidisciplinary project-based experiences. All six projects are multidisciplinary in content and integrate different elements of chemical, computer, civil, electrical and mechanical engineering^{13,14}. Students start the spring semester with a second 7-week project course, followed by a 7-week department specific course.

This paper describes one of the six project-based courses. The project title is Analytical and Experimental Evaluation of a SMARTBEAM and it includes elements of civil, mechanical and electrical engineering. The course integrates aspects of finite element modeling, stress, strain and deformation analysis, and experimental investigation. Integration of these topics occurs via study of cellular steel beams, which are defined as steel I-beams having circular web voids along their length. A cellular beam is formed by cutting alternating semicircular and straight line patterns along the web of a root beam. When cutting is completed the beam halves are separated, longitudinally shifted, and welded back together to form a new, deeper section. This process is shown in Fig. 1.

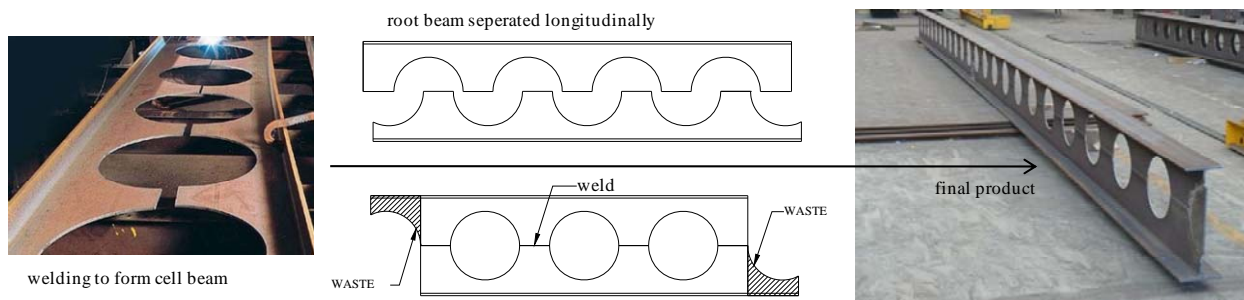


Figure 1: Cellular beam technology

During the project, the students analyze a cellular beam as well as the root beam from which that cellular beam is fabricated using theoretical, computational and experimental methods. In addition, students are introduced to cellular beam technology and the economy that is derived based on the higher order relationship that exists between stiffness and beam depth. Sensor technology used in testing includes load cells, linear variable deflection transducers, and strain gages. The students were also introduced to the basics of the Wheatstone bridge and how a strain gauge functions to develop their understanding of strain sensor technology. The experience allows for the full integration of engineering analysis, sensor technology and experimental investigation as shown in Fig. 2.

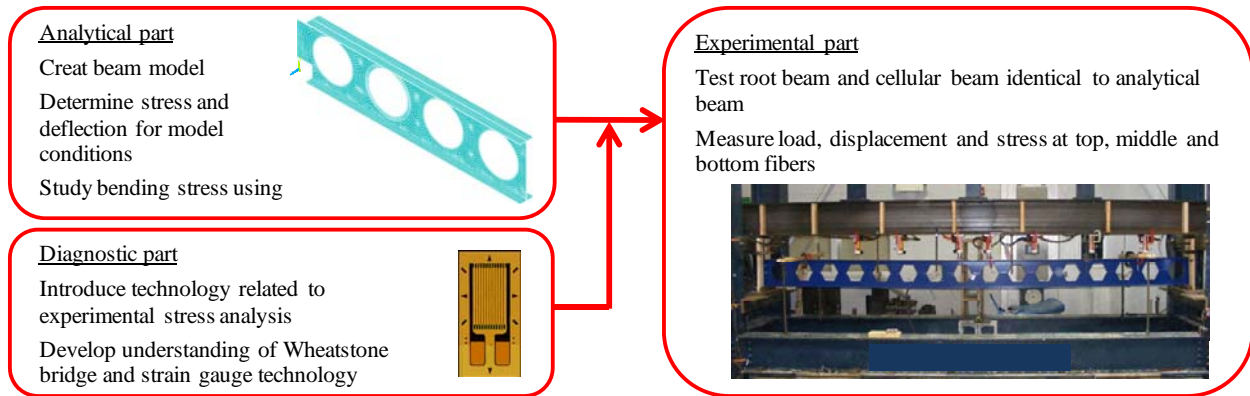


Figure 2: Integration of analysis, instrumentation and experimental investigation

Finally, at the conclusion of the course students are required to write a technical report and make a technical presentation on the experience. The emphasis here is on the importance of effective written and oral communication in the engineering profession.

2. Course Overview and Method of Delivery

During the 7-week sequence of the project-based course, the class meets for 1 hour and fifteen minutes twice a week. There are a total of 14 meetings and a poster session at the end of the course. Average class size is about 20 students. Three different instructors are involved in the course representing the civil, mechanical and electrical engineering departments. Lecture notes are posted on WebCT before class and students are required to come with paper copies of the lecture notes. Lectures are delivered interactively using PowerPoint during class. Meetings take place in a variety of locations including the home-base classroom, electrical engineering laboratory, and structural engineering teaching and research laboratory (SETRL). The class schedule and course overview as delivered in fall 2010 is provided in Fig. 3

Week (#)	Day							
	Monday				Wednesday			
	Location	Lecture #	Topic	Instructor	Location	Lecture #	Topic	Instructor
1	Homebase	L1	Syllabus, Force-Deformation	CEE	Homebase	L2	Stress-Strain, Elastic-Plastic	CEE
2	Homebase	L3	Finite Element I	ME	Homebase	L4	Finite Element II	ME
3	Homebase	L5	Finite Element III	ME	ECE Lab	L6	Strain Gauge I	ECE
4	ECE Lab	L7	Strain Gauge II	ECE	ECE Lab	L8	Strain Gauge III	ECE
5	Homebase	L9	Test Setup & Failure Data	CEE	SETRL	L10	SETRL Tour	CEE
6	SETRL	L11	Elastic Test	CEE	Holiday no class			
7	Homebase	L12	Presentation Skills	All	Homebase	L13	Tech. Writing Skills	All
8	Homebase	L14	Summary and Review	All	CEER 001	na	Poster Session Conference	All

Figure 3: Course overview and individual class details

From Fig. 3, the first two lectures (L1, L2) are related to basic material and force-deformation behavior. This is followed by three finite element lectures (L3, L4, L5) and then three strain gauge lectures (L6, L7, L8). The students are then introduced to methods of experimental investigation (L9) and are given a tour of Villanova's SETRL (L10). The students return to the SETRL in L11 to perform an elastic cyclic test on a cellular beam. From this test they are given a data file with load, deflection and strain on the top, middle, and bottom fibers at center span. Meetings L12 and L13 focus on oral and written communication, respectively, and L14 is reserved to summarize the course and answer any questions related to the technical report and poster presentation.

Course deliverables include homework assigned with each lecture (40% of final grade), class participation and attendance (10% of final grade), poster and presentation (25% of final grade), and final report (25% of final grade). For the final report students are provided a comprehensive outline of the entire course and given specific minimum requirements that must be included. Homework is done in groups of two, with a different partner for each assignment. The poster and final report are done in groups of four. In the following sections details related to the individual course elements are presented.

3. Project Content and Integration of Topics

The course objective is to have freshman students understand the relationship between mathematical analysis of structural systems and actual physical behavior under nominal conditions. The importance of the free body diagram as an analytical tool that physically represents the load, support and stiffness characteristics of the system is emphasized. To achieve this objective the project is divided into three modules including theoretical, computational and experimental evaluation. The first component of the project-based course covers the basic theoretical concepts related to the project. The theoretical module was followed by introduction to finite element modeling and experimental evaluation in a laboratory setting. The hands-on experience in finite element modeling allows students to become familiar with general computational modeling procedures as well as to visualize new theoretical concepts such as stress, strain and force-deformation relationships. The actual beam testing in the structural engineering laboratory provides the students with an opportunity to observe the physical testing and compare the finite element modeling results with experimental data. In the following sections, each project module is explained in detail.

3.1 Basic Theoretical Concepts

The focus of the SMARTBEAM mini project experience is to explore structural behavior using basic theoretical concepts related to axial and flexural loading, the finite element modeling technique, and finally experimental in the laboratory. To develop basic theoretical concepts students are first introduced to fundamental force-deformation behavior of steel structures using simple thought experiments that are easy to visualize. This exercise begins with simple axial loading in tension. Students are instructed to visualize a simple axial tension test, where a steel rod sample of cross section area A and original length L is loaded in tension with a force P , and then the load is released. Concepts of axial deformation, strain, stress, cutting planes, free body

diagrams, and equilibrium are all extensions of this simple exercise. Sample figures related to the discussion are provided in lecture material and shown as well in Fig. 4. Students recognize intuitively that the rod gets longer, the change in length being defined as δ (Fig. 4a). At this point axial strain ϵ is defined as the change in length divided by original length. Students also recognize the rod is in equilibrium by the forces applied equal in magnitude at each end. An extension of this concept is the cutting plane and exposure of internal material. The force acts along the entire length of the member or is internal along the entire length. This leads to a discussion of normal stress σ , and the understanding that the force is not concentrated at a point in the cross section, but rather all fibers of the section resist the force equally. The force divided by the cross sectional area is defined as normal stress σ , and the distribution is uniform on all material fibers of the cross section (Fig. 4b).

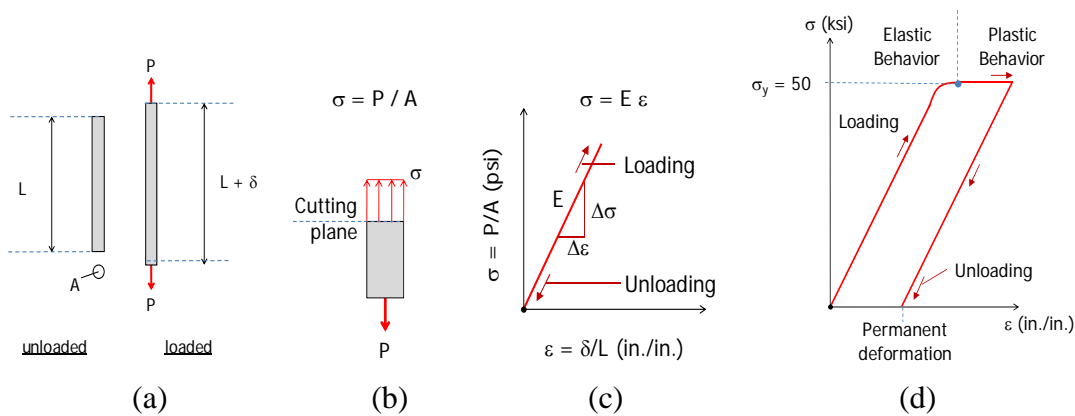


Figure 4: (a) Axial load experiment. (b) Internal material and normal stress. (c) Stress-strain and elastic behavior. (d) Elastic-plastic behavior

Based on the discussion given above, stress and strain are recognized to be normalized forms of force and deformation, respectively. Plotting stress versus strain yields a graph that is characteristic of the material, and not the size and shape of the test specimen. This leads to the development of the stress-strain diagram for steel. As the specimen is loaded the deformation is proportional to the applied force. When the specimen is unloaded the deformation is eliminated (Fig. 4c). This simple understanding introduces the concept of elastic behavior, Young's Modulus E (Fig. 4c) and Hooke's Law $\sigma = E\epsilon$. The discussion continues and the class recognizes that every structure has finite strength so that at some point the elastic behavior must end. For steel, termination of elastic behavior represents yield of the material and transition to plastic behavior where deformation occurs under constant load (Fig. 4d). When the structure is unloaded in the plastic region there will be permanent or residual deformation. At the conclusion of this simple discussion the students are firmly grounded in force-deformation response and associated elastic and plastic behavior.

The same force-deformation discussion as described above is now developed for bending in beams. Students are instructed to visualize a steel beam in flexure, noting the bending deformation causes material fibers on top to compress and fibers on the bottom to stretch. Thus there is compression on top of the beam and tension on the bottom. Logic dictates that between the top and bottom there must be a location of neutral deformation and neutral stress. This

location is defined as the neutral axis (NA) or neutral surface and is shown in Fig. 5a. The bending stress distribution is then recognized to be linear above and below the NA (Fig. 5a) and defined by the flexural formula $\sigma = M(y)/I$. Now, this relationship is first introduced as a function of internal "force" in the numerator, moment in this case, and a property of the cross section in the denominator, moment-of-inertia or I. Thus the bending stress calculation is similar to the axial stress calculation being a function of internal force and a property of the cross section. The cross section is then defined as a series of connected plates, with the top and bottom referred to as flanges with dimensions $b_f \times t_f$, and the vertical middle called a web with dimensions $h_w \times t_w$. The calculation for I is simply given as $\{2x(b_f)(t_f)(\frac{1}{2}d - \frac{1}{2}t_f)^2\}_{\text{flange-parts}} + \{\frac{1}{12}(t_w)(h_w)^3\}_{\text{web-part}}$. Using this relationship, a simple parametric investigation is executed where the cross section area (A) and moment of inertia (I) are investigated by increasing h_w between 10 and 15 inches with all other dimensions held constant. The results are shown in Fig. 5c and the exponential growth in I is noted compared with the relatively flat linear increase in A. This (Fig. 5c) is the value of the SMARTBEAM technology, where the beam depth is increased with no net increase in material. Thus, understanding the relationship between stress and moment-of-inertia, and then the dependence of moment-of-inertia on the square of depth, the students can recognize the economy of using a deeper section.

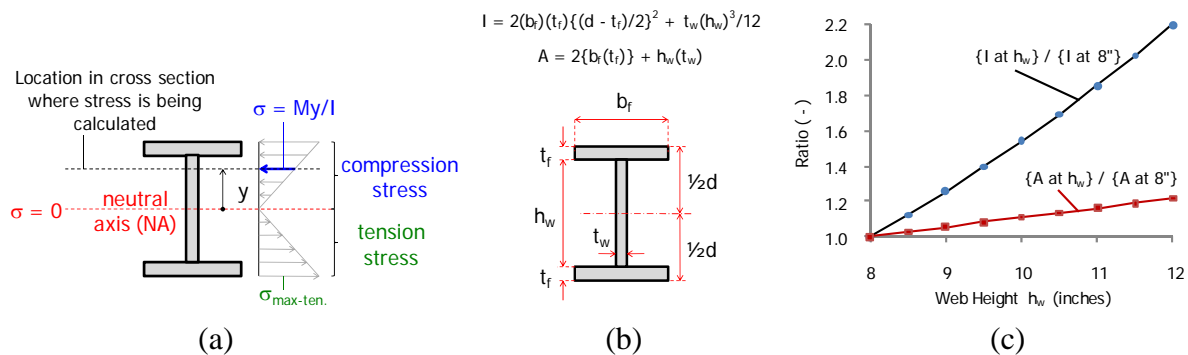


Figure 5: (a) Bending stress distribution. (b) Member cross section. (c) Parametric study of moment of inertia and cross section area

3.2 Finite Element Modeling

Finite element modeling (FEM) module of the project took part after the theoretical concepts were covered and before the students performed the actual testing on the SMARTBEAM in the structural engineering laboratory. This module aimed to enhance the students' understanding of the mechanics concepts and to introduce students to computational methods and tools during the first year of their undergraduate study. The main learning objectives for this module were (i) understanding the general concept of FEM and its application areas (ii) learning to generate a finite element model of a structure and interpret the results under various loading conditions using a commercial finite element software (iii) gaining a better understanding of mechanical behavior by visualizing stress-strain, load-deformation related concepts in different structures using the finite element software.

The finite element modeling part of the project was composed of three lectures (L3, L4, L5 in Fig. 3). Following the initial introduction of general concepts of FEM and case studies from different engineering fields, the students were introduced to hands-on use of the finite element program. The teaching version of the commercial finite element program ABAQUS¹⁵ was used in the course. The instructor explained and went through each step of creating a geometry, defining boundary conditions, applying loads, meshing and identifying material properties on a simple model that involved a two-dimensional square plate with and without a hole under tension. This simple model allowed students to become familiar with the main components of FEM program. After completing the models, the students ran the simulations and obtained deformation, stress and strain data from the simulations. The assessment of the results helped the students develop their understanding of stress distribution, deformed shape, and the concept of stress concentration due to discontinuities in a structure.

Following the simple model, the students were asked to create an FEM model of the SMARTBEAM (Figure 6a) using the actual dimensions of the cellular beam that was going to be tested in the structural engineering laboratory under four-point bending. Using the simulation results students evaluated the strain and displacement values from the finite element model (Figure 6b and 6c) at specific locations corresponding to points where they will be taking measurements in the laboratory. In addition, the students compared the expected theoretical beam behavior that was covered at the beginning of the project to the finite element model results to improve their understanding of mechanical behavior.

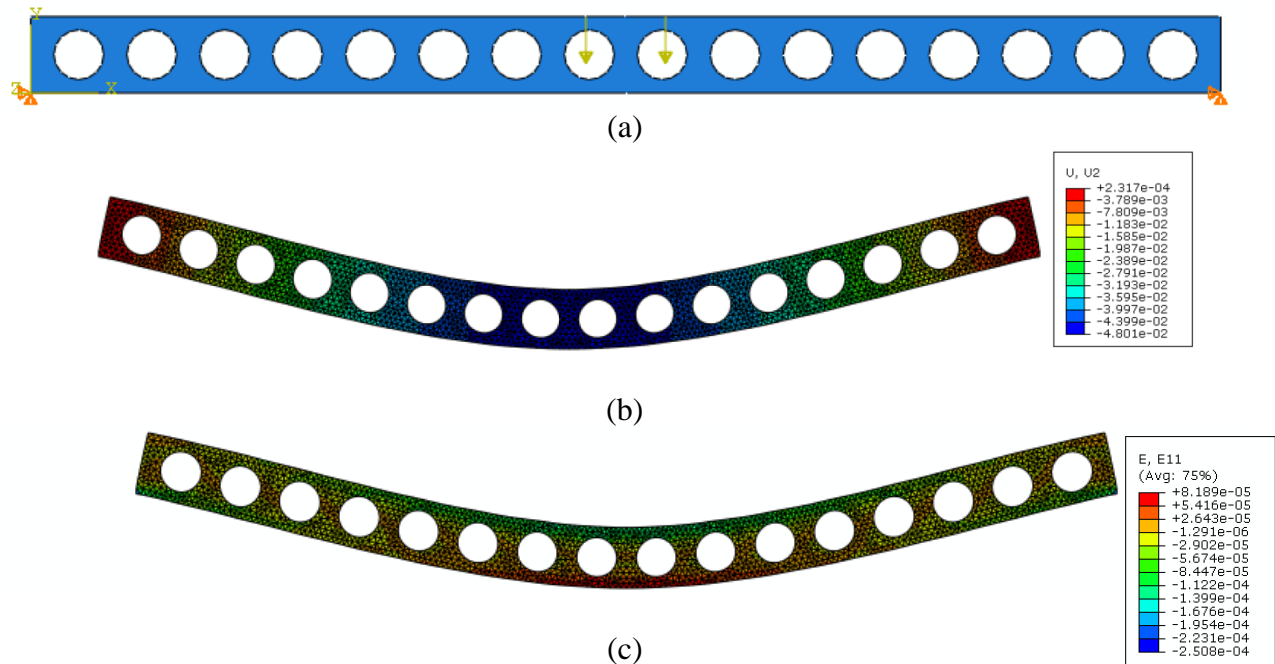


Figure 6: (a) Finite element model of the cellular beam. (b) Deformed shape and displacement contour of the cellular beam under four-point bending (c) Strain contour of the cellular beam under four-point bending.

3.3 Experimental Investigation

With a firm understanding of basic flexural theory and data from a finite element analysis, the students are introduced to measured experimental behavior of a SMARTBEAM in Villanova's Structural Engineering Teaching and Research Laboratory (SETRL). The test involves four point bending as is shown in Fig. 7. Three individual beams are tested, 1) a root beam to failure, 2) a castellated version of the root beam to failure, and 3) a cellular version of the root beam elastically. Data for the first two tests is provided and the students will enter the SETRL to perform the third test.

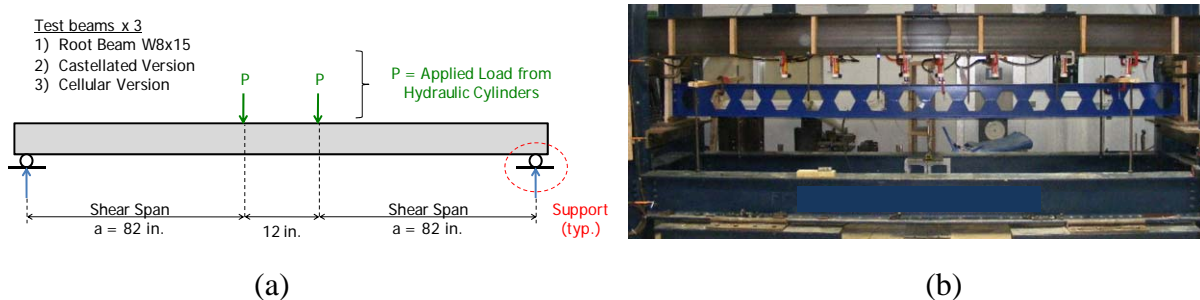


Figure 7: (a) Schematic of test load and support conditions. (b) Photo of SETRL test setup

Before entering the SETRL for the elastic test, students are provided a lecture where the details related to the experimental procedure are described. The intent is to develop a sense of understanding for how the actual test will be executed, as well as create a sense of anticipation for the event, which they will observe in a subsequent meeting. The testing procedure details related to the following experimental elements are provided: hydraulic cylinders for applying load, hydraulic system components (pump, manifolds, distribution hoses, hydraulic fluid), sample support conditions, strain gage instrumentation, displacement and force transducers, data acquisition system, and finally loading concerns. Elements of this discussion are provided in Fig. 8.

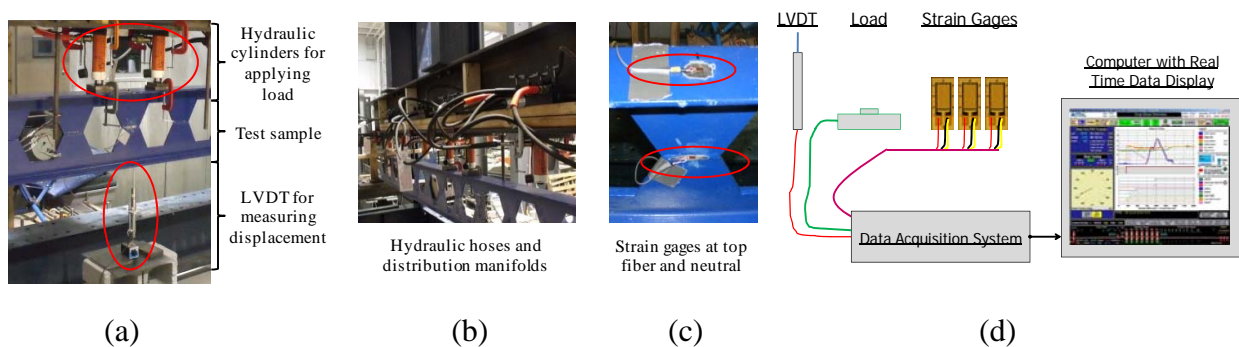


Figure 8: (a) Load and displacement. (b) Hydraulic system. (c) Strain gauge instrumentation. (d) Data acquisition.

Data plots in the form of load-deflection (Fig. 9a) and load-strain (Fig. 9b) for the root beam (W8x15) and castellated beam are provided and discussed before visiting the SETRL. Students

are able to correlate elastic and plastic behavior and the stress distribution as related to maximum fiber stress at top and bottom, and zero stress at the middle fiber.

Finally, the experimental results are compared to the expected behavior predicted using the basic theoretical flexural relationships and results from the finite element model. Importantly the students are exposed to the importance of comparing predicted behavior with measured behavior and that this comparison allows engineers to objectively understand the value and accuracy of their mathematical model. The correlation is, for simple systems with known load, support and material conditions, usually quite good. However, the analysis of large complex structures often requires simplifying assumptions, and engineers must rely on measured behavior to know if their model represents realistically well the behavior of the physical system.

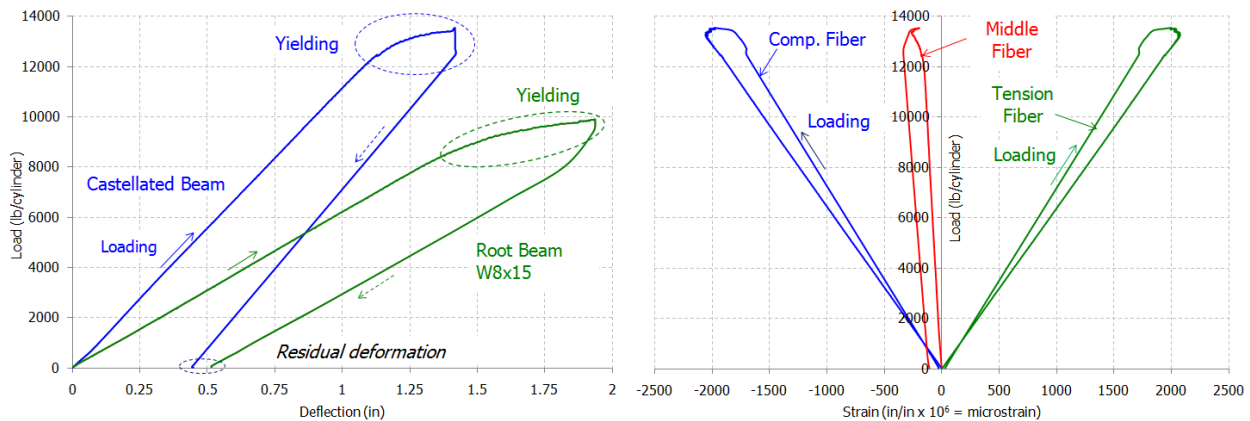


Figure 9: (a) Load-deflection results. (b) Load-strain results

3.4 Integration of theoretical concepts, finite element modeling and experimental testing

After completing all three modules of the project that included theoretical concepts, finite element modeling, and laboratory testing the students were asked to integrate their knowledge from each of the three modules by writing a technical report and presenting their results in a poster presentation session. The technical report and the presentation involved summarizing each component of the project and relating each component to the overall understanding of mechanical behavior of a beam. Combining the components at the end of the class as a technical report is expected to increase the understanding of the concepts learned during the semester. The evaluation of the theoretical equations, finite element results and experimental findings provide an opportunity for the students to understand the limitations and sources of error in computational and experimental approaches. Furthermore, the integration of all components through a technical report allows students to reflect on the interrelation between theoretical, computational and experimental components and their respective significance in engineering analysis, design and research.

4. Course Assessment

The students were given three surveys during the semester in addition to the course evaluation that was administered at the end of the semester. The surveys were given after each module of the project to evaluate the contribution of theoretical, finite element modeling and experimental parts of the project. The surveys were composed of six questions and the first four questions were common in all surveys. These four questions evaluated the students' understanding of the new concepts at various stages of the project. The last two questions were aimed at evaluating the effectiveness of each module. Survey questions and when they were administered are given in Table 1.

Table 1: Survey questions and times administered

Question		Administered in Survey *
1	How do you rate your understanding of stress-strain relationships?	1, 2, 3
2	How do you rate your understanding of a beam behavior under bending?	
3	How do you rate your understanding of the deformed shape of a beam under bending?	
4	How do you rate your understanding of stress and strain distribution in bending?	
5	How did the theoretical concepts covered in the first two lectures help you visualize and understand beam bending behavior?	1
6	Covering the theoretical concepts was sufficient for me to understand beam bending behavior.	
5	How did the finite element modeling covered in the last three lectures help you visualize and understand beam bending behavior?	2
6	Combined theoretical and finite element modeling approach allowed me to understand beam bending behavior better.	
5	How did the testing in the laboratory help you visualize and understand beam bending behavior?	3
6	Combined theoretical, finite element modeling and laboratory approach allowed me to understand beam bending behavior better.	

* Surveys 1, 2, and 3 administered after theoretical, finite element and experimental parts, respectively.

The students were given a scale ranging between 1 to 5 for each question in the surveys (For Questions 1 to 4: 1 = I do not understand it, 5 = I fully understand it; for Question 5: 1 = I do not visualize/understand it, 5 = I fully visualize/understand it; for Question 6: 1 = I do not agree, 5 = I agree). The surveys were given to both sections that were taught in Fall 2010. The sections had a total of 42 students.

Due to the variation in total number of students that responded to the surveys, the results were presented as percentage of total students for each survey. The responses for Questions 1 through 4, and Questions 5 and 6 are plotted in Figures 10 and 11, respectively. As outlined before, Questions 1 to 4 were the same in all three surveys. The change in the students' response to these questions in each survey indicates their perception of their understanding of the material covered

during the project. The responses showed that, in general, the understanding of the stress-strain concepts increased with the progression of each module. The responses that correspond to a good understanding of stress-strain behavior (ratings 4 and 5) increased with each survey indicating the increase in understanding of the concepts. The highest total percentages for ratings 4 and 5 were obtained for Survey 3 which was given at the end of the project after the experimental module. This indicates that the experimental observations and hands-on experience in the lab helped students solidify their learning of the new concepts. The lowest total percentage for ratings 4 and 5 was obtained for Question 4 that refers to the understanding of the stress-strain distribution in a beam in bending. Furthermore, the percentage of students who did not report confidence in their understanding of the concepts (ratings 1 and 2) decreased from a range of 8-20% from Survey 1 for first four questions to 0-3% for Survey 3. This highlights that 97% of the students reported a moderate to good understanding of the concepts.

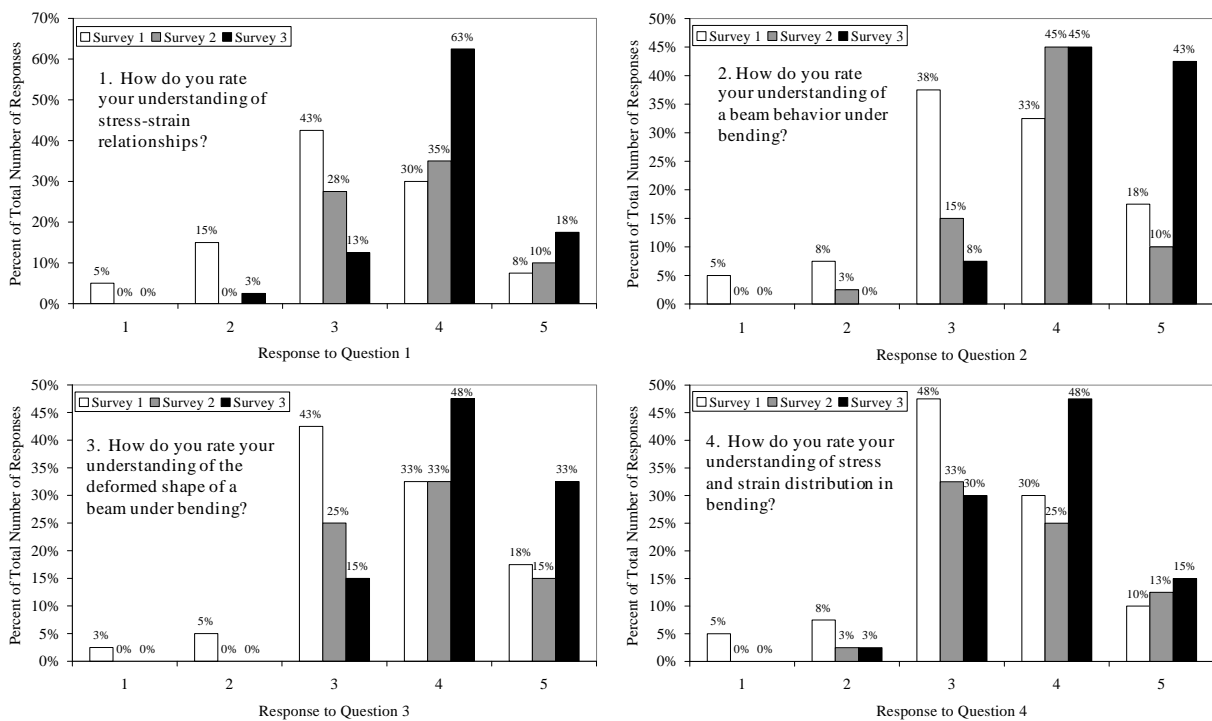
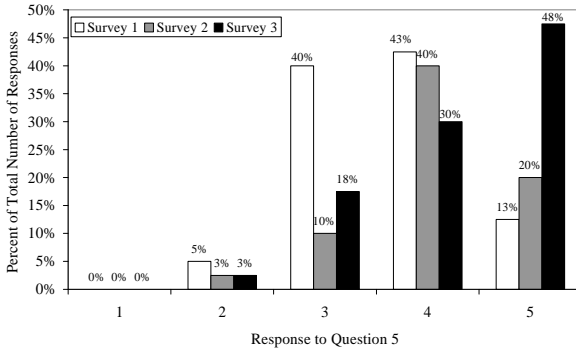
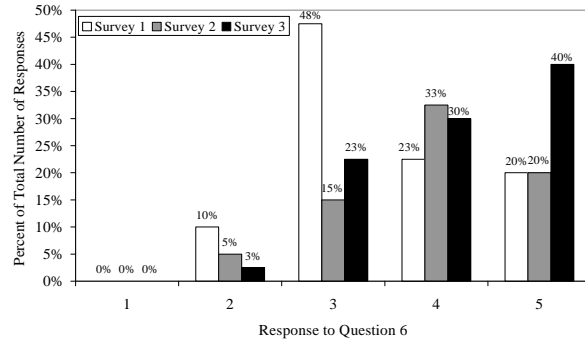


Figure 10: Student responses to Questions 1, 2, 3 and 4. Note the scale ranges between 1 and 5 (1 = I do not understand it, 5 = I fully understand it).

The same analysis was performed for Question 5 and 6 that assessed the perception of students about the contribution of each module to their understanding of the concepts. The results of the surveys showed the same trends as the first four questions where ratings 4 and 5 increased with each survey indicating the contribution of each module. The highest percentages were again observed for the last survey that was given at the end of the project. Furthermore, the percentage of students who did not report confidence in their understanding of the concepts (ratings 1 and 2) decreased from a range of 5-10% from Survey 1 for questions 5 and 6 to 0-3% for Survey 3. This reinforces the observation from the first four questions and indicates that 97% of the students reported a moderate to good agreement with the contribution of each module and the overall project structure to their learning and understanding of the concepts.



5. (Survey 1) How did the theoretical concepts covered in the first two lectures help you visualize and understand beam bending behavior?
5. (Survey 2) How did the finite element modeling covered in the last three lectures help you visualize and understand beam bending behavior?
5. (Survey 3) How did the testing in the laboratory help you visualize and understand beam bending behavior?



6. (Survey 1) Covering the theoretical concepts was sufficient for me to understand beam bending behavior.
6. (Survey 2) Combined theoretical and finite element modeling approach allowed me to understand beam bending behavior better.
6. (Survey 3) Combined theoretical, finite element modeling and laboratory approach allowed me to understand beam bending behavior better.

Figure 11: Student responses to Questions 5 and 6. Note the scale ranges between 1 to 5 (for Question 5 1 = I do not visualize/understand it, 5 = I fully visualize/understand it, and for Question 6 1 = I do not agree, 5 = I agree)

5. Discussion and Recommendations

This paper summarized the course development and assessment of a freshman project “Analytical and Experimental Evaluation of a SMARTBEAM” as a part of the new Villanova University freshman engineering program. The project presented in this paper provides an integrated approach to engineering education by combining theoretical, computational and experimental components around a hands-on project. Integration of computational and experimental analysis with theoretical concepts is expected to improve the students’ understanding of the mechanics concepts. The course assessment performed throughout the project provided evidence for the benefits of the integrated approach developed in this project. At the conclusion of the project, 97% of the students reported moderate to good understanding of the concepts covered in the course. In addition to contributing to the improvement in students’ learning, the exposure of students to an integrated project allows them to recognize all the different approaches essential in solving an engineering problem and is expected to improve their preparedness for engineering practice after graduation.

This course could serve as a model for future development of a semester long project-based course with a similar overarching content that could be offered later in the student’s undergraduate education. Should the student have a deeper understanding of fundamental flexural mechanics, the experimental component could be expanded to include measurement of normal stress, shear stress and principal stresses through plane stress transformation. As well, fuller development of the finite element method and strain gauge instrumentation component could be achieved. Important in this discussion is the need to educate engineering students who understand the integration of theoretical, computational and experimental methods as related to the study of engineering systems.

References

1. Carlson, L. and J. Sullivan, *Hands-on engineering: learning by doing in the integrated teaching and learning program*. International Journal of Engineering Education, 1999. **15**: p. 20-31.
2. Hadim, H.A. and S.K. Esche. *Enhancing the engineering curriculum through project-based learning*. in *Frontiers in Education, 2002. FIE 2002. 32nd Annual*. 2002.
3. Knight, D., L. Carlson, and J. Sullivan. *Improving engineering student retention through hands-on, team based, first-year design projects*. in *31st International Conference on Research in Engineering Education*. 2007. Honolulu, HI.
4. Richard N. Savage, Jonathan Stolk, and L. Vanasupa. *Collaborative Design of Project-Based Learning Courses: How to Implement a Mode of Learning That Effectively Builds Skills for the Global Engineer*. in *Proceedings of the American Society for Engineering Education Annual Conference*. 2007. Honolulu, HI.
5. Sheppard, S.D. and R. Jenison. *Thoughts on freshman engineering design experiences*. in *Frontiers in Education Conference, 1996. FIE '96. 26th Annual Conference., Proceedings of*. 1996.
6. Brown, B. and B. Brown. *Problem-based education (PROBE): learning for a lifetime of change*. in *Proceedings of the 1997 ASEE Annual Conference and Exposition*. 1997. Milwaukee, WI.
7. Rubino, F.J. *Project based freshman introduction to engineering technology courses*. in *Proceedings of the 1998 ASEE Annual Conference and Exposition*. 1998. Seattle, WA.
8. H. Jenkins and J. Mahaney, *Improving mechanical design education using solid modeling and finite element analysis modules*, ASEE Southeastern Section Conference, 2005.
9. L. C. Brinson, T. Belytschko, B. Moran and T. Black, *Design and computational methods in basic mechanics courses*, Journal of Engineering Education 86 (1997), 159-166.
10. W. E. Howard, J. C. Musto and V. Prantil, *Finite element analysis in a mechanics course sequence*, American Society for Engineering Education Annual Conference & Exposition, 2001.
11. C. J. Lissenden, G. S. Wagle and N. J. Salamon, *Applications of finite element analysis for undergraduates*, American Society for Engineering Education Annual Conference & Exposition, 2002.
12. Caverly, R., Fulmer, H., Santhanam, S., Singh, P., O'Brien, J., Jones, G., Char, E., Mercede, F., Weinstein, R., Yost, J. *Project-Based Freshman Engineering Experience: The Core Course* American Society for Engineering Education Annual Conference & Exposition, 2010.
13. Dinehart, D., Yost, J., Gross, S., Radlinska, A. *The role of structural engineering in multi-disciplinary freshman projects*. American Society for Engineering Education Annual Conference & Exposition, 2010.
14. Comolli, N., Kelly, W., Wu, Q. *The artificial kidney: investigating current dialysis methods as a freshman design project*. American Society for Engineering Education Annual Conference & Exposition, 2010.
15. ABAQUS, Teaching Edition, version 6.9, 2009, Simulia , Providence, RI