

Introducing Finite Element Analysis in Statics

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Abstract

When new technologies are developed, often they are introduced to engineering and technology students at the upper baccalaureate or graduate level. Over time, as the technologies mature, they are introduced to students and used by students earlier in the educational process. Such is the case with finite element analysis (FEA). FEA up to now generally has been introduced to engineering and technology students at the junior or senior level. Recently, associate degree graduates with exposure to FEA have been in demand by some industries. The sophistication and relative user-friendliness of modern modeling and analysis software has made it possible for an early introduction of FEA. This paper relates the experience and advantages of introducing FEA in a Statics course. The application of FEA was used to verify manual calculations and help predict if failure would occur where expected and in an expected mode. Through the analysis, build, and test process the students gained an appreciation for the power and limitations of FEA. Students also gained a first use experience that serves as a foundation for more sophisticated models and analysis for FEA use in future courses.

Introduction

Finite element analysis (FEA) has become a major tool in the design or redesign of many mechanical devices. As with many technical tools, as industry starts using the tools, engineering schools introduce these same tools in the graduate or upper baccalaureate-level work. Over time these tools trickle down to the middle baccalaureate and finally associate-level education. This trickle-down is a function of two concurring events. First, the tool becomes easier to understand and use. Second, industry uses the tool for more applications and more complex applications. The use of FEA is following this pattern. For example, in Indiana, the automotive industry uses FEA for almost all design and failure analysis. This, in turn, has created a demand for AS and BS graduates with FEA experience. This trend exists elsewhere as suggested by Boronkay and Dave¹.

In an attempt to provide students with a useful FEA exposure, initial educational experience with FEA should occur as early as possible in a technical program to allow for other FEA assignments throughout the degree program. Statics is the first technical course for both mechanical engineering and mechanical engineering technology students and is therefore the logical place to introduce FEA. In previous papers the author has discussed the truss design, build, and test project that he incorporates into his Statics class². This paper will detail how FEA was added to the design project and the results of two classes' experiences.

The Project

The truss project used to be assigned about week eleven of a fifteen-week semester and required the students to work in pairs. Each student team was to design a truss to span thirty inches between supports and support a centrally-applied load. The truss was to be built of a pack of materials including twelve feet of half-inch diameter 6061T3 tubing, one sixteenth-inch 6061T3 sheet for gusset plates and 3/16-inch aluminum rivets (one rivet per member per joint). There were two basic goals for the project. First, the students were to predict accurately the failure load (material strengths were given) and where failure would occur. Second, the teams were to design an efficient structure as defined by the maximum supported load divided by the truss' weight. More specifics of the assignment may be found in Pike².

When the FEA aspect was added, two alterations to the basic project were made. First, since work was added, the assignment was started in week nine to allow for more work time. Second, a progress report, collected in week twelve, included the truss design (drawn using CAD) and manual calculations using the classical methods of Method of Joints and Method of Sections to determine the maximum supportable load. The material packs were distributed to the teams after this progress report was graded. A 2-D FEA analysis was to be done during the construction of the truss to perform a check of the manual calculations and determine if any of the truss members would buckle. A 2-D analysis was performed based on the assumption that since the structure was planer and all loads were in the same plane as the structure, there would be no 3-D effects of consequence. Limited buckling information was given in the initial assignment. Therefore, this last analysis was critical to verify the design since buckling analysis is beyond Statics students' abilities.

Introducing FEA

Since this was the first time the students had seen FEA, special attention was given to the method of introducing FEA to the students, aiding the students in performing their analysis, and educating the students on the potential problems in building an accurate model and in correct interpretation of the results. The students first saw the use of FEA during the class meeting that introduced the truss project. There was a short lecture on the mathematics of calculating forces and deflections given geometry, constraints, and loads. This lecture was accompanied by a handout outlining the same information.

After the lecture, three demonstrations were performed going through the complete analysis cycle of model definition, analysis, and obtaining results. The first demonstration was a simple truss. The second demonstration was a more complex truss. A fabric sheet held at the edges with a weighted ball in the center was modeled for the last demonstration. The first two demonstrations were done so that the students could see cases similar to what they were expected to analyze. The last demonstration was to show the power of the software to analyze a geometrically simple but analytically complex system.

At the end of this class, a second handout was given to the students which included a step-by-step and command-by-command list of the second demonstration. This listing also included editorial notes giving reasons for each step and what general aspect of model definition each

group of steps were defining. The second demonstration was repeated so that the students could follow the command list for better understanding.

Using FEA and Project Results

Purdue University School of Technology uses COSMOS® for all its FEA work. COSMOS® is easy to use with a good user interface to create models and excellent post-processing capabilities to obtain results. The students had varying ease using COSMOS®. The author made himself available to answer questions and assist with the analysis as needed. Some groups needed no help while others needed some help mainly with defining the model. In general, the students verified that their manual calculations matched FEA results. The students also determined that no individual truss member would buckle. These results raised the confidence that the students' designs would meet the goals initially defined.

As always, during the testing of the trusses, all the trusses buckle out of plane at very light loads. A steel C-channel was used to constrain the truss and remove 3-D effects and more closely match the assumptions used in all calculations. Of the two classes that have gone through the project, all trusses failed at or slightly above the calculated maximum loads. The out-of-plane buckling was discussed after the testing as to why it occurred and why the FEA process did not predict that buckling would occur. This led to a discussion about the importance of analysis assumptions and the impact they will have on the final FEA results. The trusses were inherently 3-D objects though they were built, analyzed and loaded in a 2-D plane. Since a 2-D assumption was used for the FEA calculations, the third dimensional effects would not be calculated. This discussion was broadened to cover careful choice of element type, the care that must be taken to model the physical world problem appropriately, and the correct interpretation of results.

Conclusion

Was the exercise worthwhile? From an instructor's perspective: yes. All the students received a good practical example of using FEA to solve a structural problem. In addition, the results of the manual calculations and the FEA calculations were verified by testing a physical model. Lastly, the exercise gave the students a good background in the basics of FEA, potential problems, and care one must take in building the model and interpreting the results.

From a student's perspective, this exercise was also a success. All students commented that they were pleasantly surprised with the ease of using the FEA software. The FEA process gave them more confidence in the potential success of their truss design. Many students expressed a desire to learn more about using FEA, from both a pure technical interest and a marketable skill point of view. Overall, adding the FEA aspect to the original design project was an educational and practical modification.

Bibliography

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