Computer Assisted Tools for Stress Analysis of Structural Components in Engineering Technology

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Abstract
A computer based module for stress analysis has been developed to enhance student learning in the field of mechanical design and analysis. The tool is comprised of programmed templates containing an open-ended structure for the stress analysis of structural and mechanical components. Using the templates, students are able to formulate their problems and develop their own equation sequences. To reduce the need for programming and increase the flexibility of the learning tool, commercial symbolic-manipulation software (e.g. Mathcad) is utilized for the calculations performed in the module. The module is available either as an application module or on the web for the students of specific courses in the subject area. The tool allows for faster solution of a problem, experimentation with the effect of various parameters of a problem on its solution, and graphical visualization. It is expected to generate greater student interest in the subject, resulting in better understanding of the underlying theories and principles. Additionally, it will enhance computer skills for solving technical problems, as sought by the industry and required by program accrediting agencies.

1. Introduction
Stress analysis is an integral part of the undergraduate mechanical design courses in both engineering and engineering technology programs. In the design analysis area of engineering programs students are taught the fundamental concepts related to stresses in mechanical components and their innovative applications. Students utilize their learning to formulate problems and analyze stresses for creative design purposes. On the other hand in technology programs, the focus is on utilizing efficient techniques for analysis of an existing designs to address a specific problem, and modify or improve the design. Therefore, the emphasis is mainly on mastering the routine techniques rather than creative solution of a problem. But, without the theoretical foundation, such techniques alone cannot ensure successful completion of a task. From experience it is found that in
technology programs, students tend to avoid topics involving detailed theoretical concepts. In the engineering technology programs, after learning the fundamental principles of statics and concepts of stress [1,2], students are engaged in problem solving methods related to stress and deformation of mechanical components. Later, students with this problem solving skill are introduced to the use of finite element packages for further analysis of complex problems. The goal is to prepare students to solve real life design and analysis problems in industry. Besides using these routine techniques, industries would utilize specific computer tools or customized commercial packages to solve specific design and analysis problems. Therefore, graduates are expected to be proficient in formulating a solution method, developing or selecting appropriate solution tools, and using the tools to solve such problems efficiently. In this paper we are presenting a computer-assisted tool developed to enhance student learning of the overall stress analysis procedure practiced in a class for design of machine and structural components. The tool leads the students step by step from initial problem specification to computation of the principle stresses in a design process.

At Western Michigan University the topics of stress analysis are taught in two sequential classes. In the first course (Statics and Strength of Materials), students learn principles of statics, concepts of stress, axial and transverse forces, bending moment; normal, shear and torsional stresses for statically determinate problems. In the second course (Product and Machine Design), students utilize states of stress, principal stresses and deflections for the analysis of a variety of design problems. Currently, students practice this by manual solution, use of Excel, or a standard application program (e.g., Matlab) to solve problems requiring extensive computation. The objective of the methodology presented in this paper is to provide students a structured tool to guide them through the steps of problem formulation and solution. This will reinforce the methodology of stress analysis learned in the class and the solution of complex problems efficiently.

During the past decade, the introduction of computers has significantly reduced manual computation requirements in engineering technology classes. There are a number of computer-aided tools [3, 4, 5] available to help students formulate the problems, solve them, and even test their understanding of subject matter. Most of these tools are accompanied by graphics to present the problem and its solution. Philpot [3] showed the use of commercially available MDSolids system for developing and solving a variety of mechanics of materials problems. Ressler [4] developed “Visual Stress Transformer,” a Visual Basic program to animate stress transformations in a strength of materials class. Prusak [6] showed available commercial software such as Working Model [7] and spreadsheet to enhance student learning. Each of the tools has some novel feature that can be beneficial in specific situation, but requires a prior background in computer applications for their efficient use.

In general, these application tools can be classified in two categories, (a) commercially available software adapted for specific curriculum requirement and (b) application programs developed in-house. The commercial software are versatile in nature and can be used to solve a variety of problems. Many of them linked to textbook problems with
instruction for usage. But they are expensive, require time to get acquainted with and above all the students cannot relate the theory with the problem solving techniques directly. On the other hand, tools developed in-house are simpler in nature, less expensive to develop and the students can learn the system faster. Since these tools directly apply the concepts related to the solution of a problem, students can see the application of the concepts and learn the subject more effectively. But they are not generalized in nature and are useful only for solution of the specific type of problems. In the following, a new tool is presented whose objective is to guide the students through solution methods used in the class and provide solutions without manual computations.

2. Stress Analysis Methodology

The developed Stress Analysis Module follows the standard methodology for stress analysis of structural components that is emphasized in the courses here at WMU, particularly the second course (Product Design). The methodology starts with the “Problem Definition” phase and goes all the way to the evaluation of the “Safety Factor” for a component. The methodology has been defined according to the following 10 steps:

(a) Problem Definition
(b) Free-Body Diagram
(c) Calculation of Reaction Forces
(d) Load Diagrams
(e) Location of Critical Cross-Sections and Critical Points
(f) Maximum Stresses at Critical Points
(g) State of Stress at Critical Points
(h) State of Stress at a given direction
(i) Principal Stresses and Maximum Shear
(j) Safety Factor

The significance of these steps is that the developed Stress Analysis Module can perform any of these steps as independent procedures or as part of the complete analysis of a component, thus giving the flexibility to the user to utilize the complete sequence or only a given subset of the methodology. This aspect is of great value to students because they can make use of a specific procedure to study and check the material and problems covered in lecture during a semester, or they can use the entire Module to do a complete stress analysis while they are working on lab projects, where they need to perform analysis and redesign tasks while putting systems together.

The module has been implemented in Mathcad, with the use of Visual Basic as a control console and to display options for graphical interface to visualize results. The type of problems that can be dealt with in the implemented module are generic statically-determined beam problems, which are the typical problems that students would need to solve as homework or as part of the lab projects. Straight beams, either simple supported, cantilever or over-hanging have been implemented so far. The use of this module does not require prior programming experience, and students can familiarize themselves with the tool by after a short demonstration.

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3. Implemented Module

The user of the Stress Analysis Module needs to run an executable Visual Basic (VB) program to start an analysis session. The initial selection will indicate the step(s) to be performed. The user has the option to perform a complete analysis (from Problem Definition to Safety Factor calculation), or specify any of the intermediate steps (e.g., obtain the Load Diagrams, Calculate Principal Stresses). The VB executable also contains the GUI (Graphical User Interface) for the methodology. Once inside the analysis methodology, the initial screen for Step (a) Problem Definition is displayed for the type of problem selected. Figure 1 shows the input screen for a simple-supported problem. The initial piece of information that is requested is general geometry (e.g., length – and units) and the number of loads of each type (e.g., point loads, distributed loads, applied moments).

![Initial screen for user interface during Problem Definition.](image_url)

Once that information has been provided, the student will start specifying the applied loads. This is a sequence of three loops, each one for the total number of loads of a given type. As each load is specified, the corresponding reaction forces and load diagrams are displayed (Figure 2). This step helps the student in understanding the modeling process and the effect of each additional load on the load diagrams. For the calculation that need to be performed for each load, the information is transferred to the Mathcad program. The Proceeding of the 2003 American Society for Engineering Education Annual Conference & Exposition Copyright © 2003, American Society for Engineering Education
transfer is transparent to the user and it is done through a text file. In Mathcad, the procedure is to apply the condition of equilibrium and to keep track of the data vectors that contain the information for reaction forces and load diagrams. By taking advantage of the symbolic manipulation features in Mathcad, the students have the capability to compare and check the equation formulated by the program for the solution of the problem against her/his own formulations. The most important aspect for the students in our first course is to have the ability to see the equations resulting from the application of the conditions of equilibrium as forces and are summed moments because it is a new concept for some of them. It is like having the professor or TA formulate the equations right in front of them. The equations formulated by the Module are the ones that are emphasized in class as most appropriate to solve the type of problem at hand. Therefore, the students are likely to have the same equations in their notes.

The equation generated is displayed on the top right corner of the interface window.

\[
\sum_{L=0}^{\infty} - \sum_{M_x} = 0
\]

\[
\sum_{M_y} = \sum_{V} = \sum_{H} = 0
\]

\[
T x = R x - P L - P T
\]

\[
M L x = \text{Total Moment about left support due to concentrated forces at}
\]

\[
M L x q = \text{Total Moment about left support due to distributed loads at}
\]

At this point, if the user has indicated that s/he only wants the Load Diagrams (typical case for our first course), the information is transferred back to the control module, where it will be displayed or can be printed out in tabular format. If the user is performing a complete analysis, the next steps for the calculation of induced and principal stresses, and its corresponding State of Stress, are carried out in the Mathcad software. The interface screen is very similar to the output window rendered when load diagrams are requested, with the addition of the information corresponding to the stresses being evaluated. The Module has the capability to determine the Critical Cross Section and calculate stresses at the potential Critical Points (e.g., extreme and neutral axis points), or the student can

Figure 2. Display of Reaction Forces, Formulation, and Load Diagrams.

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indicate a specific location where stresses need to be calculated (Figure 3). Once in the stress evaluation screen it is possible to look for stress transformations in order to determine the State of Stress at a given orientation, or the student can proceed with the analysis and request the State of Stress for the principal and maximum-shear orientations. The display of these State of Stress is shown in Figure 4.

Figure 3. Resulting Principal State of Stress for Critical Location.

Once the complete stress results are obtained, the student compares those results to the ones s/he calculated. If the analytical solution produced by the student differs from the computer solution, the student can locate the source of error by looking at the entire procedure in Mathcad, and then rectify until the two solutions are in agreement. The option to look at the equations being used for stress evaluation exits by scrolling in the Mathcad session window, but at this point there is no option to display partial results.

Experimentation by students ('what-if' scenarios) can be performed by redefining the input parameters. This capability exists on the initial screen where load conditions and geometry are being provided. The option does not exist, at this point, for intermediate problems when a complete analysis is being performed. By redefining the input parameters the students can investigate their effect on the resulting load diagrams, or location of critical points, or magnitude of stresses and ultimately on the Safety Factor. This experimentation and solution matching help the student to develop intuition on the cause-effect of the various parameters. This aspect is most useful in the lab session for

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our second course. In absence of such tool this learning would be achieved only after prolonged practices.

Figure 4. Resulting State of Stress for specified location.

4. Conclusions

The Stress Analysis Module presented here is designed to aid and facilitate the learning of equilibrium principle and stress analysis theories in Statics, Strength of Materials, and Design courses. The use of the new module will build student confidence in the application of theoretical concepts and the use of a computer tool for solving technical problems. It is expected that instead of only focusing on the formulation of equations and routine problem solving techniques, the student will be allowed to follow the procedures step-by-step, thus increasing their interest in a full understanding of the concepts by performing what-if analyses.

The use of symbolic manipulation tools allows students to check their formulations. Simultaneous study of the implemented methodology, integration of the use of computer tools, practice of exercise problems and experimentation with the design parameters is expected to improve student learning in this area of mechanics.
5. Bibliography


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