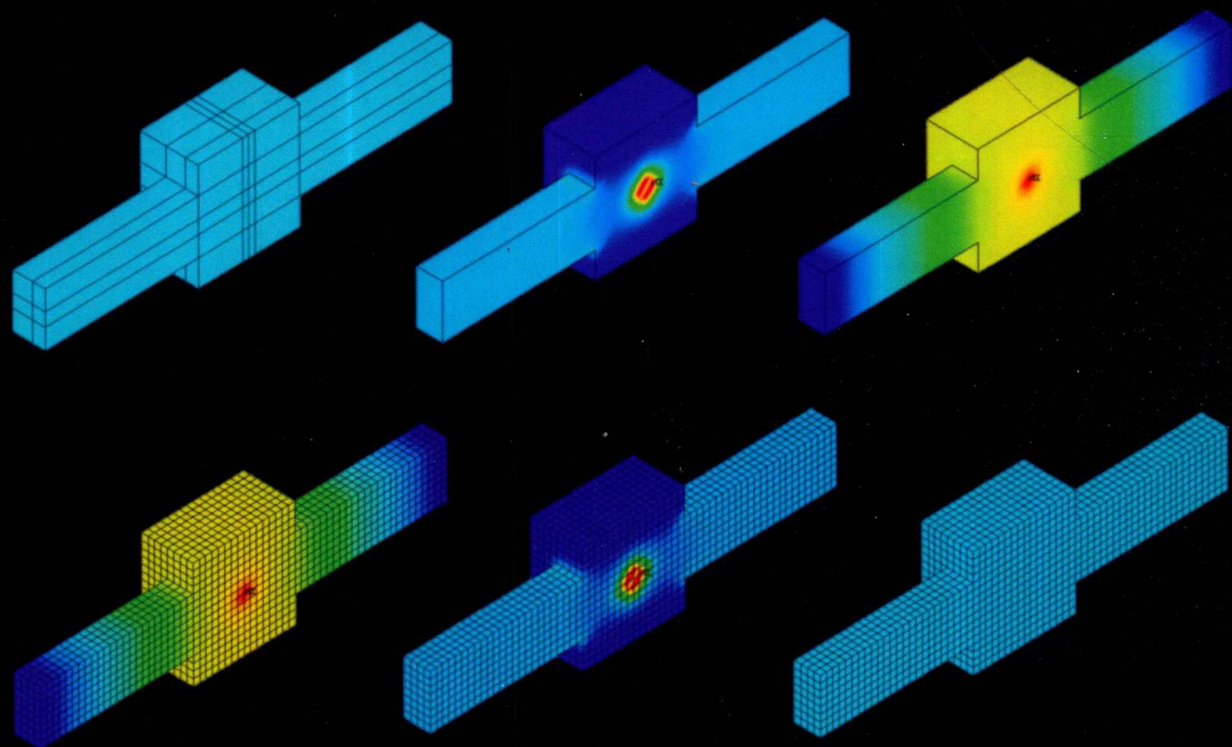
ANSYS Mechanical APDL for Finite Element Analysis



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ANSYS Mechanical APDL for Finite Element Analysis

To Veronica

Mother, Wife, Inspiration

Preface

Commercial finite element programs provide a powerful and extensive collection of tools for the design, analysis, and optimization of complex engineering systems. Unfortunately, learning to use finite element software can be a difficult and time-consuming process. This book was written to reduce the learning curve associated with ANSYS Mechanical APDL and to prepare you to use the program and its documentation as quickly and painlessly as possible.

This book was written using the Academic Research version of ANSYS Mechanical APDL 17.2. Since ANSYS Mechanical APDL was designed to be backward compatible, you should be able to use the book with future versions of the program as well.

We have marked information in the book that we believe is likely to become out of date quickly, such as specific product names and the number of reference manuals for a given product, with a superscript asterisk (*) for your reference. An appendix has also been included to help you to identify specific information in the program documentation, even if the documentation numbering changes. However, the authors of this book are not involved with changes that may be made in the future to the ANSYS Mechanical APDL software or the related documentation. Therefore the asterisks and appendix are for guidance only and may not identify all future changes in such software or documentation.

Each chapter in the book includes suggested readings from the ANSYS Mechanical APDL user manuals. Most chapters are also accompanied by one or more hands-on exercises. This book does not duplicate or replace the information in the documentation. Instead, it is intended to help you to understand and use the documentation. Thus the reading assignments in the ANSYS user manuals are strongly recommended. To help you develop comfort and confidence as an independent analyst, each exercise introduces new skills and increases the complexity of the models while gradually decreasing the amount of guidance given. We recommend completing all of the exercises, even if they are not immediately relevant to your work.

This book can be used for self-study or as part of a formal course in finite element applications. It is suitable for professional engineers and engineering students at all levels. When you have finished the book, you should be able to use the present ANSYS documentation to build, solve, and postprocess sophisticated finite element models on your own.

The world is full of interesting and important problems. This book gives you some of the tools that you need to help solve them. Good luck!

Mary Kathryn Thompson and John M. Thompson
Pittsburgh, PA, USA

Acknowledgments

This book was originally developed as the course text for a graduate level IAP course at the Massachusetts Institute of Technology (MIT). The goal of that course was to prepare students to perform research quality finite element analyses with ANSYS in 5 days or less. We began writing in 2002 and began teaching with the book in 2004. In 2008 the book and the course moved to Korea. In 2012 the book moved to Denmark. And in 2016 it moved home again to the United States. Over the years, we have received a tremendous amount of support from wonderful people all over the world. We would like to acknowledge some of them here.

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Chapter

1

Introduction to ANSYS and Finite Element Modeling

Suggested Reading Assignments:
None

CHAPTER OUTLINE

1.1 What Is the Finite Element Method?
1.2 Why Use the Finite Element Method?
1.3 Basic Procedure for Finite Element Analysis
1.4 Engineering Software—Not an Engineer
1.5 A Brief History of ANSYS and Finite Element Analysis
1.6 ANSYS Today*
1.7 ANSYS Licensing
1.8 Functionality and Features of the ANSYS Mechanical APDL Family
1.9 ANSYS: Backward Compatibility and Legacy Code

This chapter provides an introduction to finite element analysis and the ANSYS Mechanical APDL family of software. It begins with an overview of the finite element method, its benefits, and its limitations. It summarizes the current ANSYS Mechanical APDL products and program capabilities. Finally, it describes the program's evolution and how that influences the use of ANSYS, Inc. products.

1.1. What Is the Finite Element Method?

The finite element method (FEM) is a mathematical technique for setting up and solving systems of partial differential (or integral) equations. In engineering, the finite element method is used to divide a system whose behavior cannot be predicted using closed form equations into small pieces, or elements, whose solution is known or can be approximated. The finite element method requires the system geometry to be defined by a number of points in space called nodes. Each node has a set of degrees of freedom (temperature, displacements, etc.) that can vary based on the inputs to the system. These nodes are connected by elements that define the mathematical interactions of the degrees of freedom (DOFs). For some elements, such as beams, the closed form solution is known. For other elements, such as continuum elements, the interaction among

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the degrees of freedom is estimated by a numerical integration over the element. All individual elements in the model are combined to create a set of equations that represent the system to be analyzed. Finally, these equations are solved to reveal useful information about the behavior of the system.

Just as a regular polygon approaches a perfect circle as the number of sides approaches infinity, a finite element model approaches a perfect representation of the system as the number of elements becomes infinite. Since it is impossible to divide the system into an infinite number of elements, the finite element method produces the exact solution to an approximation of the problem that you want to solve. When the number of elements becomes sufficiently large, the approximation becomes good enough to use for engineering analysis. However, this may increase the number of equations to be solved beyond the point where it is practical or desirable to solve them by hand. For this reason, the finite element method is associated with computer programs that set up, solve, and visualize the solutions of these large sets of equations for you.

1.2. Why Use the Finite Element Method?

The cost, in terms of the manpower and computer resources, required to set up and solve a finite element model for a simple problem like a cantilever beam is very high compared to the benefit. Simple problems can—and should—be solved with simple methods (or obtained from engineering handbooks). But not all problems are simple. For example, if a bridge is built using a simple truss supported by two piers, the deflections and stresses in the bridge can be found using information taught in an introductory statics and strength of materials class. But as the complexity of the truss increases, solving this problem using the engineering fundamentals becomes more difficult, leaving the analyst with long hours of error-prone calculations. As system complexity continues to increase, closed-form analysis rapidly becomes impossible. The real benefit of finite element analysis lies in the ability to solve arbitrarily complex problems for which analytical solutions are not available or which would be prohibitively time consuming and expensive to solve by hand.

1.3. Basic Procedure for Finite Element Analysis

There are 10 basic steps in any finite element analysis. First, the solid model geometry is created, the element type(s) and material properties are defined, and the solid model geometry is meshed to create the finite element model. In ANSYS, these steps are performed in the Preprocessor (PREP7). Next, loads and constraints are applied, solution options are defined, and the problem is solved. These steps are performed in the Solution processor (SOL). After the solution is ready, the results are plotted, viewed, and exported in one of the postprocessors (POST1 or POST26). Finally, the results are compared to first-order estimates, closed-form solutions, mathematical models, or experimental results to ensure that the output of the program is reasonable and as expected. (Processors will be addressed in more detail in chapter 2.)

/PREP7

1. Define the Solid Model Geometry
2. Select the Element Types
3. Define the Material Properties
4. Mesh

/SOLUTION

5. Define the Boundary Conditions
6. Define the Loads
7. Set the Solution Options
8. Solve

/POST1 or /POST26

9. Plot, View, and Export the Results
10. Compare and Verify the Results

It is sometimes possible to omit one or more steps. For example, the default solution options are often sufficient for a simple analysis. It is possible to perform some steps out of order. For example, the element types and material properties can be defined in either order. Similarly, the loads and boundary conditions can be defined in either order. It is occasionally necessary to perform these steps out of order. For example, solid model geometry is not required for a finite element analysis. When the nodes and elements are generated directly, the element type(s) must be specified before the geometry can be created. Finally, complicated analyses may involve multiple trips through one or more processors.

For simplicity, this 10-step procedure will be used in this book whenever possible.

1.4. Engineering Software—Not an Engineer

As with all computer programs, the quality of your results will depend on the quality of your model. This includes the accuracy of the material properties, the appropriateness of the material models, how closely the simulated geometry and loads match the actual geometry and loads, and the validity of the simplifications and assumptions made. Simply put, Garbage In = Garbage Out. Finite element software programs can be thought of as very sophisticated calculators that help you to analyze engineering systems that could not otherwise be evaluated. They integrate the section properties of the system with the material properties to generate the equations to be solved. They convert the applied loads to the appropriate forms and apply them to the specified DOFs. They solve the generated system of equations. And, they help you to visualize and understand the results. But a finite element program will not comment on the validity of any assumptions made in setting up the model as long as the laws of physics are not violated. It also will not ensure that you are using the correct laws of physics for a given problem. Any errors that the program reports will be associated with the use of the program, and not with the physical or analytical system. In addition, it will not provide any commentary on the quality or implications of the results. Finite element software is only a tool. In the end, you, and you alone, are responsible for determining whether or not the results of your finite element model can be used to make or justify engineering decisions.

1.5. A Brief History of ANSYS and Finite Element Analysis

The finite element method was first proposed in the early 1940s as a numerical technique for solving partial differential equations. At that time, a mesh of elements could be defined and the interaction of the elements could be used to create the system of equations to be solved. However, the system of equations still had to be solved by hand. This limitation rendered the finite element method an academic curiosity until the early 1960s when computers that could