

What Do Engineers and Architects Need to Know about Finite Element Methods?

Course Outline

Finite element method is a powerful engineering analysis tool. It has been widely used in engineering since it was introduced in the 1950s. This course presents the basic theory and simple application of the finite element method (FEM) along with the common FEM terminology. The emphasis of this course is the fundamental concepts of finite element analysis. A list of major commercial software using FEM is also presented in this course along with their features and capabilities. This course includes a multiple-choice quiz at the end, which is designed to enhance the understanding of course materials.

Learning Objectives

At the conclusion of this course, the student will:

1. Understand the concept of Finite Element Method (FEM);
2. Recognize the important role played by FEM in today's engineering world;
3. Understand matrix operations used in FEM;
4. Be familiar with the different types of finite elements;
5. Be familiar with the terminology used in FEM; and
6. Be able to use solve simple structural problems using FEM.

Course Content

In this course, there are many [hypertext links](#) to related information. The reader is encouraged to visit the content within these links to get familiar with the linked subject for better understanding of the course content.

What Are Finite Element Method (FEM) and Finite Element Analysis (FEA)?

Many engineering phenomena can be expressed by "governing equations" and "boundary conditions". The governing equations are often in the form of [partial differential equations](#) (PDE) or [ordinary differential equations](#) (ODE). From mathematical standpoint, [Finite Element Method](#) (FEM) is a [numerical method](#) used for solving a set of related [differential equations](#) such as

$$\frac{\partial \sigma_{xx}}{\partial x} + \frac{\partial \sigma_{xy}}{\partial y} + \frac{\partial \sigma_{zx}}{\partial z} + f_x = m\ddot{u}_x$$
$$\frac{\partial \sigma_{xy}}{\partial x} + \frac{\partial \sigma_{yy}}{\partial y} + \frac{\partial \sigma_{yz}}{\partial z} + f_y = m\ddot{u}_y$$
$$\frac{\partial \sigma_{zx}}{\partial x} + \frac{\partial \sigma_{yz}}{\partial y} + \frac{\partial \sigma_{zz}}{\partial z} + f_z = m\ddot{u}_z$$

From an engineering standpoint, the Finite Element Method (FEM) is a numerical method for solving a set of related equations by approximating continuous field variables as a set of field variables at discrete points (nodes). For structural problems, the related equations are equilibrium equations, and the field variables are nodal displacements and loads.

Finite element solutions are achieved by either eliminating the differential equation completely (steady state problems), or rendering the PDE into an equivalent [ordinary differential equation](#), which is then solved using standard techniques such as finite differences. Use of the FEM in engineering for the analysis of physical systems is commonly known as [finite element analysis](#).

Why Use FEM?

Many engineering problems have complicated geometry and boundary conditions, which makes it impossible to come up with [closed-form solution](#). Therefore, numerical methods such as the Finite Element Method, Finite Strip Method, [Finite Difference Method](#), [Finite Volume Method](#), [Boundary Element Method](#) and [Hybrid BE-FE Method](#) were introduced to provide approximate solutions to the complicated engineering problems through the use of a computer. Among the above-mentioned numerical methods, Finite Element Method is the most powerful and most popular, and often forms the core of many commercially available engineering analysis software.

Because the Finite Element Method can be adapted to problems of great complexity and unusual geometry using grid or mesh, it is an extremely powerful tool in the solution of critical problems in heat transfer, fluid mechanics, electrostatics, and structural and mechanical systems. Furthermore, the availability of fast and inexpensive computers allows engineers and architects to solve daily engineering problems in a straightforward manner using the finite element method.

Common Finite Element Terminology

Domain - In mathematics, a domain is a set of values of the independent variable for which a function is defined. In finite element analysis, a domain is a continuous system (region) over which the laws of physics govern. In structural engineering, a domain could be a beam or a complete building frame. In mechanical engineering, a domain could be a piece of machine parts or a thermal field.

Governing Equations - The governing equations for a system are the equations derived from the physics of the system. Many engineering systems can be described by governing equations, which determine the system's characteristics and behaviors.

Boundary Conditions - The boundary conditions are values of a function at the edge of the range of some of its variables. We need to know some of the boundary conditions in order to solve an engineering problem or to find an unknown function.

Element - An element is a portion of the problem domain, and is typically some simple shape like a triangle or quadrilateral in 2D; or tetrahedron or rectangular solid in 3D.

Node - A node is a point in the domain, and is often the vertex of several elements. A node is also called a nodal point.

Mesh (Grid) - The elements and nodes, together, form a mesh (grid), which is the central data structure in the FEA.

Mesh Generation - Most FEA software automatically generates refined grid or mesh to achieve more accurate results. For large scale or complex finite element analysis, it is often imperative for computers to generate finite element mesh automatically. There are many different algorithms for automatic mesh generation. Click [here](#) to see some automatically generated mesh samples.

