Introduction to Finite Element Analysis (FEA)

Biomechanical Design
051 : 083

Lecture 4

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http://www.engineering.uiowa.edu/~bme083/

Introduction to Finite Element Analysis

- What is FEA?
- Why do we need FEA?
- How does FEA work?

What is FEA?

- All the physical phenomena can be modeled by differential equations or governing equations.

$$F = ma = m\frac{d^2x}{dt^2} \quad \text{2nd Law of motion}$$

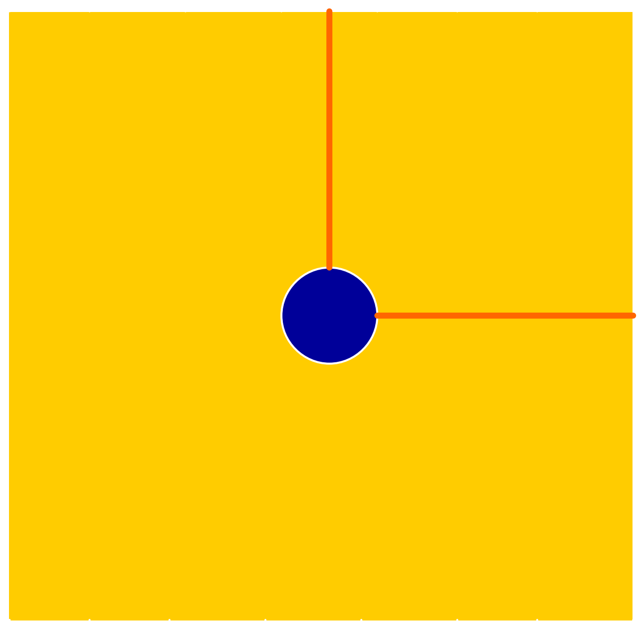
$$s = Ee = E\frac{du}{dx} \quad \text{Hooke's Law}$$

- A differential equation can be solved by classical analytical methods or numerical methods.

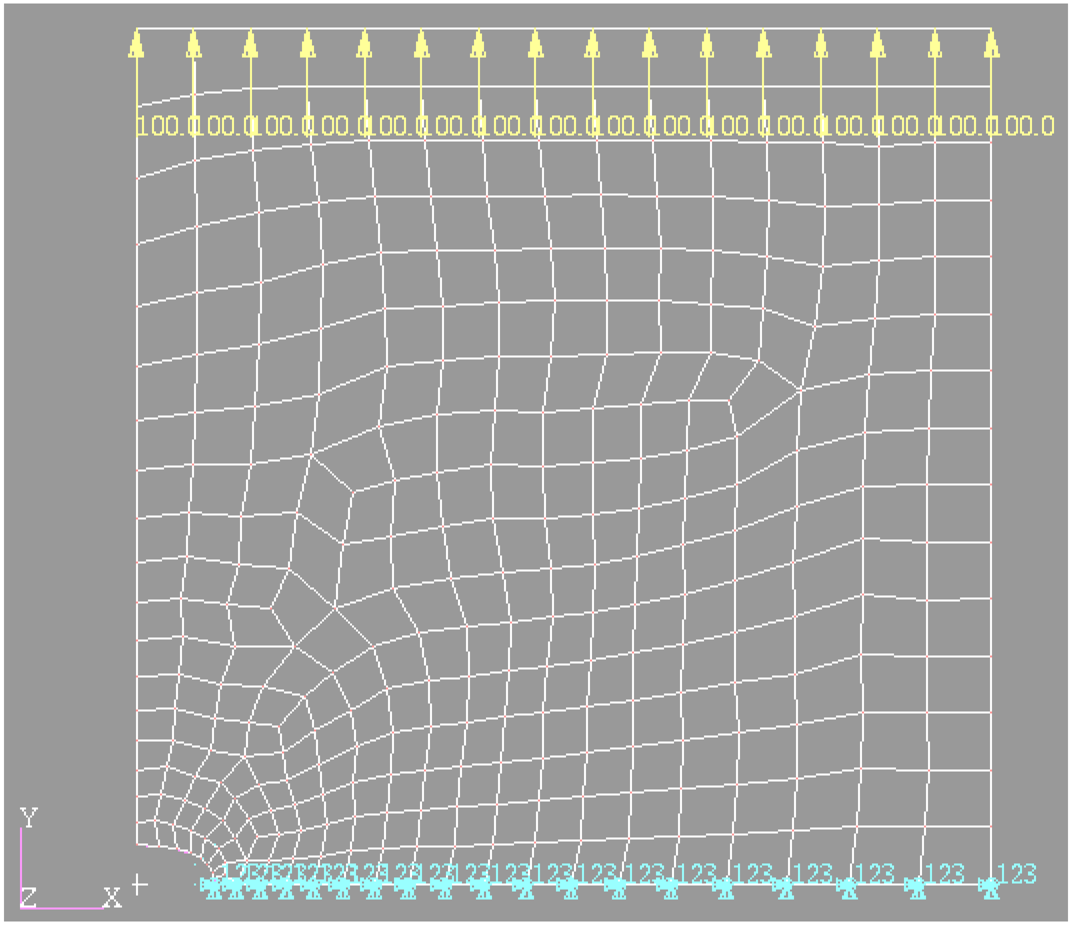
What is FEA?

- FEA is one of numerical methods to attain approximate solution of governing equation by dividing a large region into small sub-regions
- The sub-regions are called *finite elements*
- The process of dividing is called *meshing*

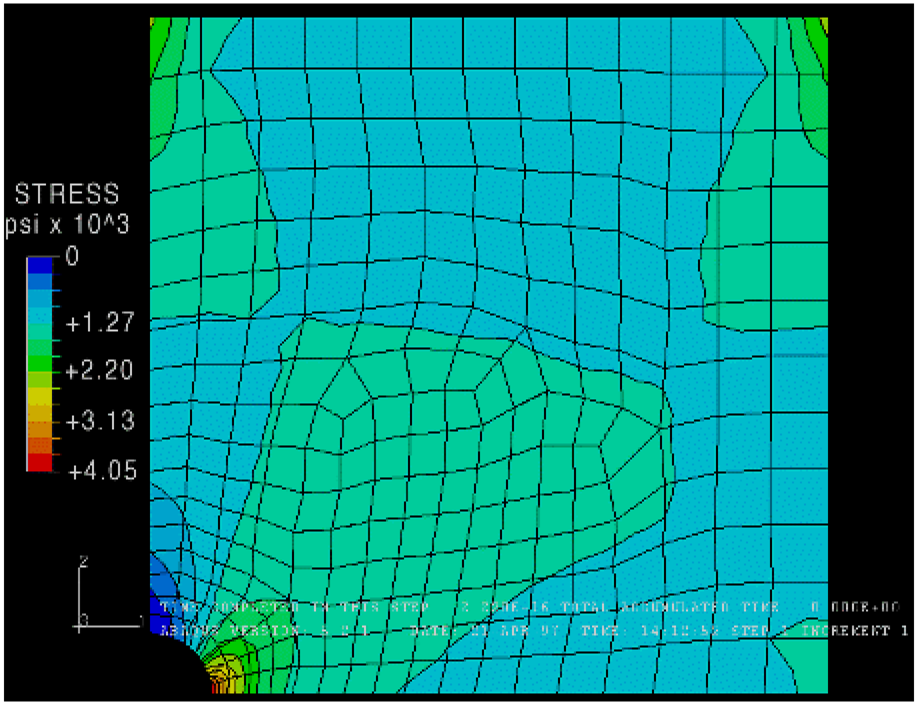
What is FEA?



What is FEA?



What is FEA?



What is FEA?

- First used by R. Courant in 1943
- Officially named as “Finite Element Method” by R. W. Clough in 1960
- Application in structural problems in 1970’s, limited use on expensive mainframes
- Popular in thermal & fluid problems in1980’s
- Fully matured in 1990’s because of the development of computer technology

Why do we need FEA?

- Engineering problems
  - Solid mechanics
  - Fluid mechanics
  - Thermal system analysis
- Ways to solve Engineering problems
  - Analytical methods
  - Numerical methods

Why do we need FEA?

- Analytical Methods
  - Great mathematical skills needed
  - Most time, too complex to solve
- Numerical Methods
  - Do-able in most cases
  - Approximate solution
  - Rely on computer to do the calculations

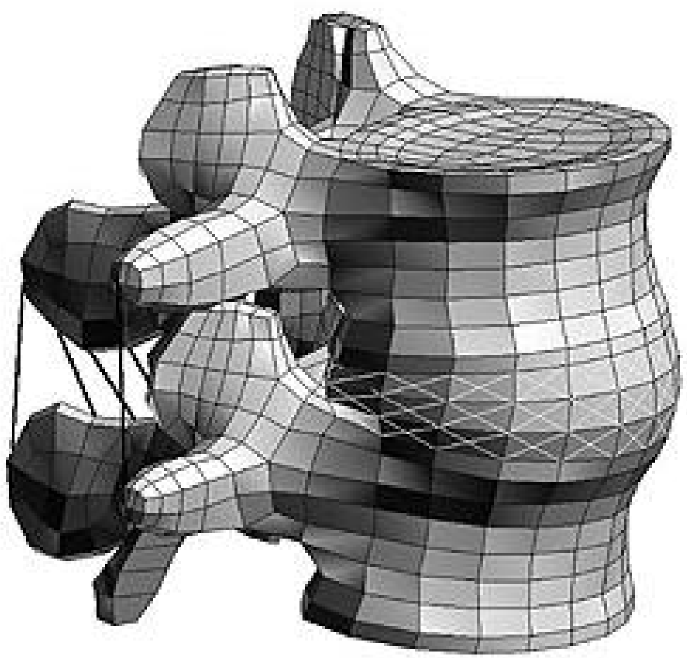
Why do we need FEA?

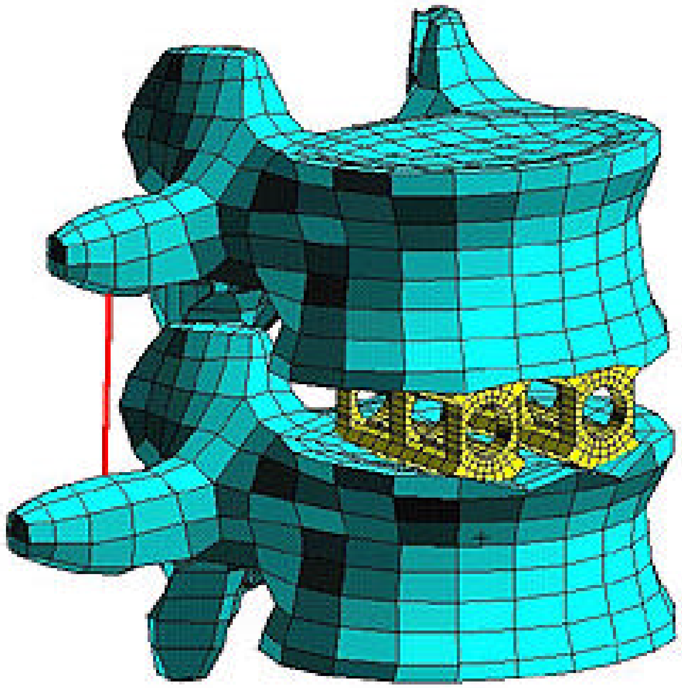
- FEA as one of numerical methods
  - It is easier to solve governing equation in a small region because the boundary conditions and/or initial conditions (dynamic problem) are simpler.
  - More important, only the approximate solution rather than the exact solution is needed, thus less demand in calculations.

Why do we need FEA?

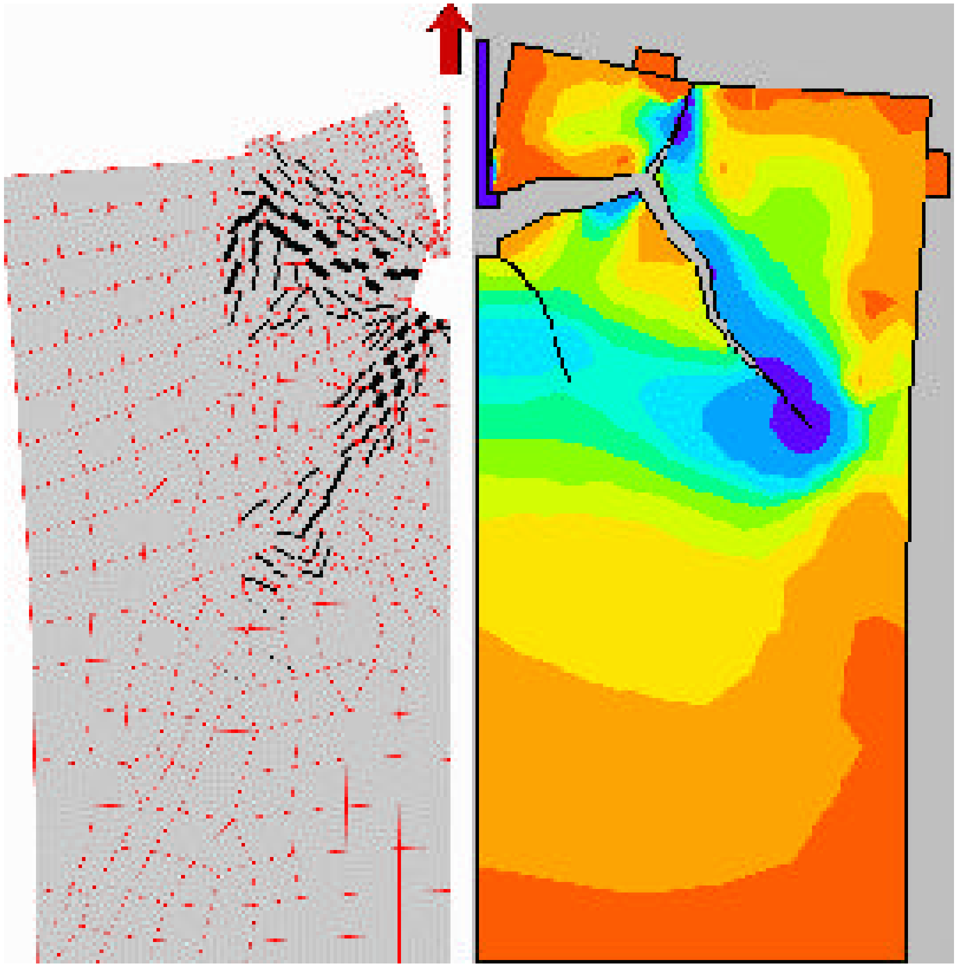
- FEA is a computer model of a material or design that can be used in
  - new product design
  - existing product refinement
  - simulating structural failure
  - investigating point of interest not accessible in reality, e.g., internal structure
  - and more

Why do we need FEA?



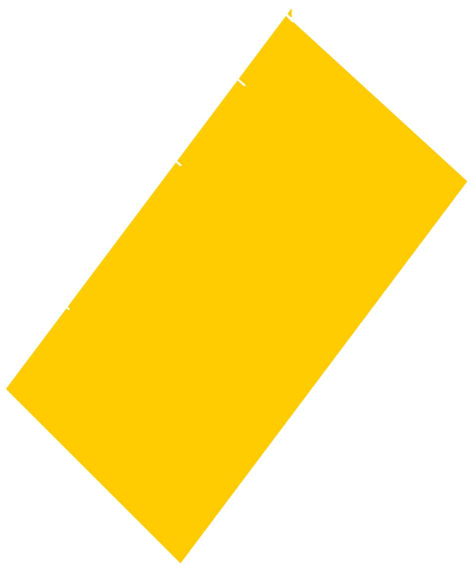


Why do we need FEA?



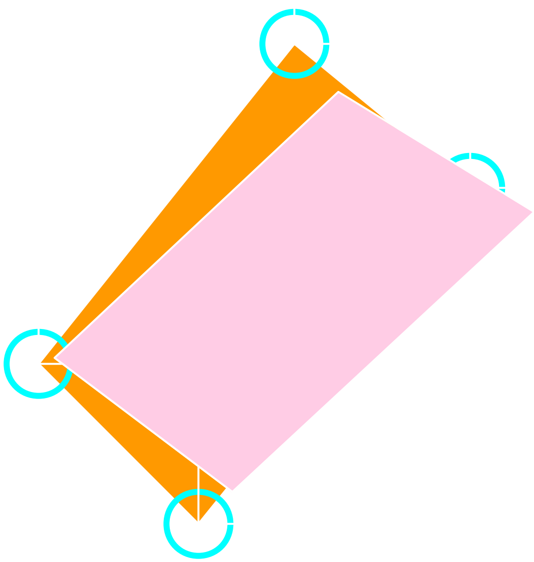
How does FEA work?

How does FEA work?



- The small region (element), compare to the whole model
  - the shape is more regular
  - the load is simpler
  - how about the internal load? (same)
  - still infinite number of loads

How does FEA work?



- Approximation
  - The loads are further reduced to, e.g., point load at the four corners (nodes), only finite number of unknown loads now
  - Instead of obtain the exact solution for the whole element, use the solutions at nodes and their combination for the rest of the area

How does FEA work?

- FEA uses a system of points called nodes that make a grid called a mesh.
- This mesh contains both the material and structural properties which define how the structure will react to certain loading conditions.
- Node density could be high in a particular area, or points of interest
  - fracture point
  - Corners
  - high stress areas

How does FEA work?

- General steps in commercial FEA software packages, e.g., ANSYS
  - 1. Pre-Processing: Modeling
  - 2. Solving: Obtain the result
  - 3. Post-Processing: Review the result
  - 4. Optimization

How does FEA work?

- 1. Pre-Processing
  - Modeling
    - Define problem type
    - Use node/line/area/volume to construct the geometry of a physical entity
    - Assign proper element type and material property to each part of the model
  - Meshing
    - Refine the model into small elements
    - If error occurs, go back to modeling

How does FEA work?

- Problem types
  - Solid
  - Fluid
  - Thermal
- Element types
  - 1D: Truss, Beam
  - 2D: Plane stress, Plane strain,
  - 3D: Tetrahedral, Brick
  - Other: Gap, Cable reinforced,…
    Custom-defined

How does FEA work?

- Material Properties such as stiffness, compressible/incompressible, heat conductivity, and so on
  - Young’s modulus
  - Shear modulus
  - Poisson’s ratio
  - And more

How does FEA work?

- Truss Structure
  - Problem Type: Solid Elasticity
    - Hooke's Law: Load = Stiffness Matrix * Deformation
    - Connect only at ends
    - Supports only axial loads
      - Tensile
      - Compression
      - No bending or buckling

How does FEA work?

- Truss Structure
  - Element Type: Truss Element
    - Treated as a spring
    - $F = Kd$ or $d = F/K$
      - Where the spring constant: $K = EA/L$

How does FEA work?

- Truss Structure
  - Material Property
    - Length *L*
    - Cross-sectional area *A*
    - Young’s modulus *E*

How does FEA work?

- 2. Solving
  - Apply loads and boundary conditions
  - Let the computer do the numerical calculations
  - Restart from pro-processing if error occurs

How does FEA work?

- 3. Post-Processing
  - – Display Results in tables or graphs
  - – Review if the result is reasonable
  - – If not, restart from pre-processing

How does FEA work?

- 4. Optimization
  - Are there something you can do, e.g., changing node numbers, element numbers, that will yield better result, or decrease the demand of computation without compromising the accuracy, or …

Next Lecture

Learn how to use ANSYS

- Illustrated by solving a beam problem

Will be presented by Mr. Kim on Wed.

Introduction to Finite Element Analysis

- Questions