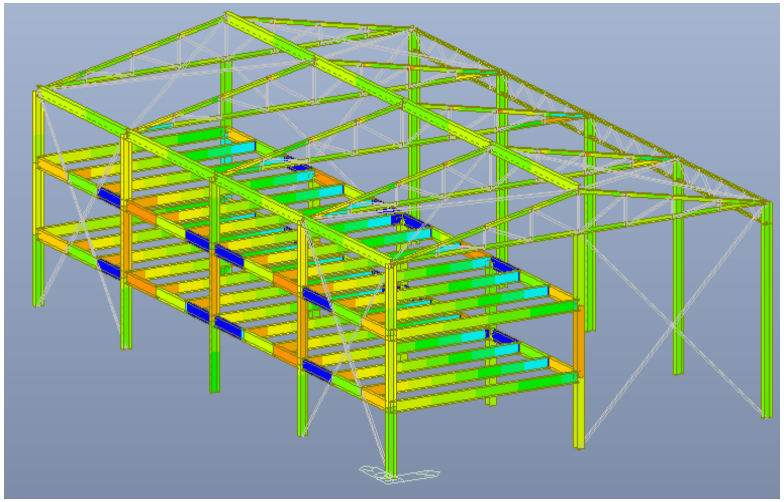
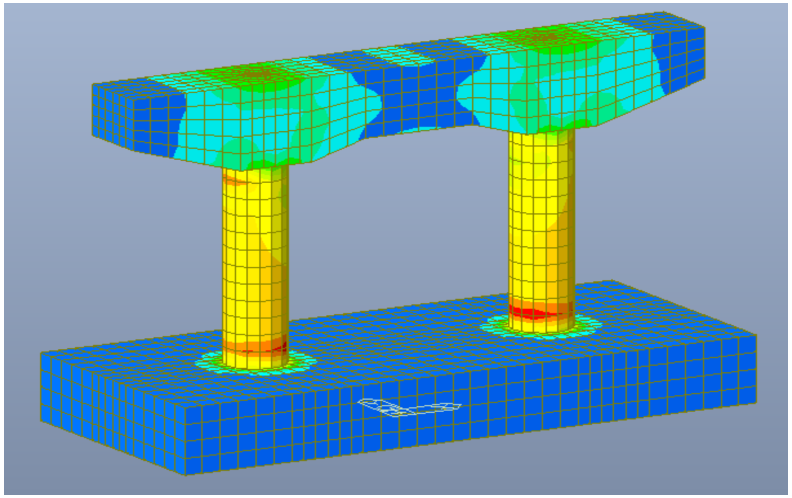
LECTURE # 1 INTRODUCTION





SE-501 STRUCTURAL ANALYSIS

DEPARTMENT OF CIVIL ENGINEERING
UET LAHORE

SE-501 STRUCTURAL ANALYSIS

Class Rules

Teachers/Instructors:

1. Prof. Dr. Asif Hameed
2. Dr. Ali Ahmed

Class Rules:

1. Attendance: You are expected in each class, Attendance less than 75% will attribute to the WF grade.
2. Participation: Class participation and discussion will be encouraged and have 5% marks.
3. Cell phone: Preferably don't bring in the class.

   However, the use of mobile phone during lecture are strictly not allowed.
4. You are expected to produce your own work
5. Assignments should be submitted in proper folder.

COURSE OUTLINE

Standard Stiffness Method:

Steps involved in the standard stiffness method for linear analysis of the following elements:

- Plane truss, space truss, Beam, plane frame, grillage and space frame elements.
- Computer software development for Pin-connected and Rigidly-connected 3-D elements
- Treatment of non-conforming joints, Condensation and sub-structuring techniques. Three-dimensional modeling of multistory building systems. Concept of symmetry. Super Members
- Introduction to numerical methods and solution techniques appropriate to discrete structural systems.

COURSE OUTLINE

Finite Element Method

Introduction to the method, Stationary Principles, the Rayleigh Ritz Method, and Interpolation. Displacement-Based Elements for Structural Mechanics. The Isoperimetric Formulation.

Weighted Residual Methods and the Finite Element Method. Numerical Error and Convergence in Finite Element Analysis

Assembly procedure for multiple ended members, Discretization of Elements, Development of Element Stiffness matrices for the following elements: Triangular and rectangular plane stress elements Triangular and rectangular plate bending elements.

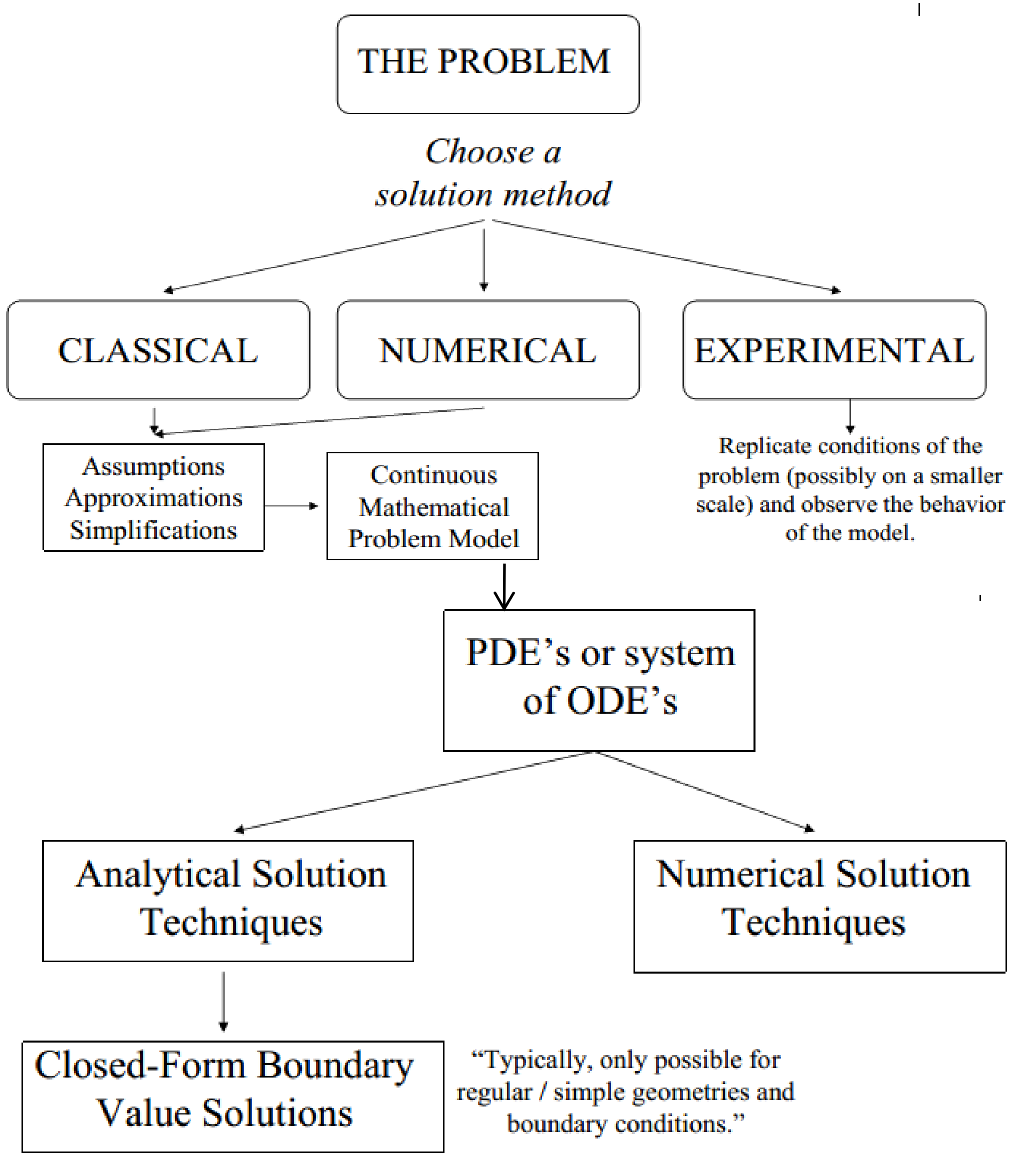
Assembly of plane stress and plate bending elements as a thin shell element.

3. **Introduction to approximate methods of analysis** for skeletal, continuum and composite space structures e.g. slab & shell analogies, Equivalent Energy Method and Girder Analogy etc.

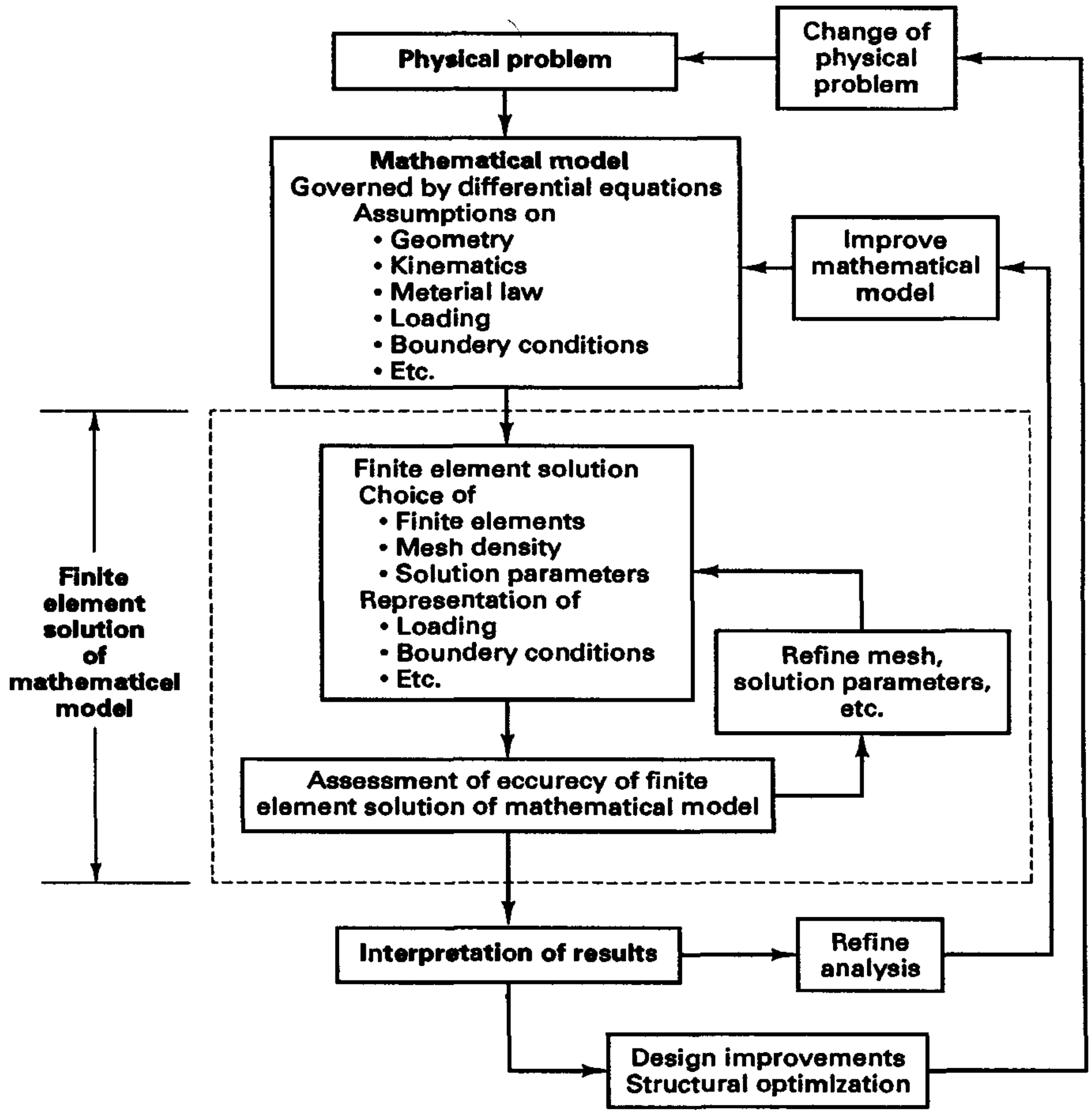
REFERENCE BOOKS

1. A First Course in the Finite Element Method Daryl L. Logan
2. Concepts and Applications of Finite Element Analysis Cook, Malkus, and Plesha
3. Fundamentals of Finite Element Analysis David V. Hutton
4. Finite Element Procedures By Bathe, 2nd Edition
5. Structural Analysis By Coates, Coutie and Kong.
6. The Finite Element Method: Volume-1 The Basis By Zienkiewicz and Taylor, 5th Edition
7. The Finite Element Method using MATLAB By Kwon and Bang

COMMON ANALYSIS METHODS



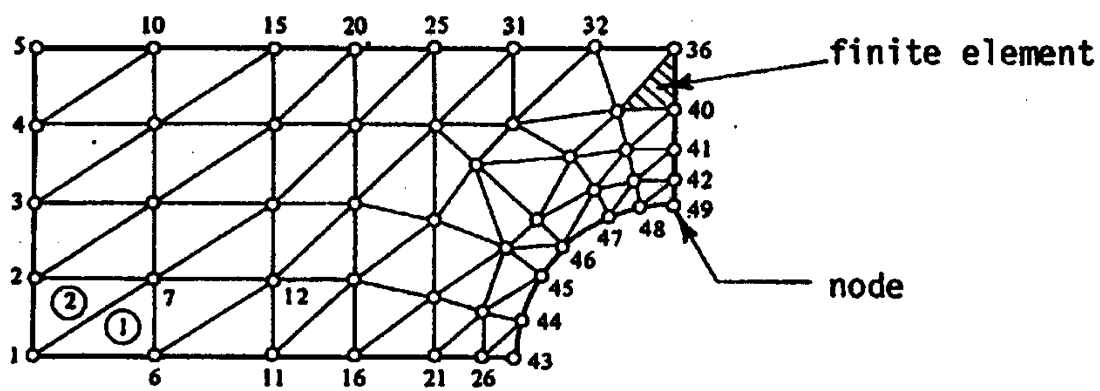
THE PROCESS OF FINITE ELEMENT ANALYSIS



FINITE ELEMENT ANALYSIS

The finite element method is a computational scheme to solve field problems in engineering and science.

The fundamental concept involves dividing the body under study into a finite number of pieces (subdomains) called *elements* (see Figure). Particular assumptions are then made on the variation of the unknown dependent variable(s) across each element using so-called *interpolation or approximation functions*. This approximated variation is quantified in terms of solution values at special element locations called *nodes*. Through this discretization process, the method sets up an algebraic system of equations for unknown nodal values which approximate the continuous solution. Because element size, shape and approximating scheme can be varied to suit the problem, the method can accurately simulate solutions to problems of complex geometry and loading and thus this technique has become a very useful and practical tool.



FINITE ELEMENT METHOD

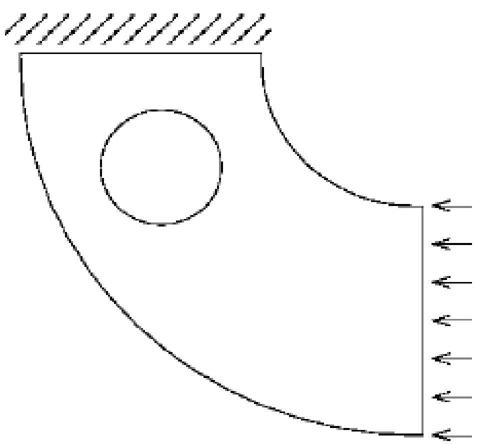
- Many problems in engineering and applied science are governed by differential or integral equations.
- The solutions to these equations would provide an exact, closed-form solution to the particular problem being studied.
- However, complexities in the geometry, properties and in the boundary conditions that are seen in most real-world problems usually means that an exact solution cannot be obtained or obtained in a reasonable amount of time.
- Current product design cycle times imply that engineers must obtain design solutions in a 'short' amount of time.
- They are content to obtain approximate solutions that can be readily obtained in a reasonable time frame, and with reasonable effort. The FEM is one such approximate solution technique.

FINITE ELEMENT METHOD

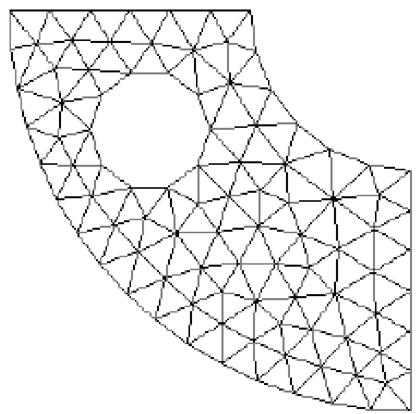
- THE FEM IS A NUMERICAL PROCEDURE FOR OBTAINING APPROXIMATE SOLUTIONS TO MANY OF THE PROBLEMS ENCOUNTERED IN ENGINEERING ANALYSIS.

- In the FEM, a complex region defining a continuum is discretized into simple geometric shapes called ***elements.***

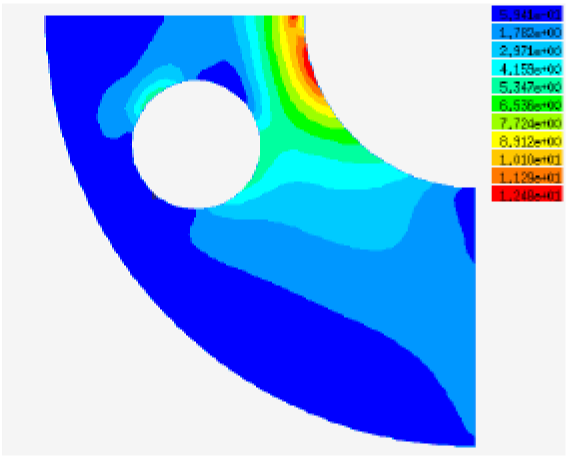
Problem, differential equations



Discretization using finite elements



Approximate, "weak" solution



FINITE ELEMENT METHOD

- The properties and the governing relationships are assumed over these elements and expressed mathematically in terms of unknown values at specific points in the elements called ***nodes.***
- An ***assembly process*** is used to link the individual elements to the given system. When the effects of loads and boundary conditions are considered, a set of linear or nonlinear algebraic equations is usually obtained.
- Solution of these equations gives the approximate behavior of the continuum or system.
- The continuum has an infinite number of degrees-of-freedom (DOF), while the discretized model has a finite number of DOF. This is the origin of the name, finite element method.

FINITE ELEMENT METHOD

- The number of equations is usually rather large for most real-world applications of the FEM, and requires the ***computational power of the digital computer***. ***THE FEM HAS LITTLE PRACTICAL VALUE IF THE DIGITAL COMPUTER WERE NOT AVAILABLE***.

- Advances in and ready availability of computers and software has brought the FEM within reach of engineers working in small industries, and even students.

ORIGINS OF THE FINITE ELEMENT METHOD

- It is difficult to document the exact origin of the FEM, because the basic concepts have evolved over a period of 150 or more years.
- The term finite element was first coined by Clough in 1960. In the early 1960s, engineers used the method for approximate solution of problems in stress analysis, fluid flow, heat transfer, and other areas.
- The first book on the FEM by Zienkiewicz and Chung was published in 1967.
- In the late 1960s and early 1970s, the FEM was applied to a wide variety of engineering problems.

ORIGINS OF THE FINITE ELEMENT METHOD

- The 1970s marked advances in mathematical treatments, including the development of new elements, and convergence studies.
- Most commercial FEM software packages originated in the 1970s (ABAQUS, ADINA, ANSYS, MARK) and 1980s (FENRIS, LARSTRAN ‘80)
- ***The FEM is one of the most important developments in computational methods to occur in the 20th century.***
- In just a few decades, the method has evolved from one with applications in structural engineering to a widely utilized and richly varied computational approach for many scientific and technological areas.

APPLICATIONS OF FINITE ELEMENTS

The range of applications of finite elements is too large to list, but to provide an idea of its versatility we list the following:

- Stress and thermal analyses of industrial parts such as electronic chips, electric devices, valves, pipes, pressure vessels, automotive engines and aircraft;
- Analysis of dams, power plants and high-rise buildings;
- Crash analysis of cars, trains and aircraft;
- Fluid flow analysis of coolant ponds, contaminants, and air in ventilation systems;
- Electromagnetic analysis of antennas and transistors.
- Analysis of surgical procedures such as plastic surgery, jaw reconstruction, and many others.

This is a very short list that is just intended to give you an idea of the breadth of application areas for the method. New areas of application are constantly emerging.

APPLICATIONS OF FINITE ELEMENT METHOD

Engineering Applications of the Finite Element Method

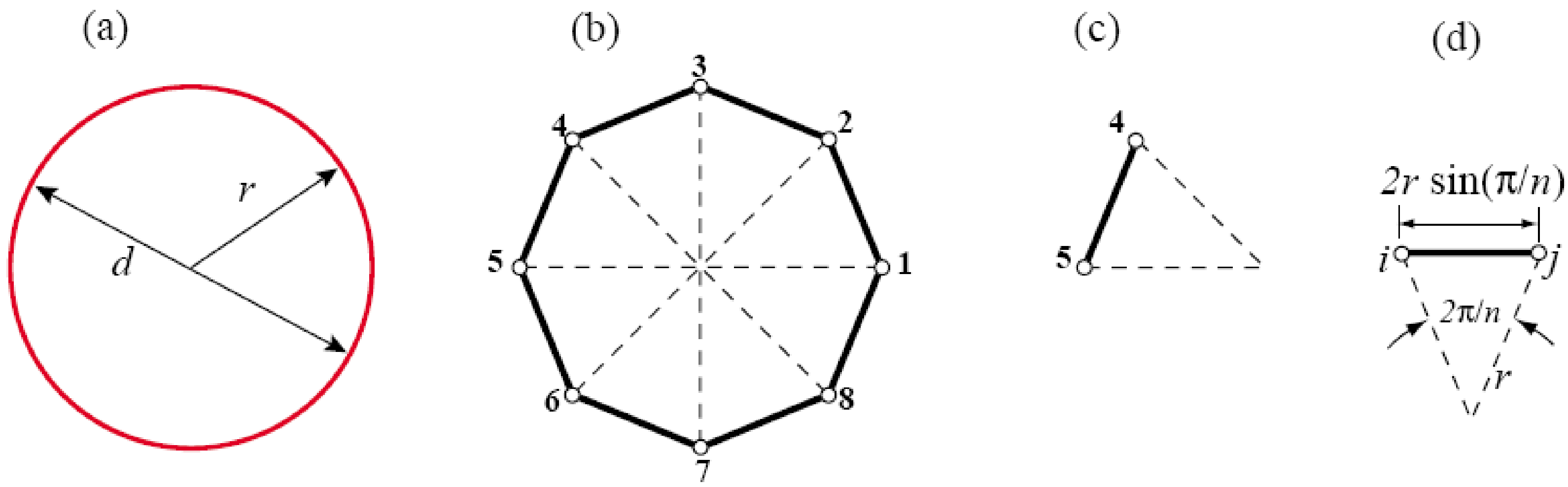
Area of study	Equilibrium problems	Eigenvalue problems	Propagation problems
1. Civil engineering structures	Static analysis of trusses, frames, folded plates, shell roofs, shear walls, bridges, and prestressed concrete structures	Natural frequencies and modes of structures; stability of structures	Propagation of stress waves; response of structures to aperiodic loads
2. Aircraft structures	Static analysis of aircraft wings, fuselages, fins, rockets, spacecraft, and missile structures	Natural frequencies, flutter, and stability of aircraft, rocket, spacecraft, and missile structures	Response of aircraft structures to random loads; dynamic response of aircraft and spacecraft to aperiodic loads
3. Heat conduction	Steady-state temperature distribution in solids and fluids		Transient heat flow in rocket nozzles, internal combustion engines, turbine blades, fins, and building structures
4. Geomechanics	Analysis of excavations, retaining walls, underground openings, rock joints and soil structure interaction problems; stress analysis in soils, dams, layered piles, and machine foundations	Natural frequencies and modes of dam–reservoir systems and soil–structure interaction problems	Time-dependent soil–structure interaction problems; transient seepage in soils and rocks; stress wave propagation in soils and rocks
5. Hydraulic and water resources engineering; hydrodynamics	Analysis of potential flows, free surface flows, boundary layer flows, viscous flows, transonic aerodynamic problems; analysis of hydraulic structures and dams	Natural periods and modes of shallow basins, lakes, and harbors; sloshing of liquids in rigid and flexible containers	Analysis of unsteady fluid flow and wave propagation problems; transient seepage in aquifers and porous media; rarefied gas dynamics; magneto-hydrodynamic flows

APPLICATIONS OF FINITE ELEMENT METHOD

(continued). Engineering Applications of the Finite Element Method

Area of study	Equilibrium problems	Eigenvalue problems	Propagation problems
6. Nuclear engineering	Analysis of nuclear pressure vessels and containment structures; steady-state temperature distribution in reactor components	Natural frequencies and stability of containment structures; neutron flux distribution	Response of reactor containment structures to dynamic loads; unsteady temperature distribution in reactor components; thermal and viscoelastic analysis of reactor structures
7. Biomedical engineering	Stress analysis of eyeballs, bones, and teeth; load-bearing capacity of implant and prosthetic systems; mechanics of heart valves		Impact analysis of skull; dynamics of anatomical structures
8. Mechanical design	Stress concentration problems; stress analysis of pressure vessels, pistons, composite materials, linkages, and gears	Natural frequencies and stability of linkages, gears, and machine tools	Crack and fracture problems under dynamic loads
9. Electrical machines and electromagnetics	Steady-state analysis of synchronous and induction machines, eddy current, and core losses in electric machines, magnetostatics		Transient behavior of electromechanical devices such as motors and actuators, magnetodynamics

WHAT DOES A FINITE ELEMENT LOOK LIKE?



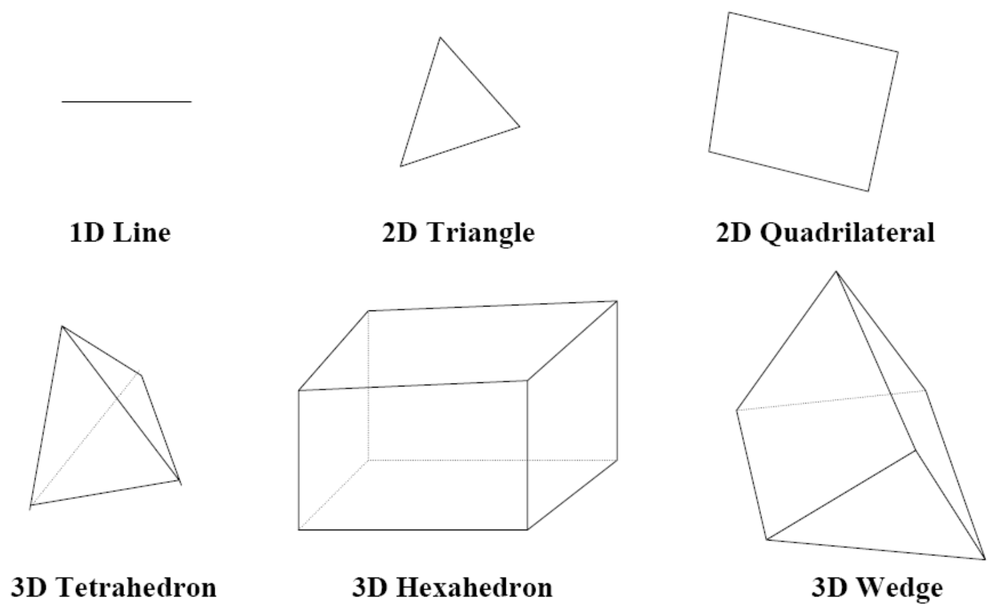
n	$\pi_n = n\sin(\pi/n)$	Extrapolated by Wynn-ϵ	Exact π to 16 places
1	0.000000000000000		
2	2.000000000000000		
4	2.828427124746190	3.414213562373096	
8	3.061467458920718		
16	3.121445152258052	3.141418327933211	
32	3.136548490545939		
64	3.140331156954753	3.141592658918053	
128	3.141277250932773		
256	3.141513801144301	3.141592653589786	3.141592653589793

GENERAL STEPS OF THE FEM

- **Step-1 Obtain a basic understanding of the problem** you are attempting to solve. Are any classical solutions (closed-form) available? Experimental solutions are possible? Which modes of deformation do you expect to significantly contribute to the structure's behavior?

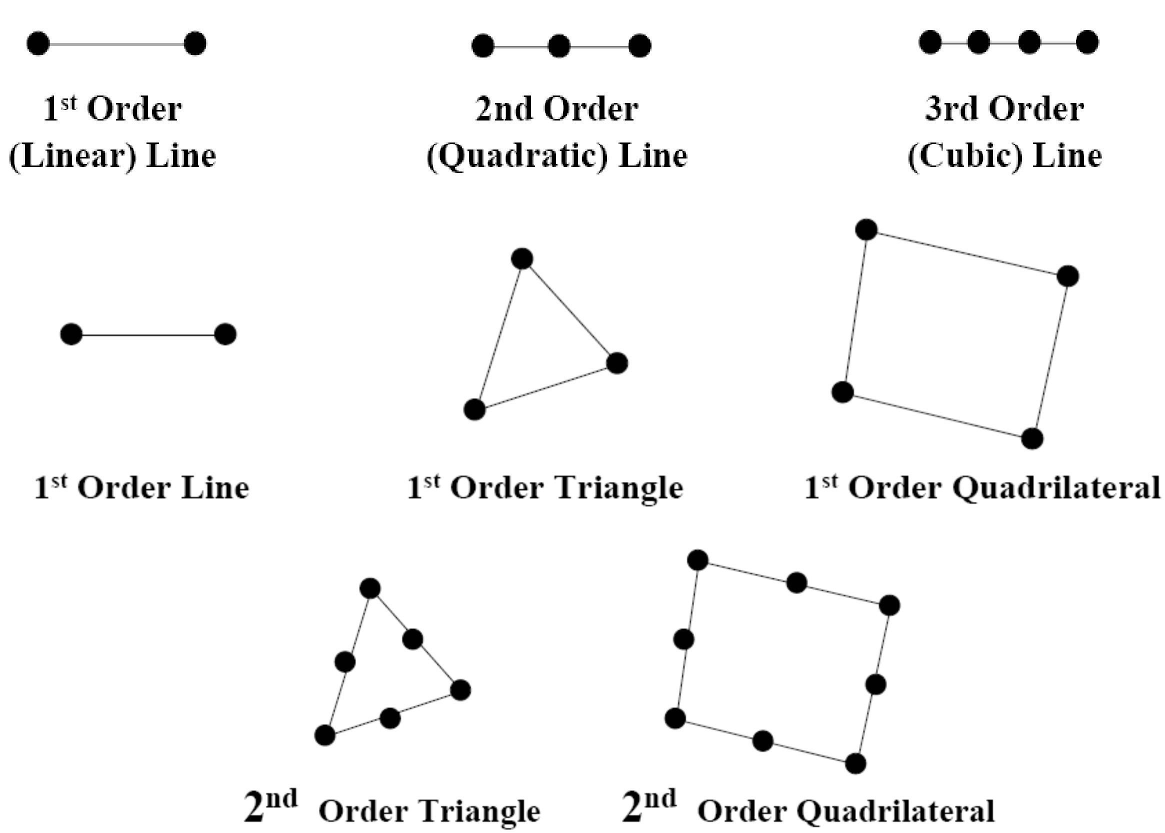
- **Step-2 Create model, select element types and discretize the problem domain.** This entails dividing the continuous structure into a finite number of elements or regions over which the unknowns (displacements, in this class) will be interpolated.

Some Basic Element Shapes



GENERAL STEPS OF THE FEM

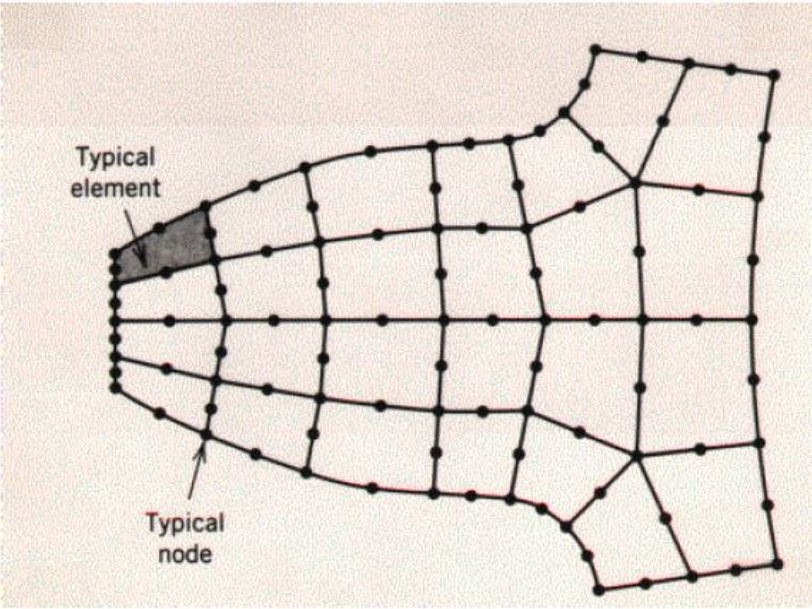
- **Step-3** Select an **approximate displacement function** within each element. ***Linear, quadratic, or cubic polynomials*** are frequently used to interpolate displacement values, within each element, from the element nodes. The number of nodes increases with order.



GENERAL STEPS OF THE FEM

- **Step-4 Describe the behavior of the physical quantities on each element.**
- **Step-5 Connect (assemble) the elements at the nodes to form an approximate system of equations for the whole structure.**
- **Step-6 Solve the system of equations involving unknown quantities at the nodes (e.g., displacements).**
- **Step-7 Calculate desired quantities (e.g., strains and stresses) at selected elements**

FEM model for a gear tooth



ADVANTAGES OF THE FINITE ELEMENT METHOD

- Can readily handle complex geometry: The heart and power of the FEM.

- Can handle complex analysis types:
  - Vibration
  - Transients
  - Nonlinear
  - Heat transfer
  - Fluids

- Can handle complex loading:
  - Node-based loading (point loads).
  - Element-based loading (pressure, thermal, inertial forces).
  - Time or frequency dependent loading.

- Can handle complex restraints:
  - Indeterminate structures can be analyzed.

- Can handle bodies comprised of non-homogeneous materials:
  - Every element in the model could be assigned a different set of material properties.

ADVANTAGES OF THE FINITE ELEMENT METHOD

- Can handle bodies comprised of non-isotropic materials:
  - Orthotropic
  - Anisotropic
- Special material effects are handled:
  - Temperature dependent properties.
  - Plasticity
  - Creep
  - Swelling
- Special geometric effects can be modeled:
  - Large displacements.
  - Large rotations.
  - Contact (gap) condition
- Versatility– the method can be applied to various problems with arbitrary problem domain shape, loading conditions, and boundary conditions.

- Accuracy Control – Solution can be as accurate as desired provided that the element formulation is proper. By increasing the number of elements (and thus nodes) in the problem discretization (mesh), the solution should converge to the exact or analytical solution.

DISADVANTAGES OF THE FINITE ELEMENT METHOD

- **A specific numerical result** is obtained for a specific problem. A general closed-form solution, which would permit one to examine system response to changes in various parameters, is not produced.

- The FEM is applied to **an approximation of the mathematical model** of a system (the source of so-called inherited errors.)

- **Experience and judgment are needed** in order to construct a good finite element model.

- **Input and output data may be large and tedious to prepare and interpret.**

- **Numerical problems:**

  Round off and error accumulation.

  Can help the situation by not attaching stiff (small) elements to flexible (large) elements.

- **Susceptible to user-introduced modeling errors:**

  Poor choice of element types.

  Distorted elements.

  Geometry not adequately modeled.

HOW CAN THE FEM HELP THE DESIGN ENGINEER?

- **The FEM offers many important advantages to the design engineer** ***Easily applied to complex, irregular-shaped objects composed of several different materials and having complex boundary conditions.***

- Applicable to ***steady-state, time dependent and eigenvalue problems.***

- Applicable to ***linear and nonlinear problems.***

- ***One method can solve a wide variety of problems,*** including problems in solid mechanics, fluid mechanics, chemical reactions, electromagnetics, biomechanics, heat transfer and acoustics, to name a few.

- ***General-purpose FEM software packages are available at reasonable cost,*** and can be readily executed on microcomputers, including workstations and PCs.

- ***The FEM can be coupled to CAD programs to facilitate solid modeling and mesh generation.***

- ***Many FEM software packages feature GUI interfaces, auto-meshers, and sophisticated postprocessors and graphics to speed the analysis and make pre and post-processing more user-friendly.***

HOW CAN THE FEM HELP THE DESIGN ORGANIZATION?

Simulation using the FEM also offers important **business advantages to the *design organization***:

- **Reduced testing and redesign costs thereby shortening the product development time.**
- **Identify issues in designs before tooling is committed.**
- **Refine components before dependencies to other components prohibit changes.**
- **Optimize performance before prototyping.**
- **Discover design problems before litigation.**
- **Allow more time for designers to use engineering judgment, and less time "turning the crank."**