AC 2007-753: THE APPLIED FINITE ELEMENT ANALYSIS COURSE AT OREGON INSTITUTE OF TECHNOLOGY

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The Applied Finite Element Analysis Course
At Oregon Institute of Technology

Abstract

Computer-aided-engineering tools, such as CAD, FEA and CAM, are becoming to be the essential tools to the engineering practices in industry. This paper describes the development and evolution, in the last 15 years, of an applied finite element analysis course that is being offered by the Mechanical and Manufacturing Engineering Technology (MET) department at Oregon Institute of Technology (OIT) .

A common vision that the OIT-MET faculty shared is the need to better prepare our graduates with the skills to use modern engineering tools. This vision was also recommended in several reports published by the National Research Council and the National Science Foundation. And this was also recognized in the ABET criterion that "graduates must have an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice."

The first finite element analysis course developed, and offered as an elective, by the Mechanical Engineering Technology department at Oregon Institute of Technology was back in 1992. Two years later, the MET department decided to integrate the finite element analysis course as a required course for the MET curriculum. The main emphases of the course are placed on both teaching the students the basic theory, as well as, to use a commercially available FEA package. The course objectives have been established as follows:

- To understand the purposes and uses of the finite element analysis in industry.
- To learn the basic concepts and procedures associated with finite element analysis.
- To gain hands-on experience with a commercially available finite element analysis package.
- Apply the techniques and skills taught to related problems in follow-on courses.

This paper describes the changes and results of the Applied Finite Element Analysis course offered by the Mechanical and Manufacturing Engineering Technology Department at Oregon Institute of Technology.

Development of the FEA course at OIT

Finite Element Analysis (FEA) is a numerical method for solving engineering problems by simulating real-life-operating situations on computers. **Finite element analysis** procedures evolved gradually from the work of many people in the fields of engineering, physics, and applied mathematics. The use of finite element analysis (FEA) become widespread in the 1960's and 70's, initially in the automotive and the aerospace industries. During that period of time, expensive mainframe computers were required to run the finite element analysis, and finite element models typically required days to create. The task of interpreting results were also very difficult. Customized software were used and a highly specialized FEA stress analyst was required to perform the FEA tasks.

By the 1980's, general purpose FEA software began to appear. It is during this period of time, FEA software became available on microcomputers. As the personal computers became widespread, FEA software also evolved to the point that a PC could be used to perform relatively complex analysis. With the changes in the computer hardware and FEA software, a competent engineer with some training can become proficient at FEA very quickly.

In 1992, the faculty of the Mechanical Engineering Technology department at Oregon Institute of Technology developed their first finite element analysis course, which was offered as an elective. It was agreed among the faculty of the MET program that the course would be an applied finite element analysis course, to expose the students to the use of a modern tool for analysis. The course was to cover the basic theoretical derivations of FEA procedures, and also hands-on experience in using a commercially available Finite Element Analysis package. Due to the limitation of the computer hardware and software, the course covered one dimensional (1-D) and two dimensional (2-D) linear static structural analyses. Two years later, the MET department decided to integrate the finite element analysis course as a required course for the MET curriculum.

In 1994, with the help of several education grants from industries, the OIT-MET department did a two year research on incorporating the leading edge Computer Aided Engineering technology into the MET and MFG programs at OIT. As a result of that research, a series of computer aided engineering (CAD/CAM) courses were developed and incorporated into the two programs. The FEA course was changed to a required course for the MET program during 1994.

The FEA course has gone through several revisions, and changes made in both the format and the course content. Today, the applied finite element analysis course covers the basic FEA theory, using a commercial FEA program and comparisons of FEA results to physical testing of actual parts. The course has used several commercial FEA packages and are currently using the I-DEAS NX software as the primary software.

Course Description

The current format of the course contains three components: **1**. An understanding of the basic FEA theory. This is needed in order for the students to gain some insights to what actually happens inside the computer. **2**. The use of a commercial FEA program for analysis. Finite element analysis programs have become fairly easy to use. With many solid modeling programs, a few additional steps are all that is required to produce a stress analysis. Many engineers are now required to perform FEA analyses that used to require a stress analyst. **3**. Physical testing of actual parts to further reinforces the concepts and principles learned. One of the focuses of the recent changes in the FEA course has been to allow students to perform comparison of real-life results to the theoretical solutions. By integrating physical testing and FEA, additional comparisons can be made, and more insights can be observed.

The course is structured in a 2-3-3 format (2 hours lecture, 3 hours lab, 3 credit hours) and the class meet for 5 hours per week. A typical week consisted of about 2 hours of classroom time and 3 hours in the computer labs. The class also has access to a classroom, a mechanical testing lab, and a computer lab. Activities of the ten weeks term includes the discussions of the basic

FEA theory, paralleled by using a commercial FEA software and physical testing, and the last week for review and advanced topics. Currently, two commercial FEA software (Pro/E and I-DEAS) are available in the OIT CAD/CAE labs. AutoCAD, Inventor and UGS NX solid modeling software are also available in the CAD/CAE labs.

The course objectives are as follows:

- To understand the purposes and uses of the finite element analysis in industry
- To learn the basic concepts and procedures associated with finite element analysis.
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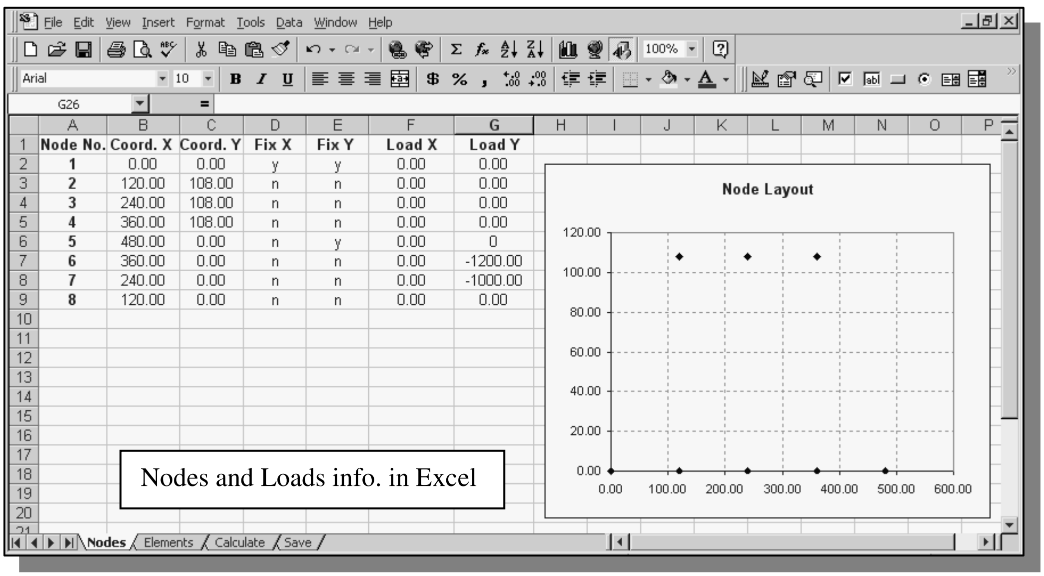
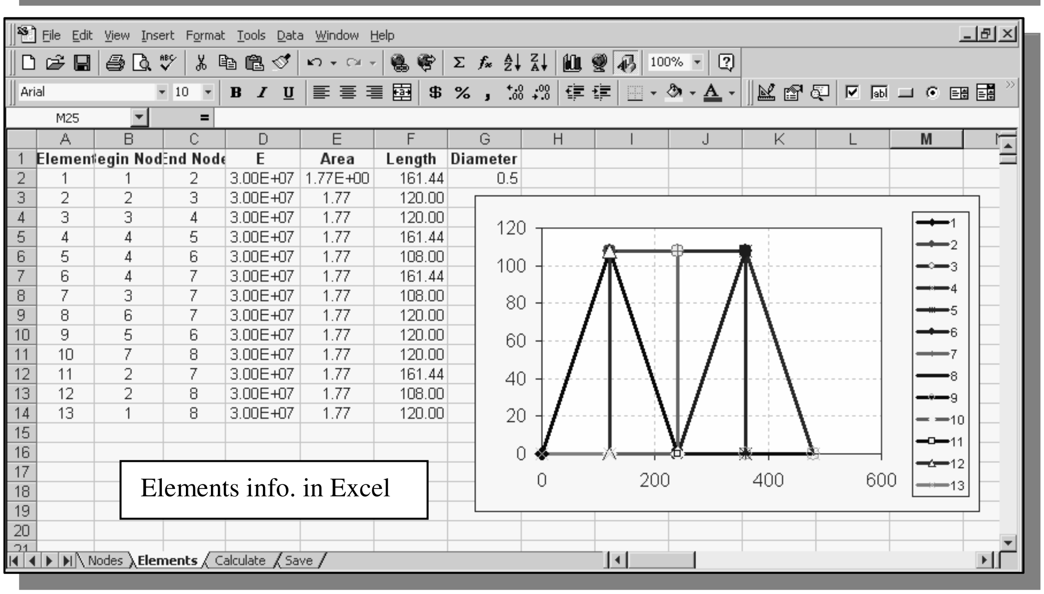
The course covers element formulations for 1-D spring, 2-D truss, 2-D beam, and 3-D truss elements by direct stiffness matrix methods. Students are required to perform the 1-D spring analysis by using a calculator and perform the 2-D truss and 3-D truss analyses using the Excel spreadsheet and the Truss Solver program. The below figures show some of the 2-D/3-D truss exercises solved with Microsoft Excel, the Truss-solver program and the I-DEAS software.



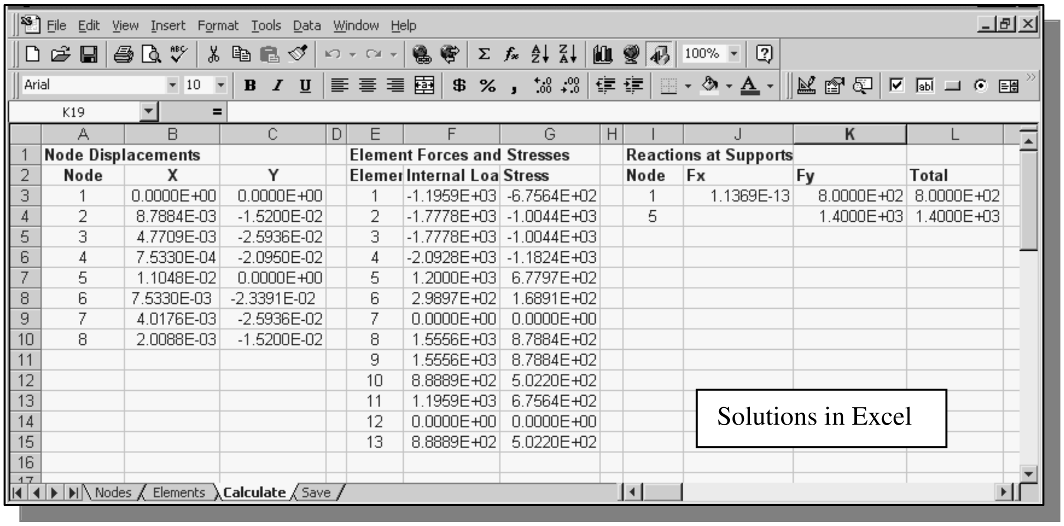
Node No.	Coord. X	Coord. Y	Fix X	Fix Y	Load X	Load Y
1	0.00	0.00	y	y	0.00	0.00
2	120.00	108.00	n	n	0.00	0.00
3	240.00	108.00	n	n	0.00	0.00
4	360.00	108.00	n	n	0.00	0.00
5	480.00	0.00	n	y	0.00	0
6	360.00	0.00	n	n	0.00	-1200.00
7	240.00	0.00	n	n	0.00	-1000.00
8	120.00	0.00	n	n	0.00	0.00

Nodes and Loads info. in Excel

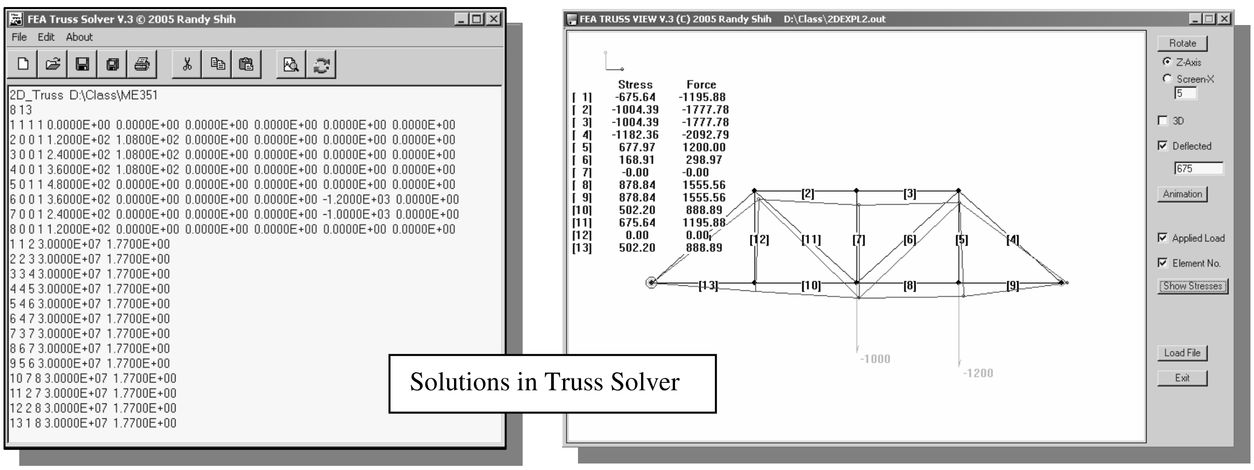


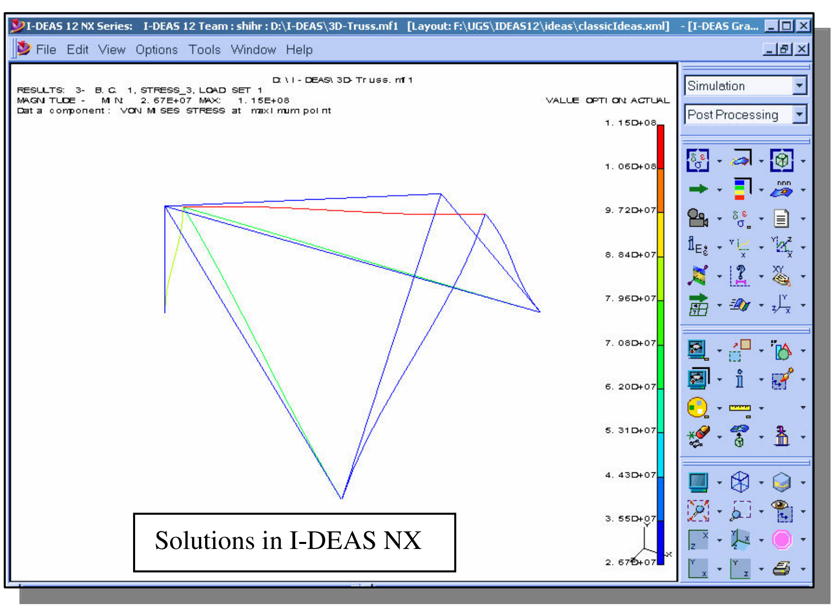
Element	Begin Node	End Node	E	Area	Length	Diameter
1	1	2	3.00E+07	1.77E+00	161.44	0.5
2	2	3	3.00E+07	1.77	120.00	
3	3	4	3.00E+07	1.77	120.00	
4	4	5	3.00E+07	1.77	161.44	
5	4	6	3.00E+07	1.77	108.00	
6	4	7	3.00E+07	1.77	161.44	
7	3	7	3.00E+07	1.77	108.00	
8	6	7	3.00E+07	1.77	120.00	
9	5	6	3.00E+07	1.77	120.00	
10	7	8	3.00E+07	1.77	120.00	
11	2	7	3.00E+07	1.77	161.44	
12	2	8	3.00E+07	1.77	108.00	
13	1	8	3.00E+07	1.77	120.00	

Elements info. in Excel

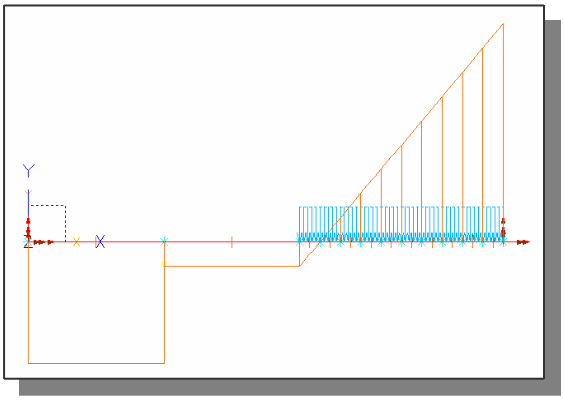


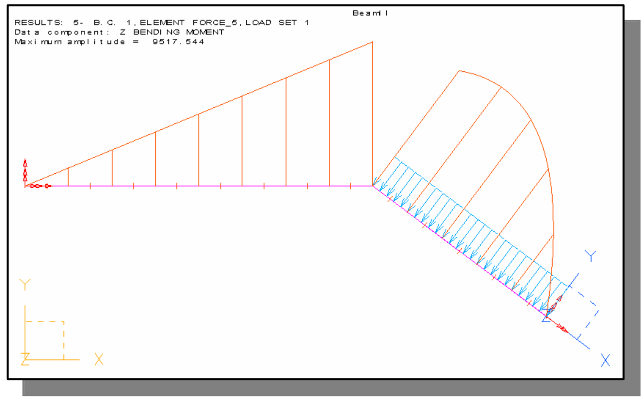
Students are required to perform FEA analyses, and compare the results, using different methods, the figures below show the solutions of problems done with the Truss Solver program developed by the author and the I-DEAS NX software.



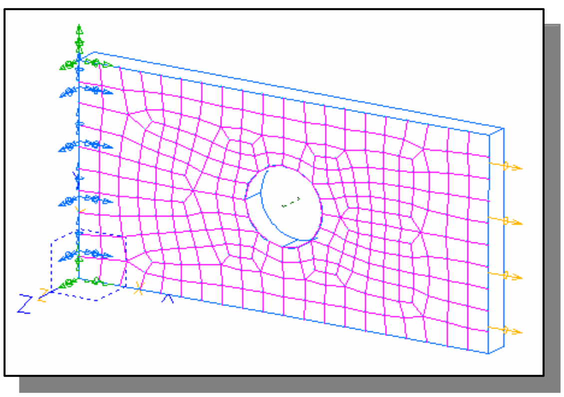


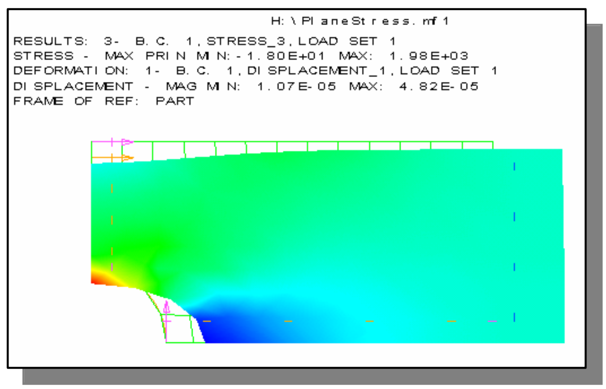
Beam element is the second type of finite element that students learned to use; exercises cover both 2-D and 3-D environments. Students are still required to perform hand calculation, as a way to check the FEA solutions. And the benefit of using FEA is becoming more obvious to the students. The topic of *statically indeterminate structures* is also discussed and exercises assigned. Below are samples of shear and moment diagrams generated with the FEA software.



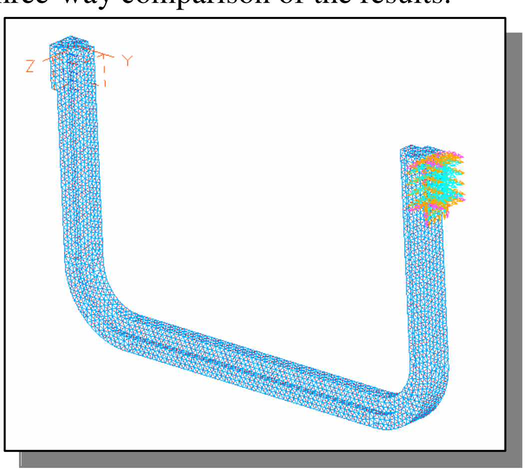


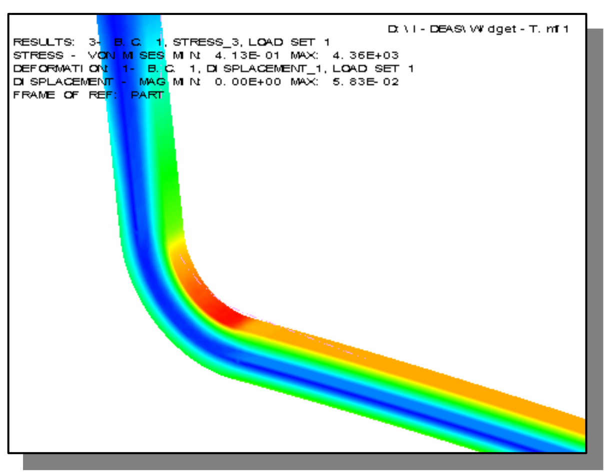
2-D solid elements are the next group of elements introduced in the class. Examples, such as the classical stress concentration effect of a hole in a square plate, are used as in the class.





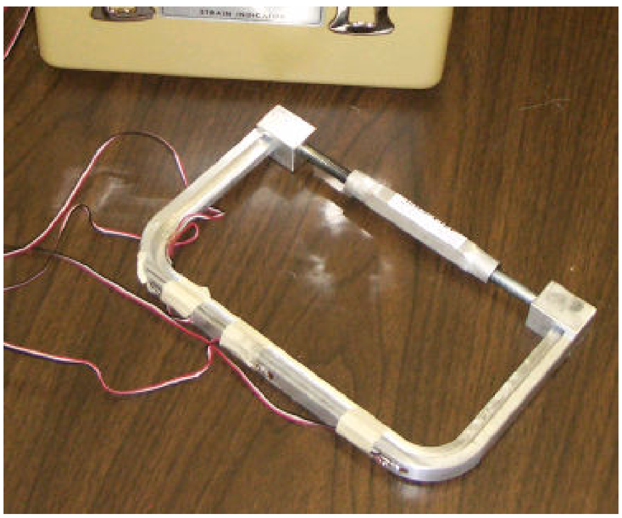
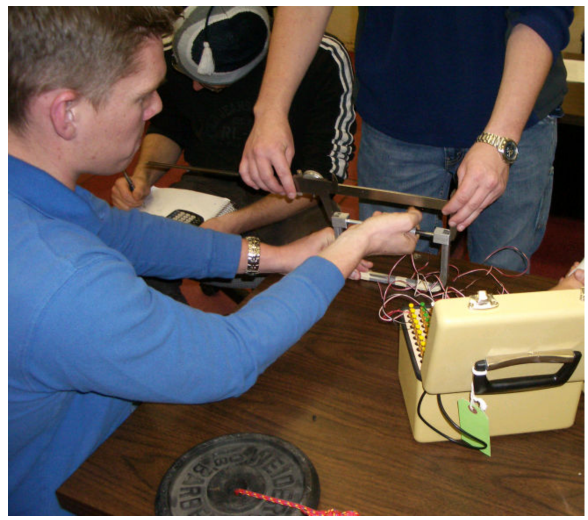
The last group of elements introduced is the 3-D solid elements. The curved beam theory is also covered in this class, and students are again required to perform hand calculations to check the FEA solutions. This is followed by testing of actual parts, which allows the students to do a three-way comparison of the results.

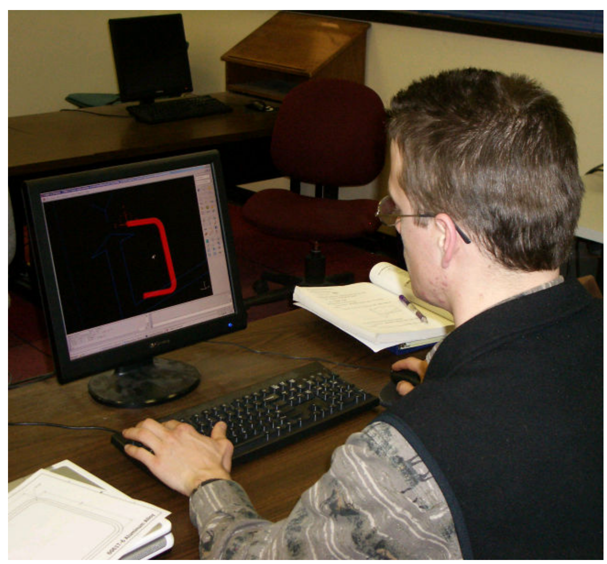




The actual testing of physical parts in the course provides the students a chance to relate the FEA results to the results of real life testing. This process helps students to raise their confidence with the FEA results, as well as realizing the importance of analysis assumptions and the correct interpretation of results

Three C-Shape parts, which are similar in sizes/dimensions but with different cross sections, are used for the testings. The C-shape parts, each with four or five strain gages mounted at different locations, are loaded by turning a turnbuckle placed at the openning. The changes in strains, as the turnbuckle is turned, are observed both at high and low stresses area. Two known weights are used to calculate the equivalent loads applied by the turnbuckles. Eight samplings are taken during each test. The testing results are compared against (1) the FEA results and (2) the hand caculations using the curved-beam theory. A review discussion, focused on the interpretation and comparison of results and the causes of the discrepancy of the results, is followed after the students reports are graded and returned.

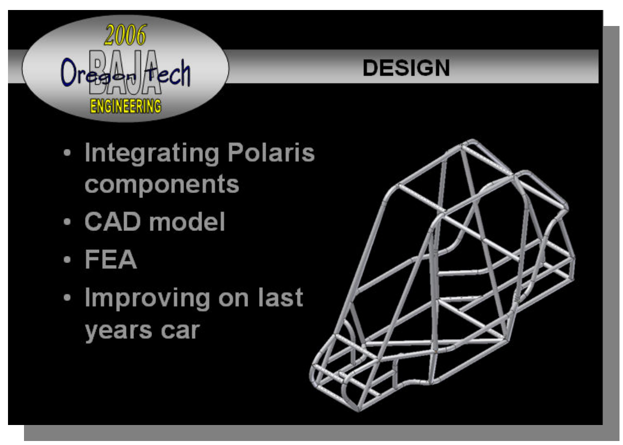



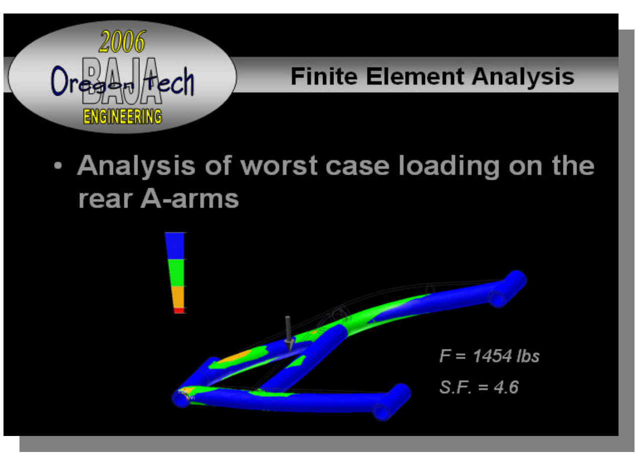


Student Projects and FEA

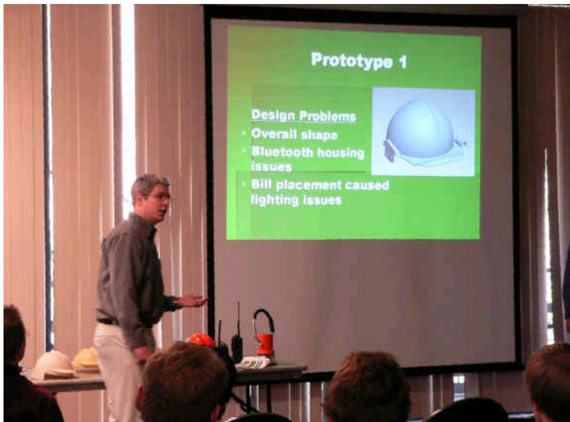
The capstone educational experience for OIT Mechanical Engineering Technology and Manufacturing Engineering Technology undergraduates is the year-long **Senior Design Project**. Over the course of three terms, teams of MET/MFG students design, build, and test their solutions to selected engineering design problems and present these solutions to a variety of audiences. Many senior design projects are sponsored by industry partners in the local area, others are sponsored by the department or initiated by the students themselves. All senior design teams work with a faculty advisor and their sponsoring organization. Some projects are MET/MFG specific and others are interdepartmental, with team members coming from other fields such as Electronice/Electrical Engineering and Computer Science. The Senior Design Project not only provides OIT Mechanical Engineering Technology students with practical experience in mechanical and industrial design, but it also sharpens their skills in project management, written and oral communication, and collaborative group work; these are all vitally important elements of success in today's global engineering workplace. Students are encouraged to be creative and perform very thorough engineering analyses for their projects. The department has noticed a steday increaes in the use of FEA in the senior design projects. During the 2005-2006 school year, four of the the six senior design projects used FEA as part of their engineering analyses.

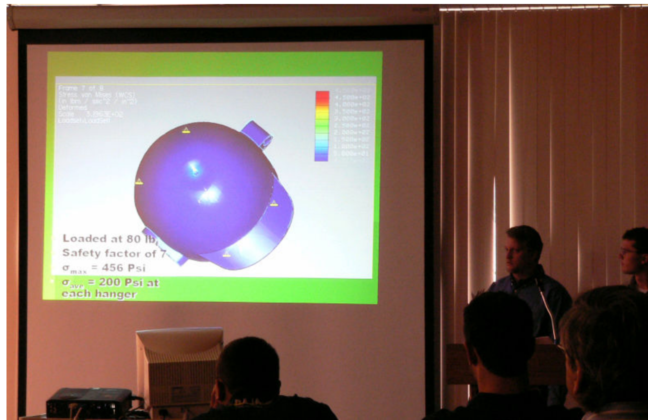
The **Mini Baja** team used FEA to improve their frame design.



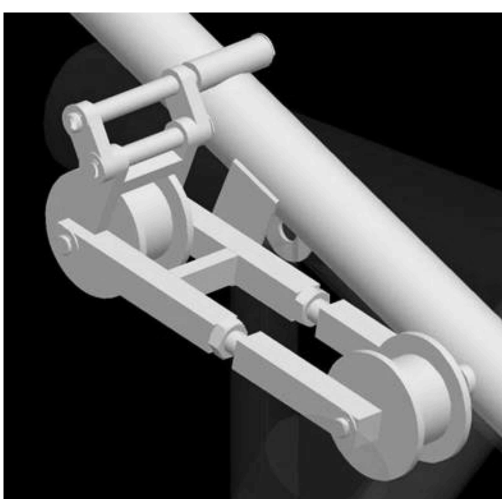


The **Hardhat** team used FEA to confirm their design will meet the ANSI/OSHA standard.

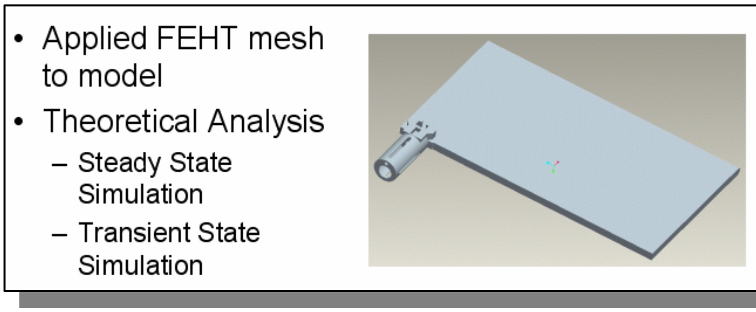


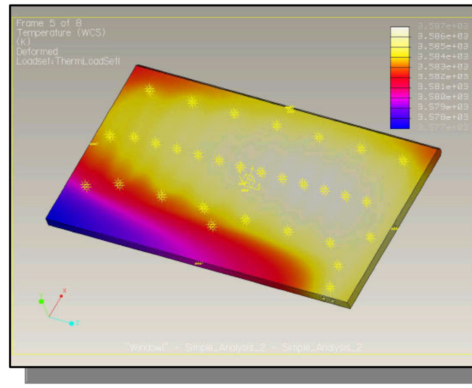


The **Kinetic Sculpture** team used FEA to improve their drive train mechanism.



The **Hot Plate** team did thermo analysis to improve a problem on an industrial hot plate for a local company.





Conclusions

This paper has presented the introductory undergraduate course on finite element theory and practice offered by the Mechanical and Manufacturing Engineering Technology department at Oregon Institute of Technology. In the past 15 years, this course has slowly evolved into the current format of an applied finite element analysis course. In this course, the fundamental finite element theory and mechanics of materials theory are strongly emphasized; this is to avoid the danger of using finite elements as a black box. The course is still an introductory level course that covers the basic finite element theory and practice. Basic knowledge about the physical behavior and usage of each element type, the ability to select a suitable element for a given problem, and the ability to interpret and verify finite element solution quality are all important topics covered in this course. The practical hands-on experience is also one of the main focuses for the course.

The increasing usage of FEA in the capstone student projects in the recent years is an encouraging indication that the applied finite element analysis course is achieving its goals. The need to better prepare the graduates with the skills to use modern engineering tools is becoming more critical as the computer technology continues to advance. The OIT-MET faculty plans to further improve the course, as the MET curriculium is constanly being improved and to keep up with the new changes in the FEA technology. And the discussions of offering additional FEA related courses, covering more advanced topics, have already begun.

Bibliography

Randy Shih is a Professor in the Mechanical and Manufacturing Engineering Technology Department at Oregon Institute of Technology. He worked as desing engineer in the automobile sector prior to starting his teaching career in 1984. He has over 20 years of experiences in the areas of CAD/CAE; and he is the author of ten CAD/CAE textbooks that are currently being used by many universities and colleges in North America.