Teaching Finite Element Analysis to Second Year Students

Marshall F. Coyle, Ph.D., P.E., Christal G. Keel
Pennsylvania State University – York

Abstract:

Finite element analysis (FEA) is a powerful analytical tool used to evaluate structural, dynamic, thermal, fluid, and electrical engineering problems. In the past, only specialists with access to mainframes conducted finite element analyses due to the massive processing power required. However, the recent advances in microcomputer technology allow this processing capability to be available to virtually anyone. Engineering students can now solve complex problems that would not be feasible or practical to solve by hand at a much earlier point in the curriculum. Still, a person using FEA software who does not have a clear understanding of the basic engineering concepts could obtain erroneous solutions, leading to a detrimental outcome. This paper discusses the justification for offering FEA to second year students, as opposed to the current fourth-year placement we see most often. Included are examples of exercises that will attempt to reinforce to the student the importance of rigorous attention to the fundamental engineering concepts crucial to any analysis.

I. Introduction

Finite element analysis software allows us to simulate the performance of a structure or component. Analyses can be conducted on structures of practically any geometry, with countless degrees of freedom.[1,2,3] Because of the recent advances in the user interface of many FEA packages, it is now practical for students with only a basic knowledge of FEA and the principles of mechanics to conduct complex analyses.[2] The availability of tutorials, workbooks, and online support contribute to a user-friendly environment for the student. [4,5]

Until now, most introductory courses in finite elements have been offered to engineering students in the fourth year of study, with more advanced theory or application being reserved for graduate programs. However, some engineering professors believe that the time has come to introduce this technology much earlier in the curriculum. In the beginning, care must be taken to ensure that the student has a firm understanding of Statics and Strength of Materials. Using finite element analysis as a tool, teachers can enhance the comprehension of these courses, as well as stress proper planning of a problem and setting reasonable expectations as to the outcome.[2] Seeing the physical representation of these basic theories can lead to an increased appreciation for the student of forces, boundary conditions, and the significance of material properties.[6] Applying a finite element analysis to a common truss problem, for example, can help the student visualize the analysis in a way previously not possible, as well as demonstrate the importance of boundary conditions and how they can affect the solution.

II. Present Trend

In an effort to get a general feel for when (and if) FEA is being taught in engineering programs, an informal survey was conducted. This survey was administered using an engineering technology list server containing roughly 2,000 people, representing over 500 educational institutions, along with a list of people recognized as experts in the finite element analysis field.[7] The survey asked educators 1) whether they currently offered finite element analysis in their curriculum, 2) when it was presented, 3) whether it was an elective, and 4) which discipline they taught.

Even though the response was small (18 responses), we feel that it reflects the current trend toward FEA being offered in engineering programs. The results indicate that roughly 78% of the universities currently offer the FEA course in the junior or senior level of a four-year program. In roughly half of these colleges, FEA was offered as an elective. A finite element analysis course was offered in virtually all of the mechanical and mechanical technology programs, and most of the civil engineering curriculums. Curiously, only a few responses related to structural engineering programs offered finite element analysis courses. The prerequisites varied slightly from one discipline to the other: mechanical programs required Strength of Materials and/or Statics in 85% of the cases. Other fields emphasized more engineering math and some computer aided design (CAD) exposure.

III. Why Introduce FEA Early In The Curriculum?

It is typical for Mechanical Engineering disciplines to teach Statics and Strength of Materials early in the curriculum. For many students, visualizing what is actually happening within a structure is a common problem, particularly in 3-D situations. Using finite element analysis not only allows the student to *see* the resulting stresses and deformations, but also serves to emphasize the critical nature of applying proper boundary conditions when solving a problem.

The assumptions made in Strength of Materials' beam problems regarding stress and strain distributions can now be seen in a visually dramatic way. A typical Statics example is a truss beam problem utilizing the assumption that all members are two force members joined by frictionless pins. By reproducing the truss beam using finite element analysis software, the student can prove that this assumption is valid. Finite element analysis can also be used to verify the hand calculations the student has performed on a problem. Until now, the perception has been that the FEA was solely the province of specialists.[2] However, the rapid expansion in the microprocessor technology, as well as the straightforward user interface of many finite element analysis packages, is causing a gradual change in this opinion. Home computers are powerful enough to rival the mainframes of just a few years ago. Many software manufacturers offer real-time online support, context-sensitive help, tutorials, and better documentation than was ever available before. Now, novice FEA users who understand the basic theories, methodologies, and pitfalls of finite element analysis can perform a useful and acceptable model. Engineers just entering the job market are being exposed to basic forms of FEA embedded in CAD packages in the form of behavioral modeling features. With the job market clamoring for entry-level engineers, it becomes even more imperative that students be exposed to finite element analysis as early as is practical.

The fact is that FEA may not be effortless, but it is presented in a more straightforward manner than it has ever been before. However, we cannot allow this fact to lead us to underestimate the complexity of the technology. Obtaining a good looking model with applied loads in no way decreases the need to *understand* the problem being approached or the impact of the assumptions used to build it. Obtaining an attractive looking mesh may be relatively trouble-free, but in no way guarantees us an accurate analysis. Obtaining a solution with the press of a few buttons may be tremendously satisfying, but cannot deliver a true understanding of the workings of the technology. Finally, obtaining a result is only half the battle: interpreting the result and having the skill to know whether it makes *sense* will be the real benchmark of a finite element analysis.

IV. Methods Used to Present FEA To Students

Most schools place Statics in the first or second year of a mechanical engineering program. It is assumed that a fundamental math and physics background has been acquired to understand the basic principles of Newtonian mechanics. The concepts of free body diagrams, forces, and reactions must be well understood at this stage. Ideally, the student will have had some introduction into the analysis of structures and the forces in beams. It would be best if these principals were reviewed to ensure that the class, as a whole, is up to speed and can proceed at the same level. This is where the FEA will begin to enhance the classroom activities. Quite often, the student has had some introductory courses in CAD, so a short primer on the basic navigation of your specific FEA software should be sufficient. This kind of “hands-on” approach to the software allows the student to become comfortable with the software.

During this introduction, call attention to the three phases of conducting a finite element analysis: preprocessing, solution, and post-processing. Also, at this time, the building blocks of finite element models (nodes and elements) should be explained. The next step is to begin with a basic problem, model it in the finite element software, and compare the FEA solution with an analytical solution. The 2-D axial loaded rod shown in Figure 1 illustrates a good initial finite element analysis exercise. This exercise demonstrates Strength of Materials concepts along with introducing the students to FEA.

In this example, Figure 1, the rod is broken up into three segments (elements) having various lengths (l_i) and cross-sectional areas (A_i). The boundary conditions at node 4 can be altered by either applying a load (P) or displacement (uy) along with applying a change in temperature (ΔT) to the model. The materials properties, such as Young’s Modulus (E_i) and coefficient of thermal expansion (α_i), may also be varied.

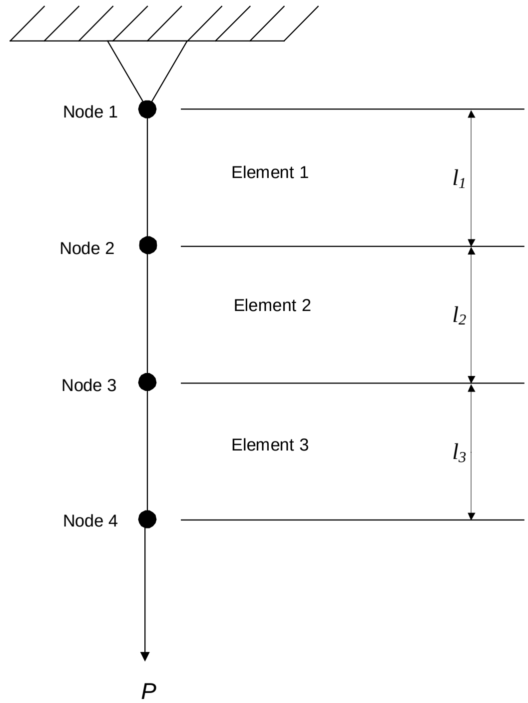

Figure 1: 2-D Axially Loaded Rod.

The student is required to validate his or her modeling techniques by comparing the FEA results with the following Strength of Material equations:

$$\sigma_i = F_i/A_i$$
$$\delta_i = (F_i\, l_i)/(A_i\, E_i) + \alpha_i\, \Delta T\, l_i$$
$$\varepsilon_i = \delta_i\, /\, l_i$$
$$\sigma_i = E_i(\varepsilon_i\ -\ \alpha_i\, \Delta T)$$

The variables should be initially set to yield solutions that are relatively computationally easy; i.e., $A_i = A$, $E_i = E$, $\alpha_i = \alpha$, and $\Delta T = 0$. Then alter the model in a step-by-step fashion, demonstrating how changing the variables and boundary conditions affect the results. Finally, change the variables and boundary conditions in a manner to make the solution computationally difficult. For example, restrain the rod from expanding, apply a change in temperature, and let each element have different areas and material properties. At this point, most second year students will not be able to solve this problem by hand. However, from previous solutions they should have a physical feel for the problem and be able to analyze the results to determine if they make sense.

Another useful exercise can be to perform a static analysis of a universal truss structure, such as the Warren Truss illustrated in Figure 2.

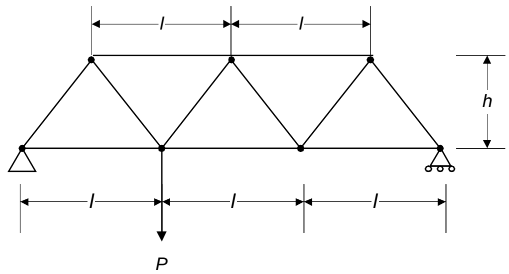

Figure 2: Warren Truss.

Students typically encounter some manner of truss problem in their first Statics class, accompanied by the standard truss assumption; i.e., that all the joints are smooth, frictionless pins. However, anyone can tell by looking at an *actual* truss structure that this is not the case and this discrepancy often confuses many students and shrouds the process with suspicion. Have the students first model the truss using link elements and then model the same structure as a frame using beam elements. It can clearly be shown that the difference between the two results is negligible. This method serves to validate the general truss assumptions as well as to alleviate the tendency of some students to question every supposition.

Engineering students are usually exposed to concepts such as Saint-Venants' Principle, stress/strain distributions, and stress concentration factors. Contour plots from FEA of solid models can vividly demonstrate these concepts

V. Conclusions

Graduating engineers who stay in the engineering field will eventually find themselves involved with FEA. The impressive graphical and animation features associated with FEA programs can enhance a students' physical feel for structural problems. The student can visually see the effects of varying the boundary conditions. FEA can also demonstrate or validate common assumptions engineers use to simplify calculations. FEA can be used as a primer or virtual lab for a Strength of Materials class; however, using finite element software without really appreciating the fundamental engineering tenets can result in profoundly misleading or inaccurate solutions. Therefore, it is important that the student has a keen awareness of the power and potential misuse of FEA.

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MARSHALL F. COYLE
Registered Professional Engineer, B.S. Civil Engineering from Virginia Military Institute, 1976, M.E. Mechanical Engineering from The University of Virginia, 1978, and Ph.D. Mechanical and Aerospace Engineering from The University of Virginia, 1995. Presently Assistant Professor at Pennsylvania State University-York.

CHRISTAL G. KEEL
Received Associate degrees in Electrical Engineering Technology (1999) and Mechanical Engineering (2000) from Pennsylvania State University- York. Currently employed as a Mechanical Engineer consultant for Ciber, Inc. Melbourne, FL.