

# **Finite Element Analysis**

## **(Part II)**

**Senior Design**  
**ME 481**

**Department of Mechanical Engineering**  
**University of Hawaii at Manoa**

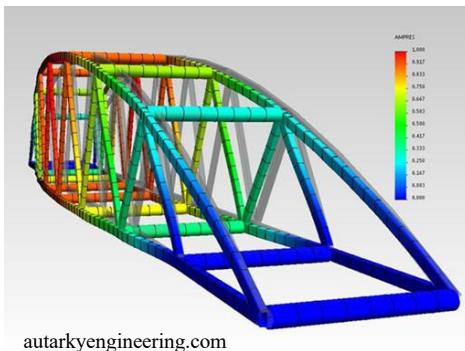
**Fall 2021**

# Performing Analyses:

- Reduce the amount of prototype testing
- Cost savings
- Time saving, reduce the time to market
- Create more reliable, better-quality designs



<https://www.youtube.com/watch?v=dzRxpp4DcLc>



autarkyengineering.com



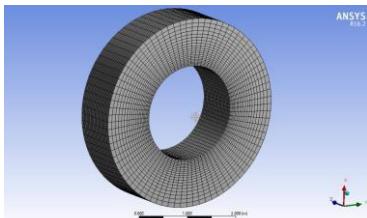
<http://enablingthefuture.org/2017/06/19/e-enable-maker-camp-national-week-of-making/>

# Performing Analyses:

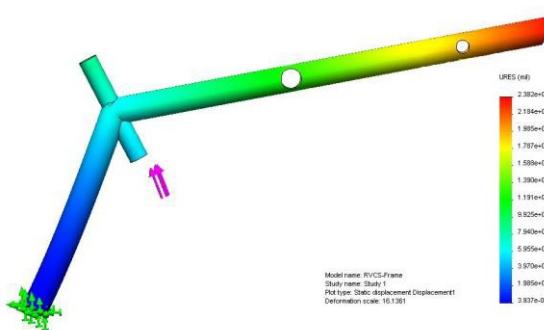
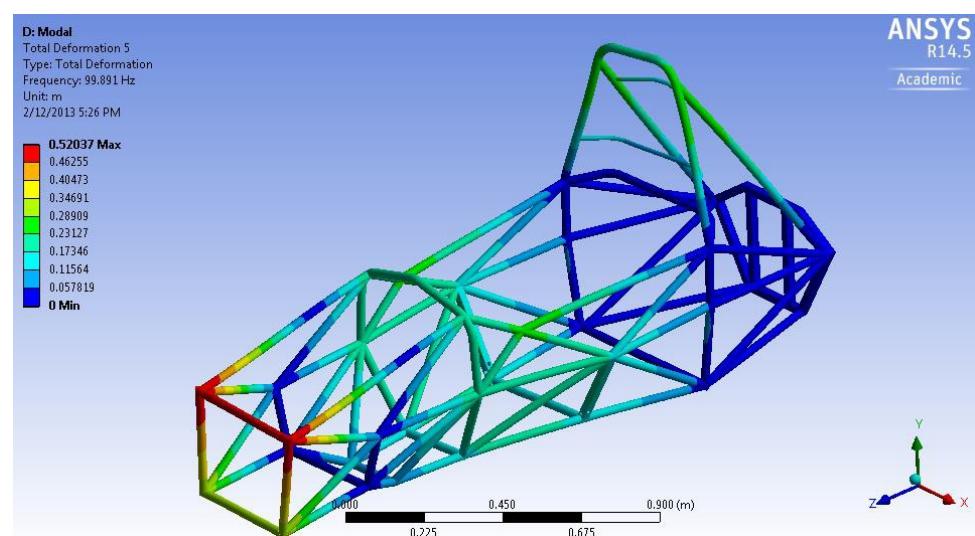
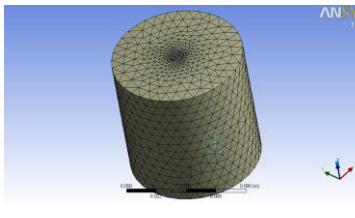
- Finite Element Analysis is a way to simulate loading, initial and boundary conditions on a design.
- Shows the design response to a loading condition.

## How good is the approximation

- Depends entirely on what you are modeling



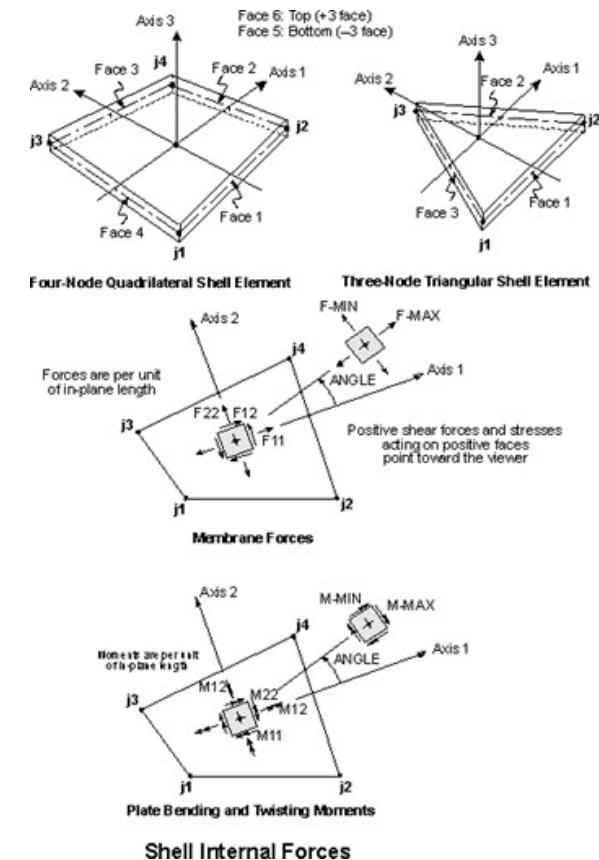
<https://www.youtube.com/watch?v=0j915gwpq4A>



<http://hpv.olin.edu/blog/?id=2013-03-20>

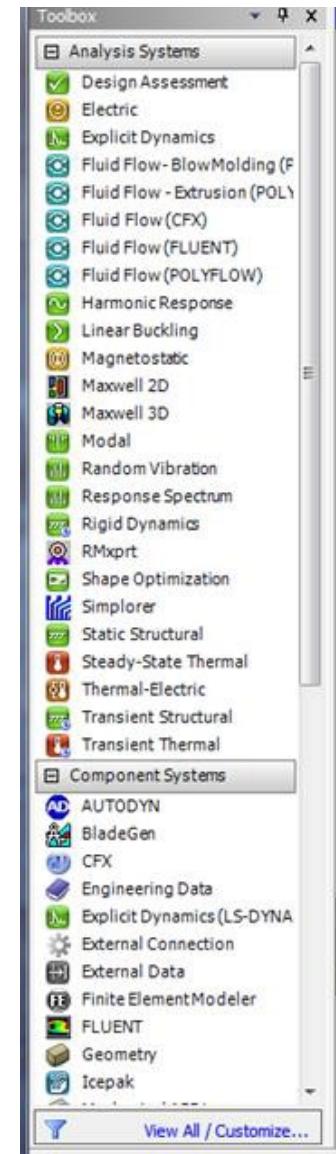
# How good is the approximation

- The design is modeled using discretized elements.
- Each element has exact equations that shows the design's responds to a certain load.
- By summarizing the response of all elements in the model, the total response of the design will be found.
- Elements have a finite number of unknowns, hence its called finite elements.



# ANSYS

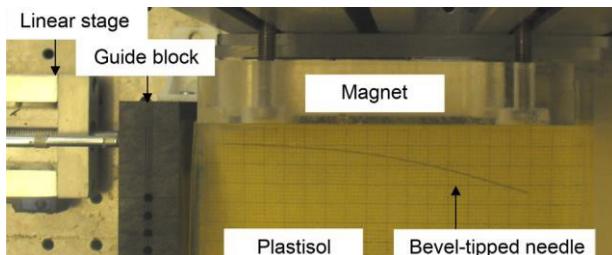
- ANSYS is a complete FEA software package to analyze:
  - Structural
  - Thermal
  - Fluid: Computational Fluid Dynamics (CFD)
  - Electrical / Electrostatics
  - Electromagnetics
- Used in industries
  - Aerospace
  - Automotive
  - Biomedical
  - Bridges and Buildings
  - Electronics and Appliances
  - MEMS



# ANSYS Multiphysics

Includes all capabilities in all engineering disciplines.

- ANSYS/Mechanical - structural & thermal capabilities
- ANSYS/Emag – electromagnetics
- ANSYS/FLOTRAN - CFD capabilities
- ANSYS/LS-DYNA - for highly nonlinear structural problems
- DesignSpace: an easy-to-use design and analysis tool meant for quick analysis within the CAD environment
- ANSYS/ProFEA - for ANSYS analysis & design optimization within Pro/ENGINEER

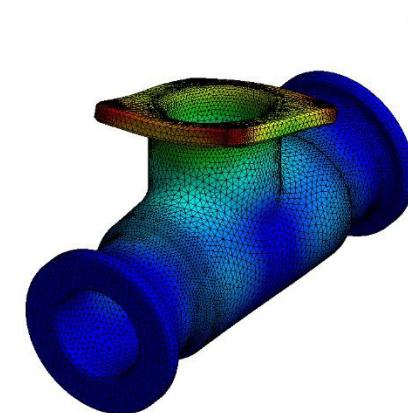


# Structural Analyses

Civil engineering structures such as bridges and buildings, Naval, aeronautical, and mechanical structures such as ship hulls, aircraft bodies, and machine housings, as well as mechanical components such as pistons, machine parts, and tools.

Strains, stresses, and reaction forces, are then derived from the nodal displacements

Static Analysis, Modal Analysis,  
Harmonic Analysis, Transient Dynamic  
Analysis, Spectrum Analysis, Buckling  
Analysis  
Fracture mechanics, Composites,  
Fatigue, p-Method



<http://www.padtinc.com/blog/the-focus/making-pretty-plots-in-ansys-mechanical-and-mechanical-apdl>

# Type of Elements

Spars: General, Bilinear (Cable)

[http://www.ansys.stuba.sk/html/elem\\_55/chapter4/ES4-10.htm](http://www.ansys.stuba.sk/html/elem_55/chapter4/ES4-10.htm)

Beams: General, Tapered, Plastic, Shear, Deformable, Elasto-Plastic

[http://www.ansys.stuba.sk/html/elem\\_55/chapter4/ES4-188.htm](http://www.ansys.stuba.sk/html/elem_55/chapter4/ES4-188.htm)

Pipes: General, Immersed, Plastic

[http://www.ansys.stuba.sk/html/elem\\_55/chapter4/ES4-16.htm](http://www.ansys.stuba.sk/html/elem_55/chapter4/ES4-16.htm)

2-D Solids: Quadrilateral, Triangle, Hyperelastic, Viscoelastic, Large Strain, Harmonic, p-Element

[http://www.ansys.stuba.sk/html/elem\\_55/chapter4/ES4-182.htm](http://www.ansys.stuba.sk/html/elem_55/chapter4/ES4-182.htm)

3-D Solids: Brick, Tetrahedron, Layered, Anisotropic, Hyperelastic, Viscoelastic, Large Strain, p-Element

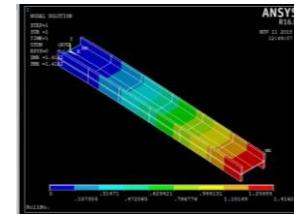
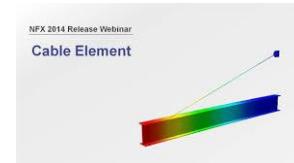
[http://www.ansys.stuba.sk/html/elem\\_55/chapter4/ES4-185.htm](http://www.ansys.stuba.sk/html/elem_55/chapter4/ES4-185.htm)

Shells: Quadrilateral, Axisymmetric, Layered, Shear Panel, p-Element

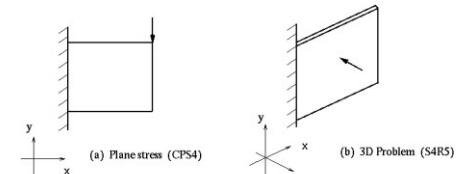
[http://ans2.vm.stuba.sk/html/elem\\_55/chapter4/ES4-181.htm](http://ans2.vm.stuba.sk/html/elem_55/chapter4/ES4-181.htm)

Contact: Point-to-Surface, Point-to-Point, Rigid Surface

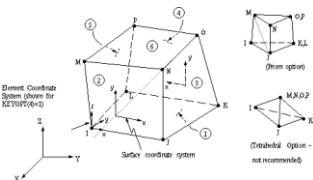
Coupled-Field: Acoustic, Piezoelectric, Thermal-Stress, Magnetic-Structural, Fluid-Structural



<https://www.youtube.com/watch?v=NsYn7oKH1Co>



<http://mechdocsblog.blogspot.com/2013/02/what-is-difference-between-shell.html>



[http://www.ansys.stuba.sk/html/elem\\_55/chapter4/ES4-45.htm](http://www.ansys.stuba.sk/html/elem_55/chapter4/ES4-45.htm)

# Structural Static Analysis

Effects of steady loading conditions on a structure

Nonlinear behavior such as large deflections, large strain, contact, plasticity, hyperelasticity, and creep can't be simulated

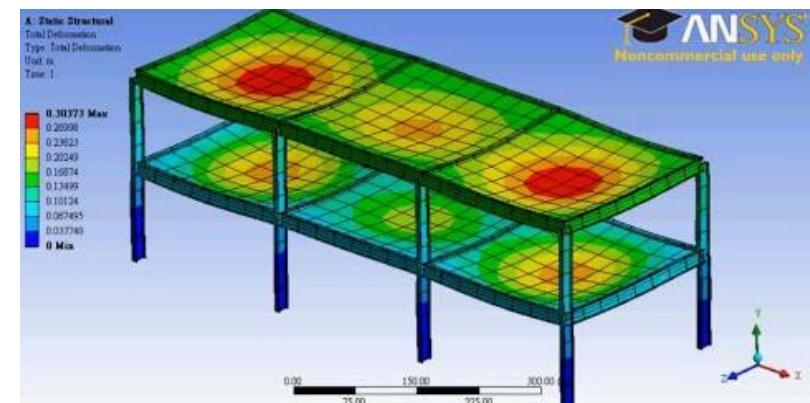
No time-varying loads

Externally applied forces and pressures

Steady-state inertial forces (such as gravity or rotational velocity)

Imposed (non-zero) displacements

Temperatures (for thermal strain)



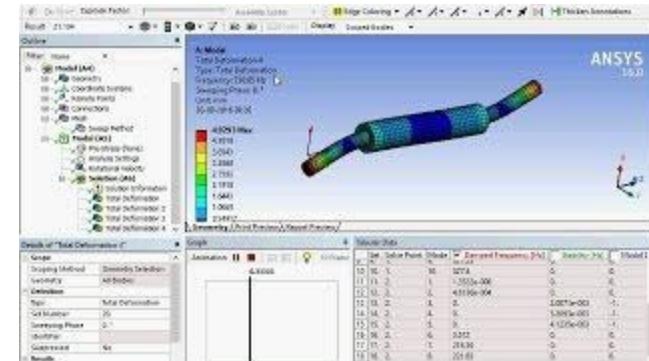
# Structural Dynamic Analysis

Includes mass and damping effects

**Modal analysis** calculates natural frequencies and mode shapes.

**Harmonic analysis** determines a structure's response to sinusoidal loads of known amplitude and frequency. to time-varying loads and can include nonlinear behavior.

Spectrum analysis  
Random vibrations  
Eigenvalue buckling  
Substructuring, submodeling



<https://www.musicjinni.com/e8ZmjR8AO2-/Inertia-Relief-Analysis-using-ANSYS-Workbench-16.html>

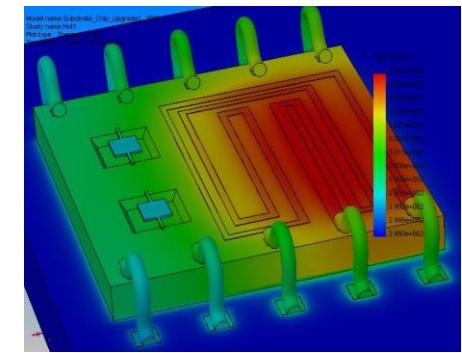
# Structural Thermal Analysis

**Thermal analysis** is used to determine the temperature distribution in an object. Other quantities of interest include amount of heat lost or gained, thermal gradients, and thermal flux.

All three primary heat transfer modes can be simulated:  
**conduction, convection, radiation**

## Steady-State

Solutions do not dependent on Time



<http://symmetric.co.in/services/cae-services/>

## Transient

Determines temperatures, etc. as a function of time.

Allows phase change (melting or freezing) to be simulated.

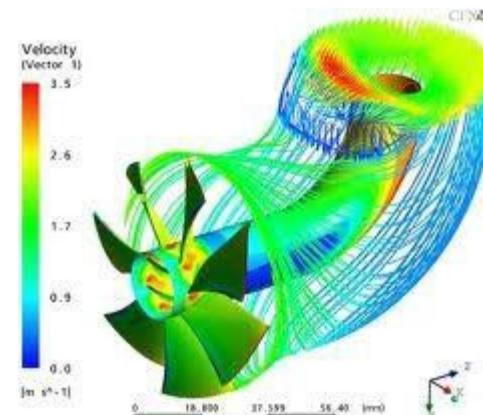
# Computational Fluid Dynamics (CFD) Analysis

Flow distributions and temperatures in a fluid

ANSYS/FLOTTRAN can simulate laminar and turbulent flow, compressible and incompressible flow, and multiple species

Applications: aerospace, electronic packaging, automotive Design

Typical quantities of interest are velocities, pressures, temperatures, and film coefficients.



# Example: Analysis of a Z-Section Beam

Z shape cantilever beam

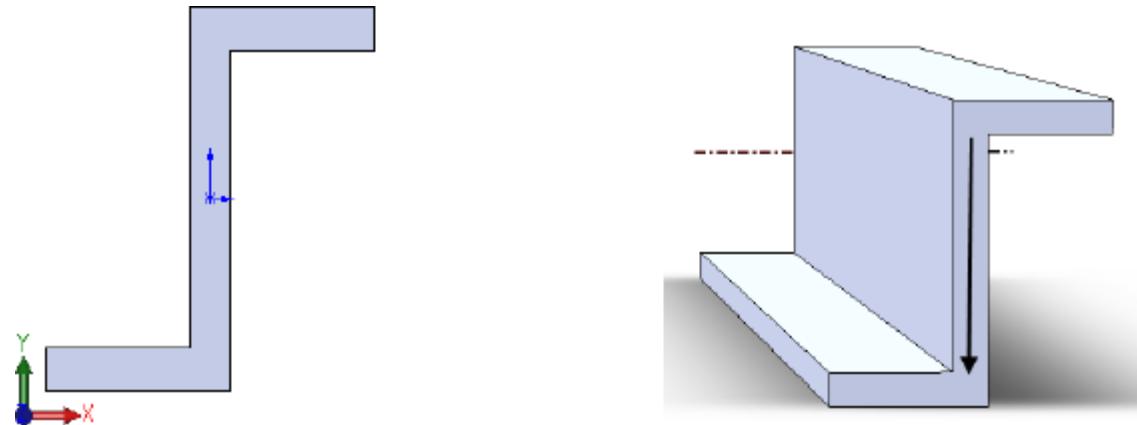
length of  $L = 500 \text{ mm}$ .

thickness of  $t = 5 \text{ mm}$ ,

each flange has a length of  $a = 20 \text{ mm}$ ,

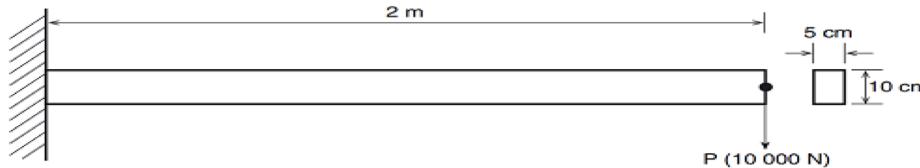
depth of  $h = 2a = 40 \text{ mm}$ .

loaded by a vertical force  $P = 500 \text{ N}$



# 2D Cantilever Beam Theory

## (Uses 1D Beam Elements)

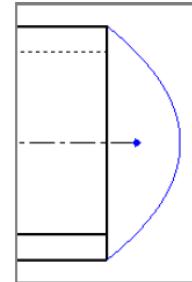
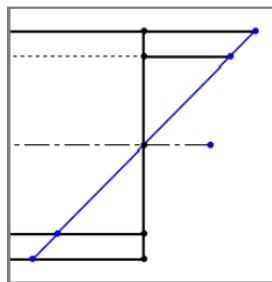
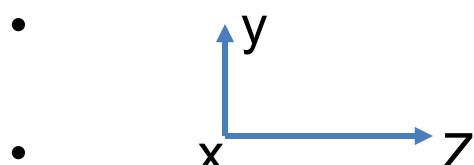


Bending moment, about the x-axis  $M = P(L - z)$  where  $z$  is the distance from the support

$$\sigma_z = [M * y / I] = [P(L-Z) * y] / I, \text{ where } I = bh^3/12, \text{ where } b=\text{width}, h=\text{height}; h/2 = C$$

$$\text{Max Beam Deflection} = U_y = PL^3 / 3EI_x$$

- For symmetric sections: Stress is zero at the neutral axis ( $y = 0$ )
- The load  $P$  causes a moment and a shear force
- Maximum Tension at top, and Maximum Compression at bottom
- Transverse shear stress ( $\tau$ ) varies parabolically through the depth and has its maximum at the neutral axis ( $y = 0$ )

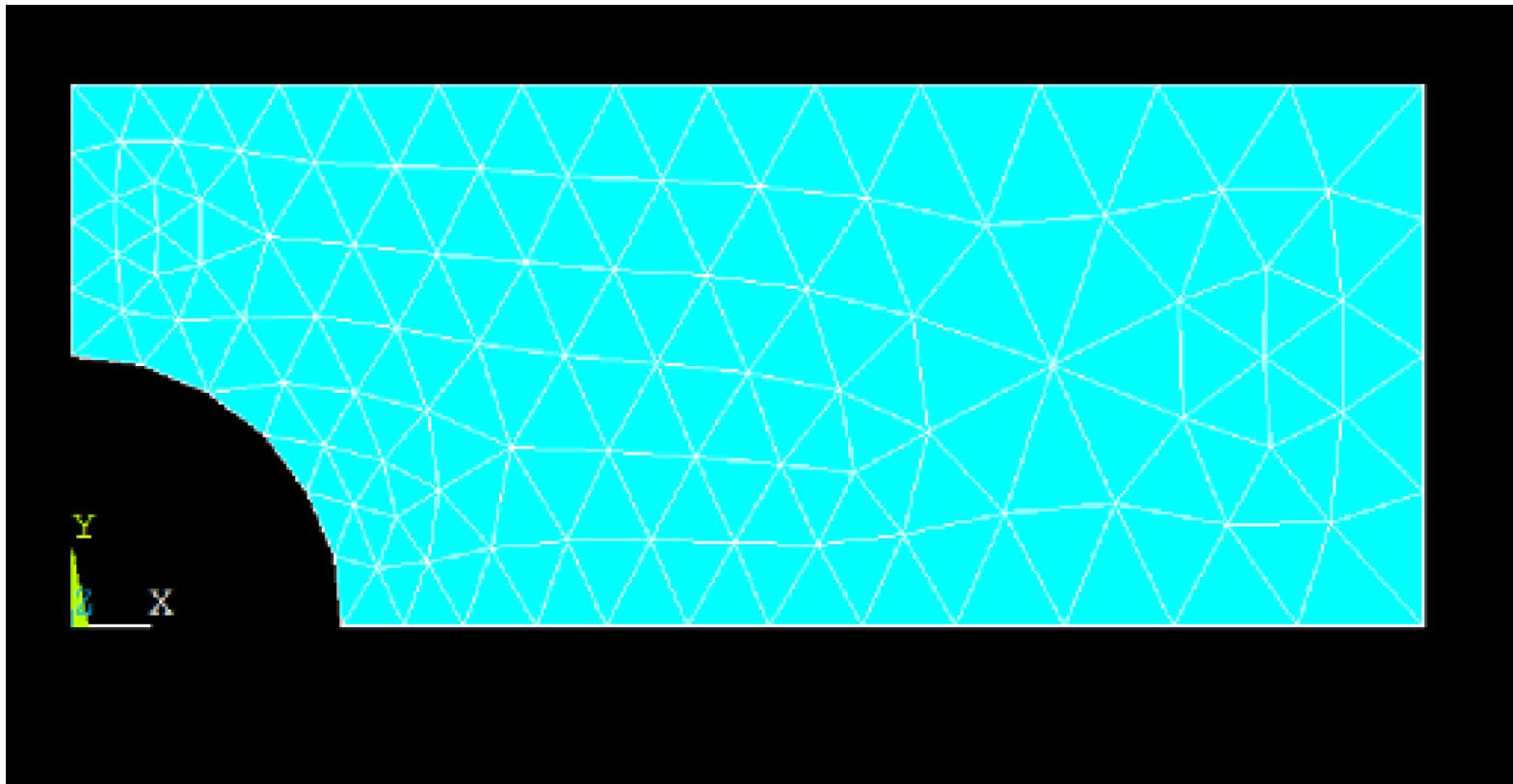


$$\tau_{xy} = \frac{3}{2} \frac{V}{A} \left( 1 - \frac{y^2}{c^2} \right)$$

$$\tau_{\max} = \frac{3}{2} \frac{V}{A}$$

# 2D Plate Theory

(Uses 2D Shell Elements)



Stress Concentration Factor =  $K = 3$