Advanced computer technology for better engineering productivity:

Computerized design analysis

by Dr. A. M. Elsaie

Revolutionary changes are taking place internationally in the areas of automotive, agricultural machinery, heavy construction and machine tool industries, through new structural analysis technology. General purpose computer programs have been developed and are widely used by organizations such as the Ontario Research Foundation, Sheridan Park, Mississauga, Ontario, to obtain solutions for a great variety of engineering problems involving these and other industries. Based on the finite element method of a structural analysis, this advanced technology is being applied to major productivity oriented projects such as turbines, pressure vessels, bridges and towers in addition to tank doors. A typical interactive graphics system used is a minicomputer-based data preparation facility.

THE concept of the finite element method was introduced in the 1940s. However, this powerful technique advanced significantly in 1956. In a paper entitled "Stiffness and Deflection Analyses of Complex Structures," the concept of modelling a complex mechanical structure as a collection of well-defined structural elements, such as beams, plates and shells, received much attention(1). The finite element method or simply, FEM, appeared first in 1960 in the aircraft industry. Computers available at that time did not provide the capability of solving a large size problem. However, simple structural components in the aircraft wing or füselage were analyzed successfully using FEM, and specific purpose computer programs were developed to solve classes of problems. The first book(2) in which three chapters were devoted to FEM, was published in 1965.

Most development activity centred not only in the generation of general purpose computer programs, but also in the development of more accurate elements and of sophisticated numerical methods of solving large sets of linear algebraic equations.

The second major milestone in the development of FEM has been the introduction of the third generation of digital computers. For the first time, the computer power required to solve complex engineering problems became available. Time sharing computers, which allowed for more efficient interaction with the engineers, and the faster solution of design problems at a reasonable cost, were also introduced. The enthusiasm of many analytical groups around the world was evident in the multitude of literature published. One of the first texts devoted entirely to FEM was written by Zienkiewicz(3) in 1967. It soon became a classic. Teaching finite element method in many schools of engineering moved from the post-graduate level to undergraduate courses.

The finite element method quickly gained recognition as a powerful design tool and engineers should be aware of this very effective technique.

What is FEM?

Considering the spring mass system shown in Fig. 1 the equation of equilibrium of this system can be written as

$$f = k.x$$

where f = force acting on the spring which equals the applied weight of the mass

k = stiffness of the spring

x = deflection of the mass.

The above equation is an equation into one unknown (one degree of freedom) which is the deflection in the vertical direction. A system of a beam supported on two springs, as shown in Fig. 2, has two degrees of freedom, which can be identified as the vertical deflection at the two springs.

Expanding this concept, any engineering component can be divided into a finite number of structural elements such as beams, plates, shells, and solids. The elements are assumed to be interconnected at common nodes. Depending upon the function of a component, each node has a number of degrees of freedom. For example, a node in a shell element may have six degrees of freedom, i.e. the deflections (Ux, Uy, Uz) and rotations (Rx, Ry, Rz) along three perpendicular axes as

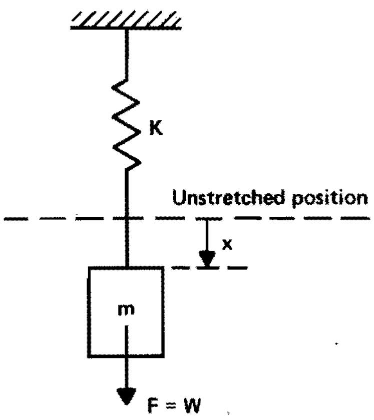

Fig. 1 — Spring-mass system.

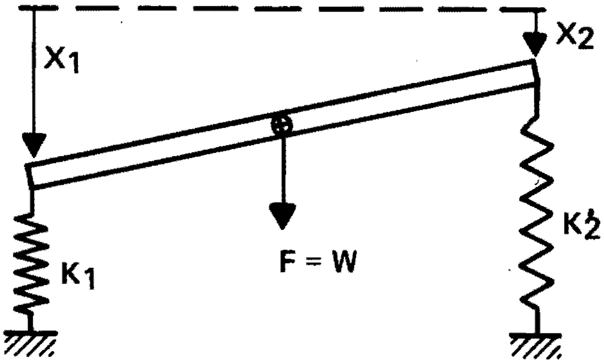

Fig. 2 — Two degrees of freedom system.

shown in Fig. 3. Any structural component can be divided into an infinite number of elements and nodes. This means that an infinite number of algebraic equations has to be solved, and this is naturally impossible. Consequently, the concept of representing a continuous structure by a model which approximates the behavior of the real structure, is equivalent to approximately representing the infinite number of elements by a finite number of elements. As such, the equations resulting from the FEM can be solved using a digital computer.

Generally, the equations established by the FEM are based on the matrix displacement method of structural analysis. The static problem may be expressed by the matrix equation

$$\{F\} = [K]\{X\}$$

The stiffness matrix [K] must be generated from a description of the geometric and physical properties of the structure. If the load vector $\{F\}$ is known, the computer busies itself in determining the unknown deflection vector $\{X\}$, from which the stresses and other quantities of interest can be calculated. Fig. 4 shows a finite element model of a turbine blade and shroud.

Applications of the finite element method cover a broad spectrum of engineering components with development extended to dynamic, stability, plastic, and heat transfer analysis. General purpose computer programs have been developed for use by design engineers.

FEM Procedure

The application of FEM to a typical problem is present in the flow chart, Fig. 5. The information is prepared for a finite element computer program by defining the three-dimensional location of nodes located on the structure. Elements are defined by specifying the interconnection of the nodes. Once defined, input information is checked by plotting the nodes and the elements defining the model. The input data are then modified and checked until the desired model is obtained. The engineer then determines the boundary conditions (support conditions and symmetry) and the loads to be used in the analysis. This information is combined with the nodes and elements data to perform the analysis. The final step is to review and evaluate both graphical and tabulated results of the analysis.

Generally, the powerful tool can be used to evaluate the performance of a new design or to offer design improvements for a failed structural component. Experience shows that introducing design changes to an existing structural or mechanical system could be more expensive than analyzing the system at the initial design stage.

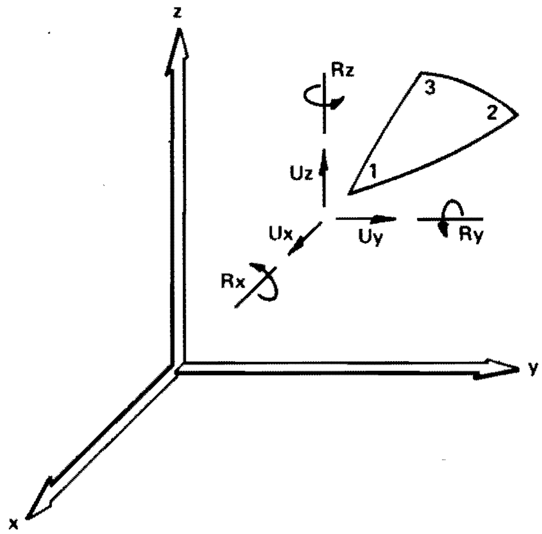

Fig. 3 — Degrees of freedom in shell elements.

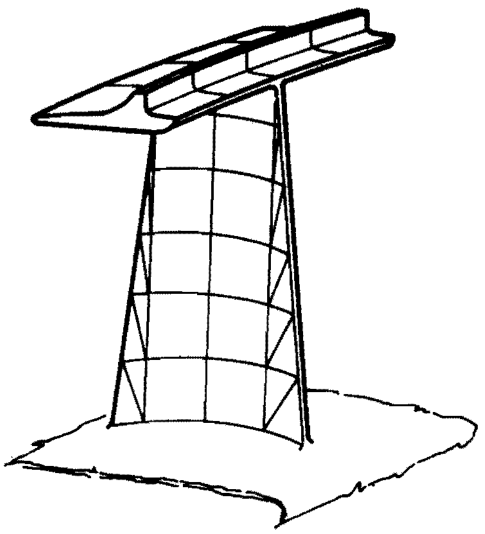

Fig. 4 — Turbine blade and shroud.

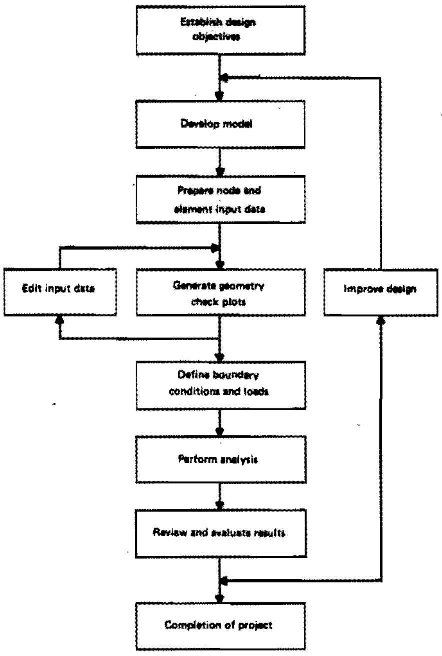

Fig. 5 — Typical finite element analysis procedure.

Interactive Graphics System

A promising approach to implementation of finite element data which saves a great deal of time is the interactive graphics system in operation at Ontario Research.

Here, the design engineer can check the computer model by literally seeing the model displayed in three-dimensional (isometric) form. In this way, the model data can be checked before execution in the computer saving both time and money.

Computer results can also be displayed on a graphic cathode ray tube in plotted form showing structural shapes and stress contours. A typical interactive graphics system for use in finite element model data is shown in Fig. 6. The system is a minicomputer based data preparation facility consisting of a graphics terminal tape and disc memory, graphic digitizer and plotter, line printer and data communications (telephone and acoustic coupler). The software installed in the system allows complete preparation of the finite element model without connection to the remote computer.

Node and element definitions are entered through the graphics terminal or digitizer, or by using the generation software of the system. The file can then be plotted locally to verify that the data have been correctly entered. When the model is satisfactorily compiled, the system automatically formats the data and transmits them to the remote computer for solution. Both the time required and the chances of error are reduced substantially when the system is employed for finite element file preparation.

Fig. 6 — HP interactive graphics system at ORF.

Recommendations

Requirements for the efficient utilization of computerized design analysis techniques involve trained engineering staff with extensive background in structural and solid mechanics, fluid mechanics and heat transfer. Besides an engineering staff computer hardware suitable for an interactive graphics system (graphics CRT, digitizer, hard copy unit, plotter and off-line data preparation devices) is also needed. Engineering staff of the Ontario Research Foundation can also assist industry and consultants in the use of these graphic display oriented computer programs to obtain solutions to complex design problems.

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References

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