Introducing Finite Element Analysis in an MET Strength of Materials Course

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Abstract

The MET Strength of Materials course at Southern Polytechnic (SPSU) was recently expanded from a four quarter-credit-hour (3-3-4) format to a four semester-credit-hour (3-3-4) format. One result of the increased instructional time available in the course was the addition of an introduction to the techniques of Finite Element Modeling (FEM) and Finite Element Analysis (FEA) for the stress analysis of objects and structures. The topics covered include FEM principles, element geometries, element types, material properties, boundary conditions, model loading, and accuracy and precision. These topics are discussed in lectures as well as in a series of exercises in which students model and analyze several different systems. Non-linear material models are introduced which show permanent deformations and residual stresses. The paper focuses on our successes, our less-than-successes, and our proposed plans for future development and improvement.

I. Introduction

The Mechanical Engineering Technology (MET) Department at Southern Polytechnic State University (SPSU) was forced to completely redesign its curriculum recently when the University System of Georgia converted from the quarter system to the semester system. As part of this conversion the system expanded its mandated core curriculum for all system institutions at the same time that it reduced the number of hours allowed in all baccalaureate degrees. The system maximum for all programs was set at 120 semester hours but the SPSU MET program was granted an exception based on ABET accreditation requirements and other program-specific factors. Even with the exception, the department was faced with the need to reduce the length of the program to 128 semester hours. Topics in Finite Element Analysis (FEA) were being taught as part of an upper-level elective course in computer applications but were not part of the required Strength of Materials course. It was decided to drop the elective course but to add some time to the Strength of Materials course to include FEA topics as an integral part of the required curriculum.

II. Content and Emphasis

Many FEA textbooks[1] introduce the topic by analyzing simple systems analytically, developing and solving the resulting systems of equations using traditional methods. Others focus on the underlying theory and use of a particular computer system [2]. Some even use fundamental principles to lead the student through writing application software [3]. We have chosen to concentrate more on developing the techniques required to use FEA as a tool for stress analysis in the design context. We were particularly interested in teaching the student to use these tools in subsequent courses such as Machine Design. A series of lectures was developed to introduce some of the basic principles and techniques and these lectures were followed by a series of exercises in which the students applied these techniques to a variety of problems. The exercises are executed using ALGOR FEA software which we provide in a computer laboratory with 14 Pentium III workstations.

The lectures, with accompanying handouts, cover such topics as meshing, element types, material definitions, boundary conditions, and loading. The meshing topics include element geometry (in both two and three dimensions), connectivity rules, and mesh density considerations. Earlier versions of the course included a manual meshing exercise to emphasize some of these topics. However, we subsequently determined that, due to improved automated meshing techniques, few of our graduates will ever be required to construct a manual mesh. Considerable emphasis is placed on the importance of using appropriate element types for the problem to be solved. The system provides a wide variety of element types ranging from simple truss elements to solid bricks. The system is also capable of modeling many different types of materials. The analysis can be either linear or non-linear with non-linearities arising from either large deflections or material properties. Composite materials can also be analyzed but are not covered in this course. The importance of using realistic boundary conditions is also emphasized by showing how poorly chosen boundary conditions can mask weaknesses in a part or assembly. Finally, techniques for applying different types of external loads and the use of different load cases on the same model are addressed.

III. Practice Exercises

Several of the exercises use tutorial materials provided by ALGOR while others have been developed locally. The ALGOR exercises are primarily focused on learning to use various aspects of the software and are key-stroke specific. The locally produced exercises use more general instructions and try to develop good analysis habits in the students. Each specific exercise is described in some detail below.

Ex. 1.Two-dimensional linear stress analysis:
In this exercise the students draw the profile of a plate using our CAD system (Bentley MicroStation), export it to ALGOR, create a surface mesh, define two-dimensional elements, apply boundary conditions, apply a uniformly distributed tension load, and analyze deflections and stresses in the model. This exercise demonstrates many of the topics addressed in the lectures and shows the student how to use many of the features of the ALGOR software while

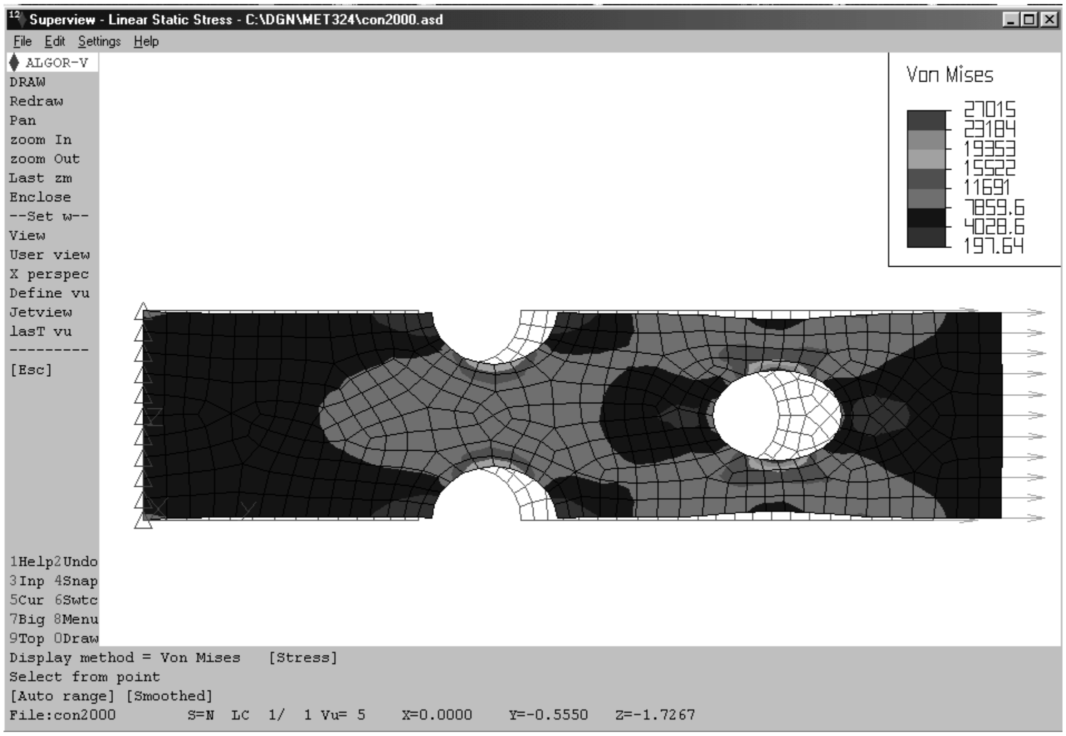

Figure 1. Linear stress analysis exercise.

solving a fairly straightforward stress analysis problem (similar stress analysis, but not deflection, calculations are done earlier in the course using stress concentration tables). Figure 1. shows the results of the stress analysis with the displaced model superimposed on the undisplaced model for comparison. The displacements are greatly exaggerated for ease of interpretation.

Ex. 2. Two-dimensional truss bridge model:
This exercise uses a tutorial provided by ALGOR. This tutorial, and many others, can be downloaded from their web site[4]. The tutorials are updated frequently to reflect the current release of the software and new tutorials are added when new capabilities are introduced. The model is a two-dimensional representation of a simple truss bridge and it introduces the use of different load cases to model a moving load.

Ex. 3. Two-dimensional beam frame model:
This is another of the ALGOR tutorials which introduces the use of beam elements to produce a 2-D frame. The tutorial also introduces the application of distributed loads on parts of the structure. The use of the system to generate shear and moment diagrams is also introduced in this exercise.

Ex. 4. The importance of boundary conditions:

We have used a couple of different approaches to demonstrate the importance of boundary conditions. One approach was to build a simple triangular frame with beam elements and apply different boundary conditions to the model subjected to the same loads. Both translational and rotational conditions are changed. The second approach is to apply different boundary conditions to the frame in the previous exercise. The ALGOR model happens to be over-constrained so that it easy to see the effect of removing unnecessary constraints on the model.

Ex. 5. A three-dimensional bicycle frame:
This is another ALGOR tutorial. In it, the students build a three-dimensional model of a bicycle frame modeling the tubes as beams. A variety of loads (including local moments) and boundary conditions are used to provide further experience in these areas.

Ex. 6. Nonlinear analysis:
The introduction to nonlinear analysis is provided by another ALGOR tutorial. In this exercise a simple two-dimensional cantilever beam is subjected to a load which exceeds the elastic limit of the material near the base of the cantilever. Removing the load then shows the permanent deformation and residual stresses which result from the overloading.

Ex. 7. Three-dimensional solid modeling:
The final exercise in the sequence is locally produced. The students produce a parametric solid model of a simple object for analysis. We have tried several different file formats for export of the model to ALGOR. We have settled on the technique of generating a stereolithography (.stl) file. This file is a triangular surface mesh which is easily handled by the ALGOR translator. This process makes the student start to think about the meshing process early in the exercise since choosing proper mesh parameters at this stage makes the subsequent process easier and more reliable. Once the model has been imported, mesh utilities in ALGOR are used to enhance the surface mesh and then to generate the solid mesh for analysis. The object is loaded by anchoring one end and by applying an eccentric, oblique load at a point on the other end. The stress tensor components are then used to display the results of the analysis. This model is shown in figure 2. Similar problems are also solved using manual methods in the course.

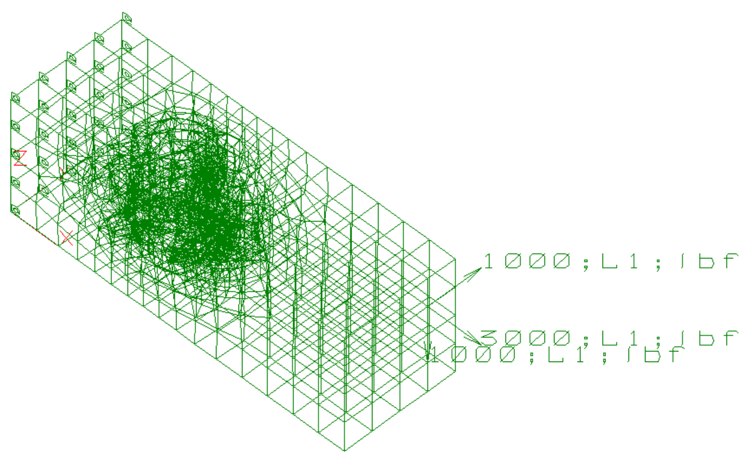

Figure 2. Completed solid model with forces and boundary conditions.

IV. Summary

We are generally satisfied with the content of the course as it has developed over the last several years. Students find the material interesting and are enthusiastic about learning these new techniques. Much work, however, remains to be done in developing the instructional materials used in the course. We need to do a better job of explaining the "why" of what we do along with the "what". This is particularly true of the ALGOR tutorials since they are primarily aimed at software training rather than instruction about the applications. Our experience with students in later courses indicates that they need more guidance in selecting appropriate boundary conditions and loadings to produce realistic models of mechanical systems. Our assessment indicates that students also need more help in correctly interpreting results and in applying information gained to produce better designs.

Bibliography

1. Logan, Daryl L. *A First Course in the Finite Element Method*. Boston: PWS-Kent (1992)

2. Moaveni, Saeed *Finite Element Analysis - Theory and Application with ANSYS.* Upper Saddle River, New Jersey: Prentice-Hall (1999)

3. Chandrupatla, Tirupathi R. and Belegundu, Ashok D. *Introduction to Finite Elements in Engineering.* Upper Saddle River, New Jersey: Prentice-Hall (1997)

4.URL: http://www.algor.com/homepag2.htm

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