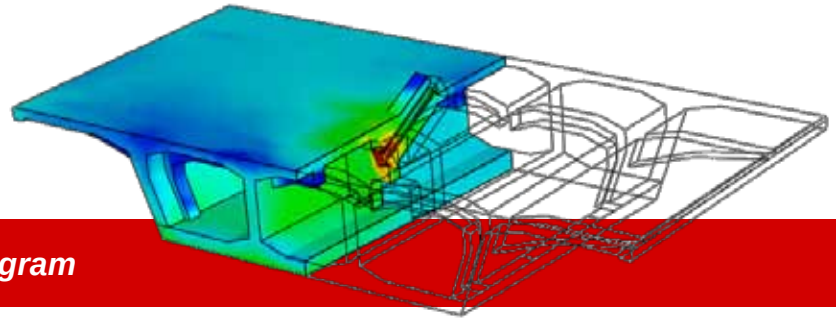
MIDAS

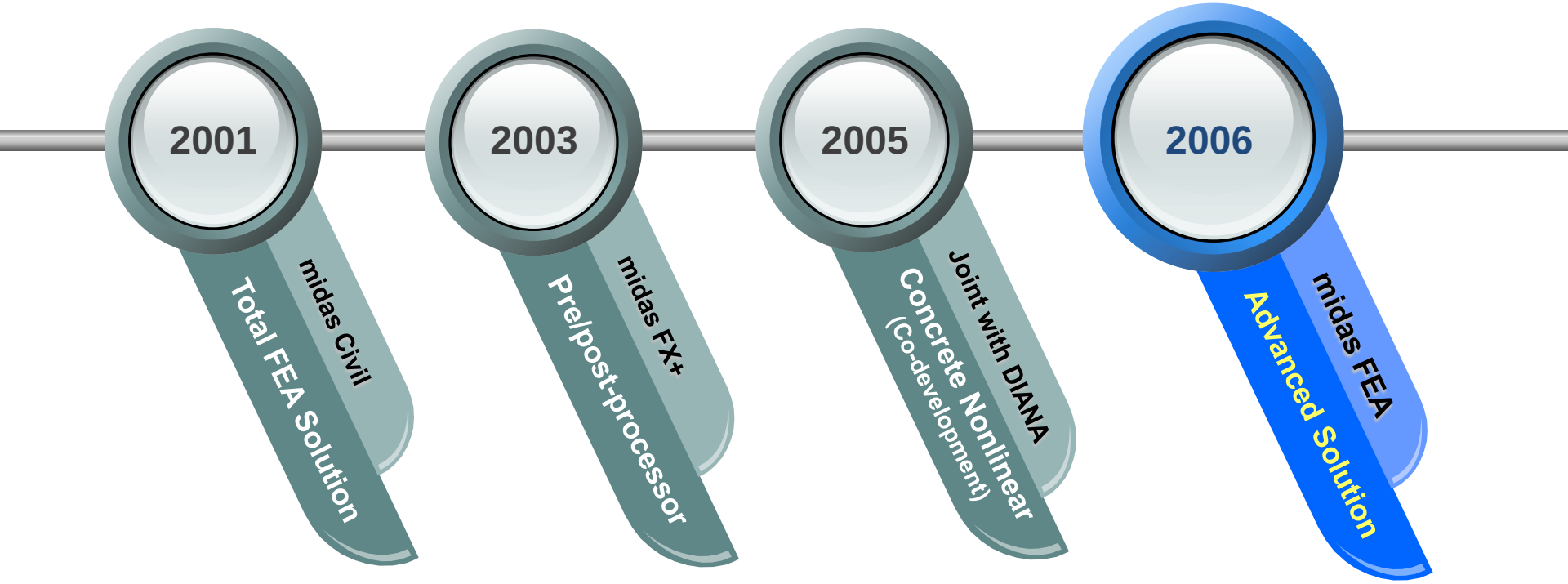


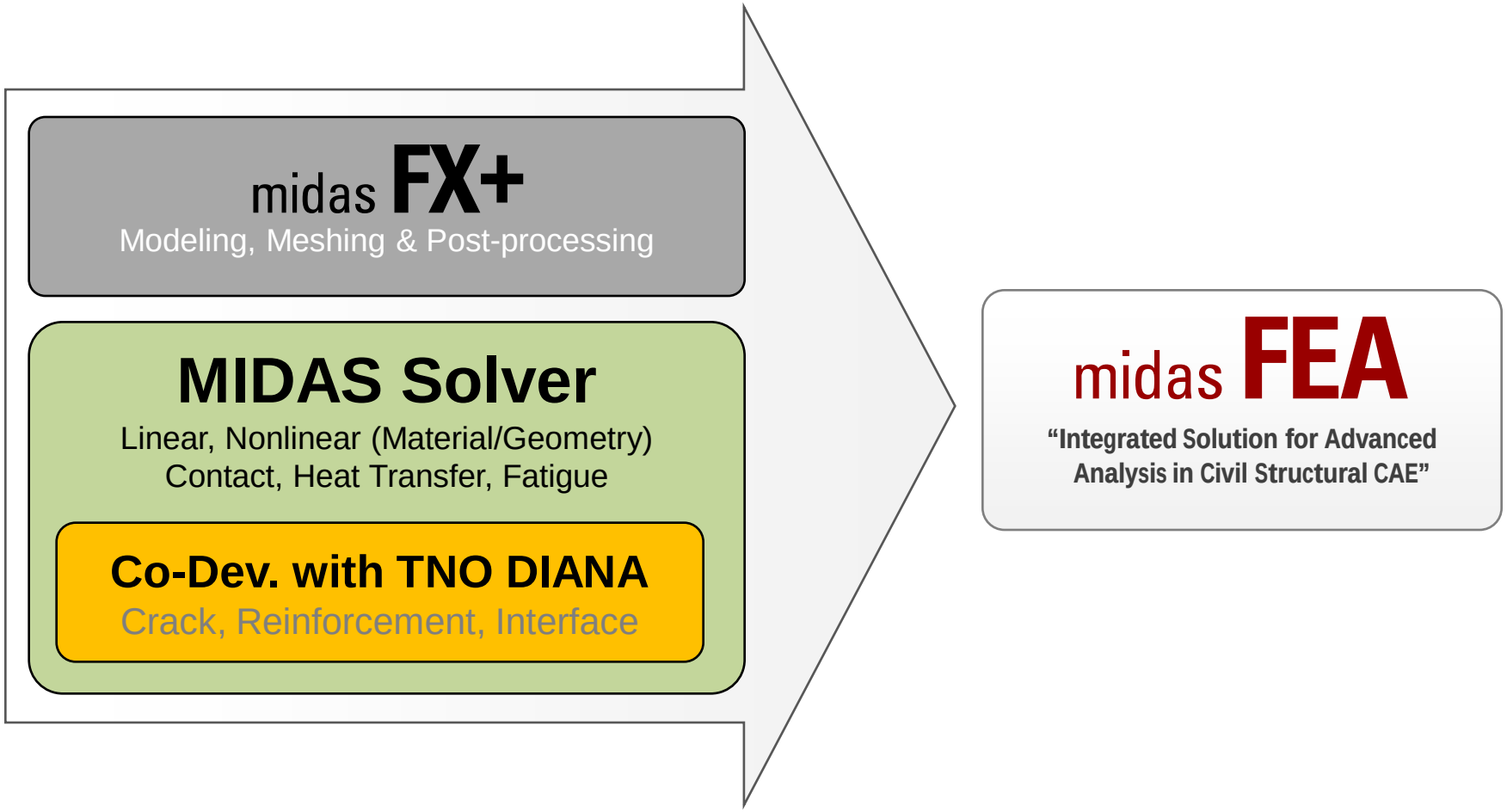
*Advanced Nonlinear and Detail Analysis Program*

# midas FEA

# Overview

"FEA is a state-of-the art **integrated finite element analysis system** for **nonlinear and detail simulations** of **civil and building structures**..."



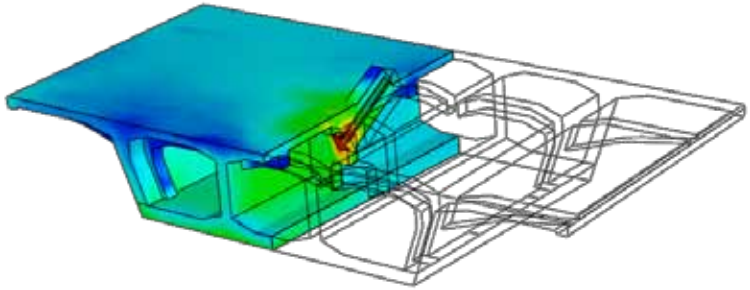

midas FX+
Modeling, Meshing & Post-processing
MIDAS Solver
Linear, Nonlinear (Material/Geometry)
Contact, Heat Transfer, Fatigue
Co-Dev. with TNO DIANA
Crack, Reinforcement, Interface
midas FEA
"Integrated Solution for Advanced Analysis in Civil Structural CAE"

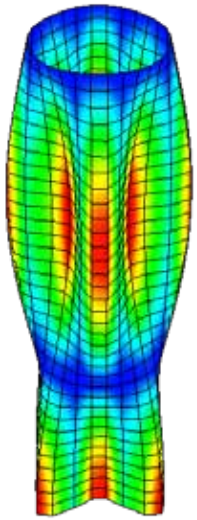
- Static Analysis
- Construction Stage Analysis
- Moving Load Analysis

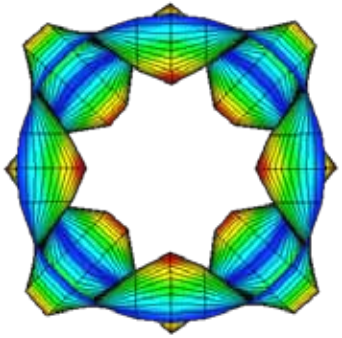
- Modal Analysis
- Linear Buckling Analysis
- Transient / Frequency / Response Spectrum Analysis

- Material / Geometry Nonlinearity Analysis
- Interface Nonlinearity Analysis
- Reinforcement Analysis
- Cracking Analysis
- Static/Explicit Contact Analysis

- Heat Transfer Analysis
- Fatigue Analysis
- Fluid Dynamics Analysis







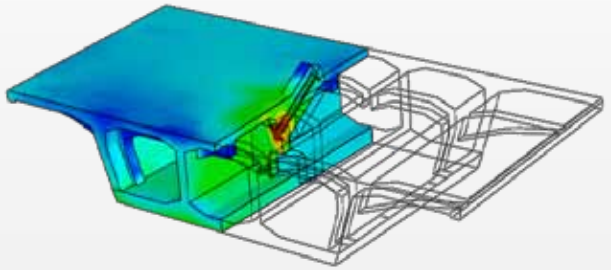
## General Detail Analysis (Linear, Material/Geometry Nonlinear)

- General detail FE analysis (linear static/dynamic analysis of concrete and steel)
- Buckling analysis of steel structure with material and geometric nonlinearity

## Concrete, Interface and Reinforcement Nonlinear Analysis

- Detail analysis of composite structure (steel + concrete)

  Thermal analysis and differential shrinkage analysis of steel-concrete composite girder, concrete filled steel tube and core of the SRC pier and so on
- 3D detail analysis considering steel, concrete and reinforcement simultaneously
- Detail analysis of CFT and analysis of the long-term behavior (differential settlement)
- Crack initiation and propagation in concrete structure
- Discrete modeling and analysis of masonry
- Composite modeling and analysis of wall in shear
- Detail analysis for tendon anchorage

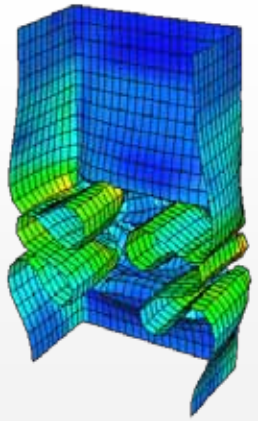


## Thermo-Elastic Analysis (Heat Transfer, Heat of Hydration)

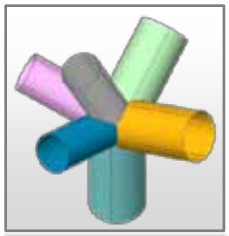
- Analysis of heat of hydration (general, special, nonlinear)
- Detail analysis for assessment of shear capacity of pavement (de-bonding failure)
- Analysis of thermal effect due to the asphalt pavement (guss asphalt)
- Fire effect on a reinforced concrete slab
- Evaluation of residual stress and integrity of welded part

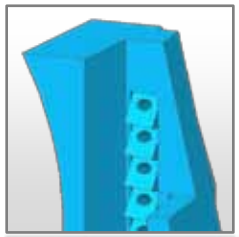
## Special Analysis (CFD, Contact, Fatigue, etc.)

- Crack and fatigue analysis of the surface of structures
- Damage estimation of pier/waterbreak impacted by ship
- Life-cycle prediction of steel-box bridges based-on moving load analysis
- Fluid dynamics analysis of bridges, high-rise buildings and tunnels
- Semi-coupled fluid-structure interaction analysis
- Direct analysis of soil-structure interaction
- High-end detail analysis (crash, fatigue, fracture mechanism)

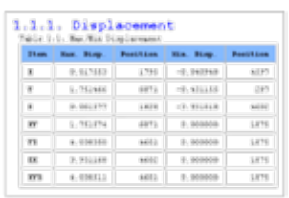


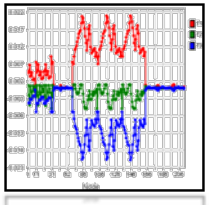
Geometry Modeler

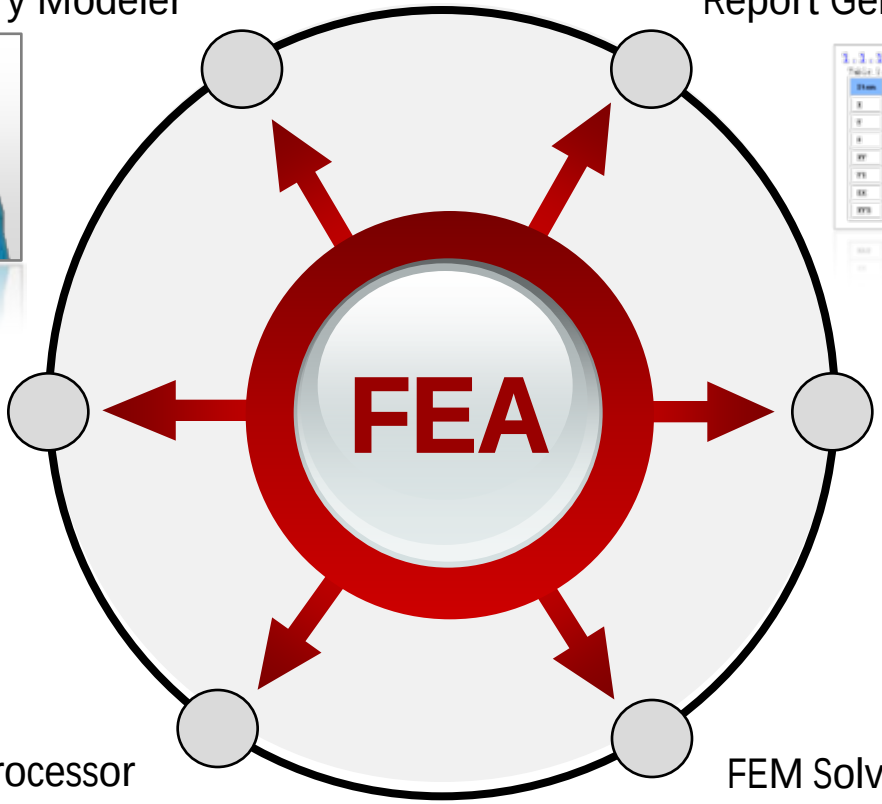




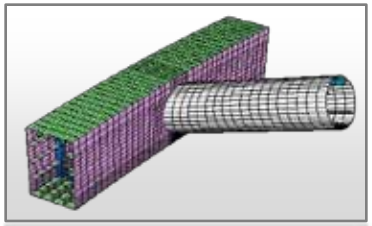
Report Generator



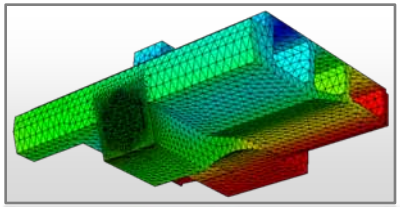




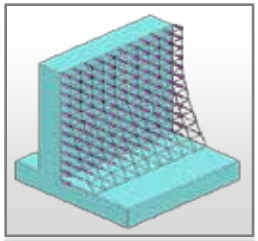

Mesh Generator

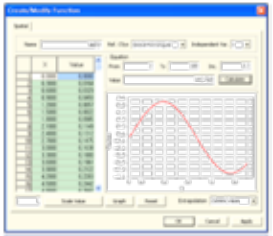


Post-processor

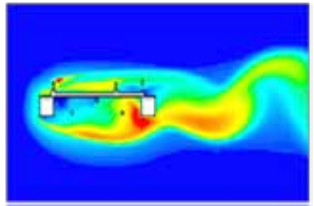


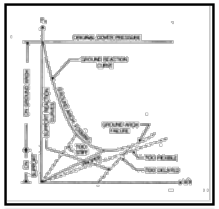
FEM Pre-processor

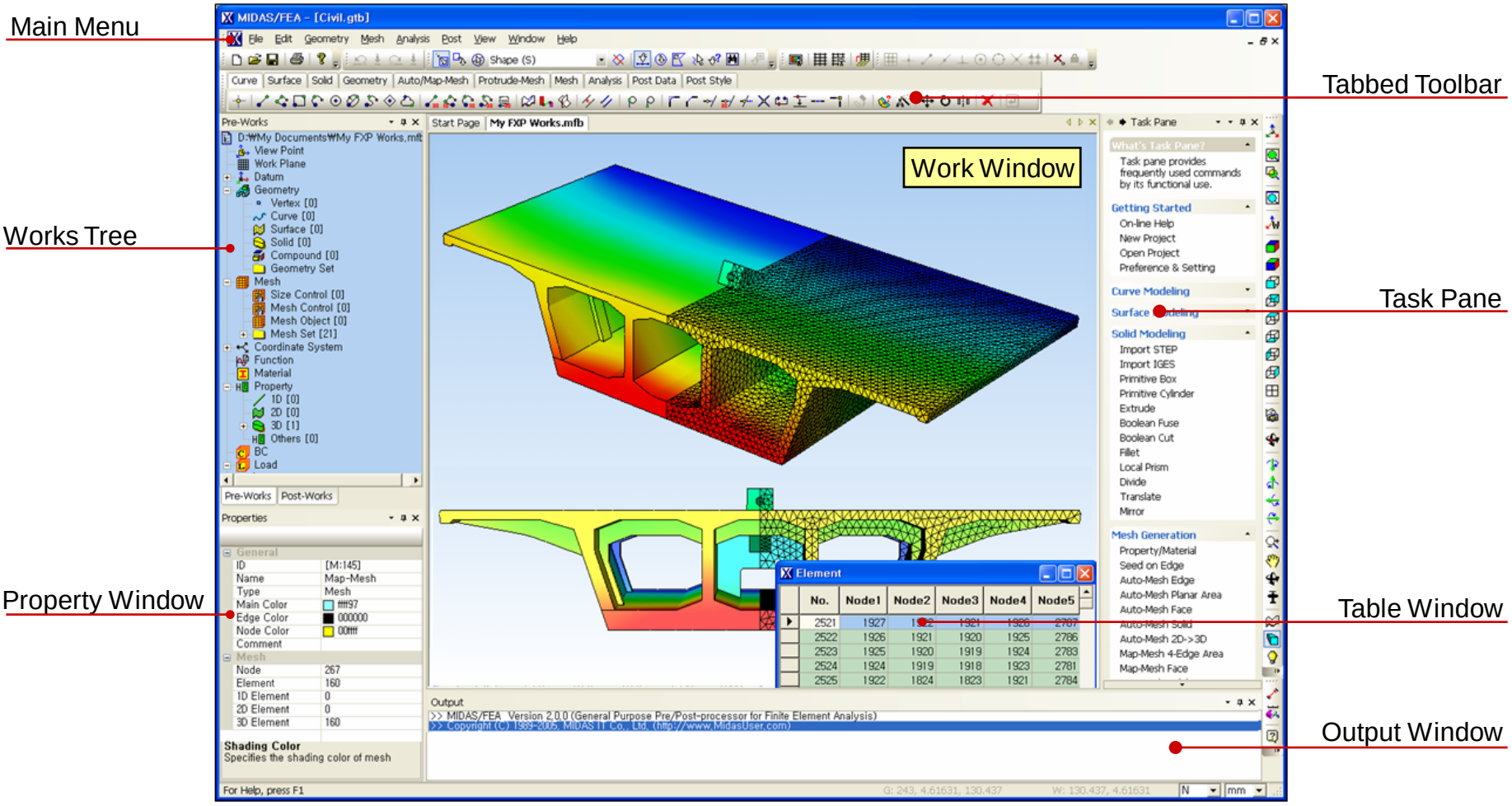




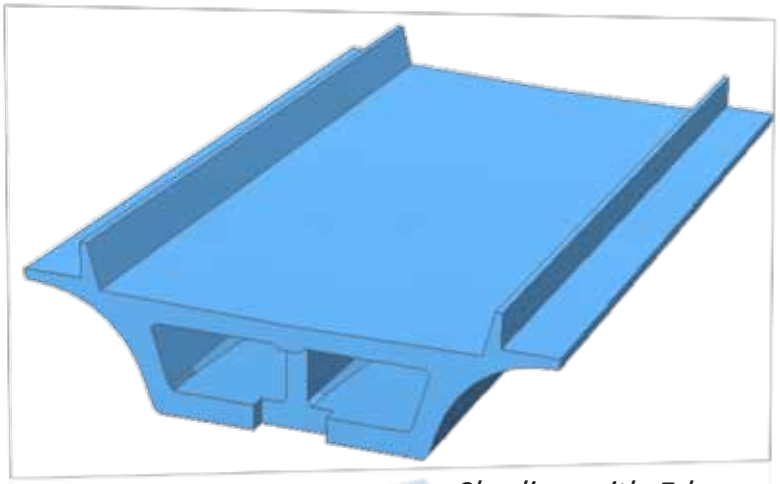
FEM Solver



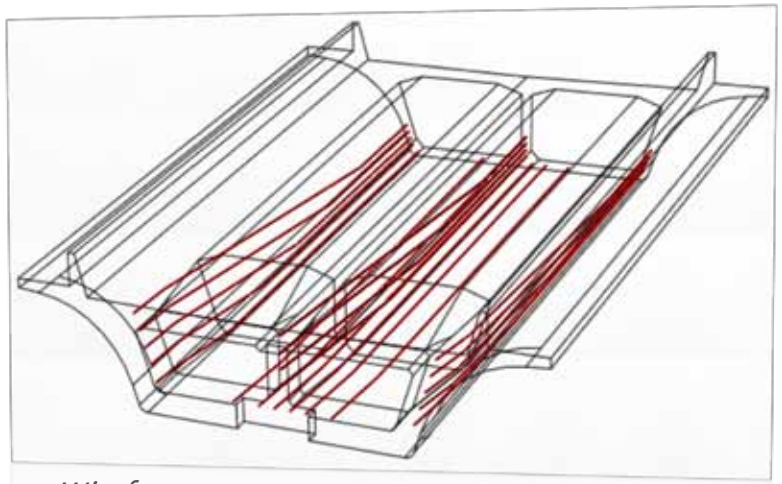




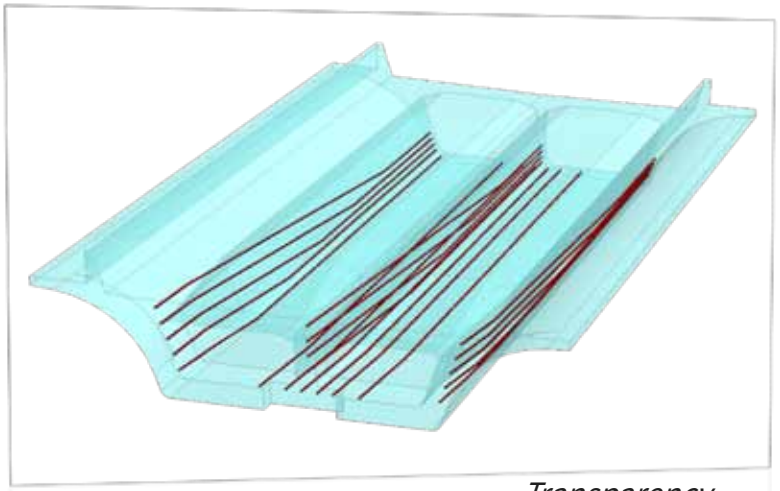

**Developed based-on Task-oriented Design Paradigm**



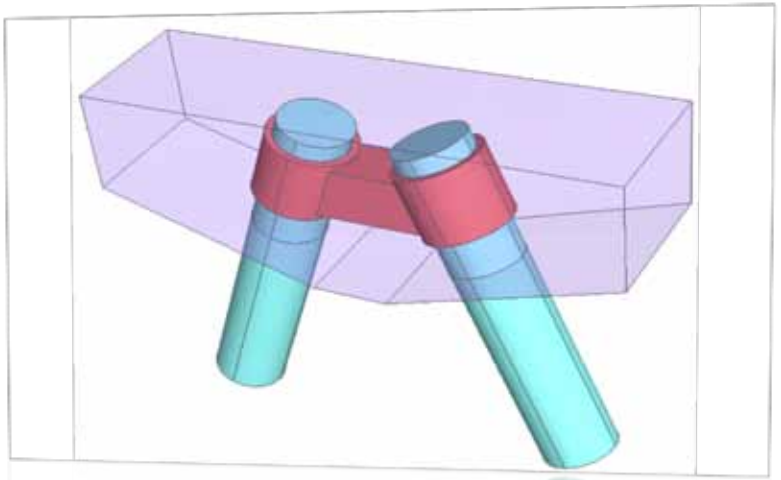
*Shading with Edge*



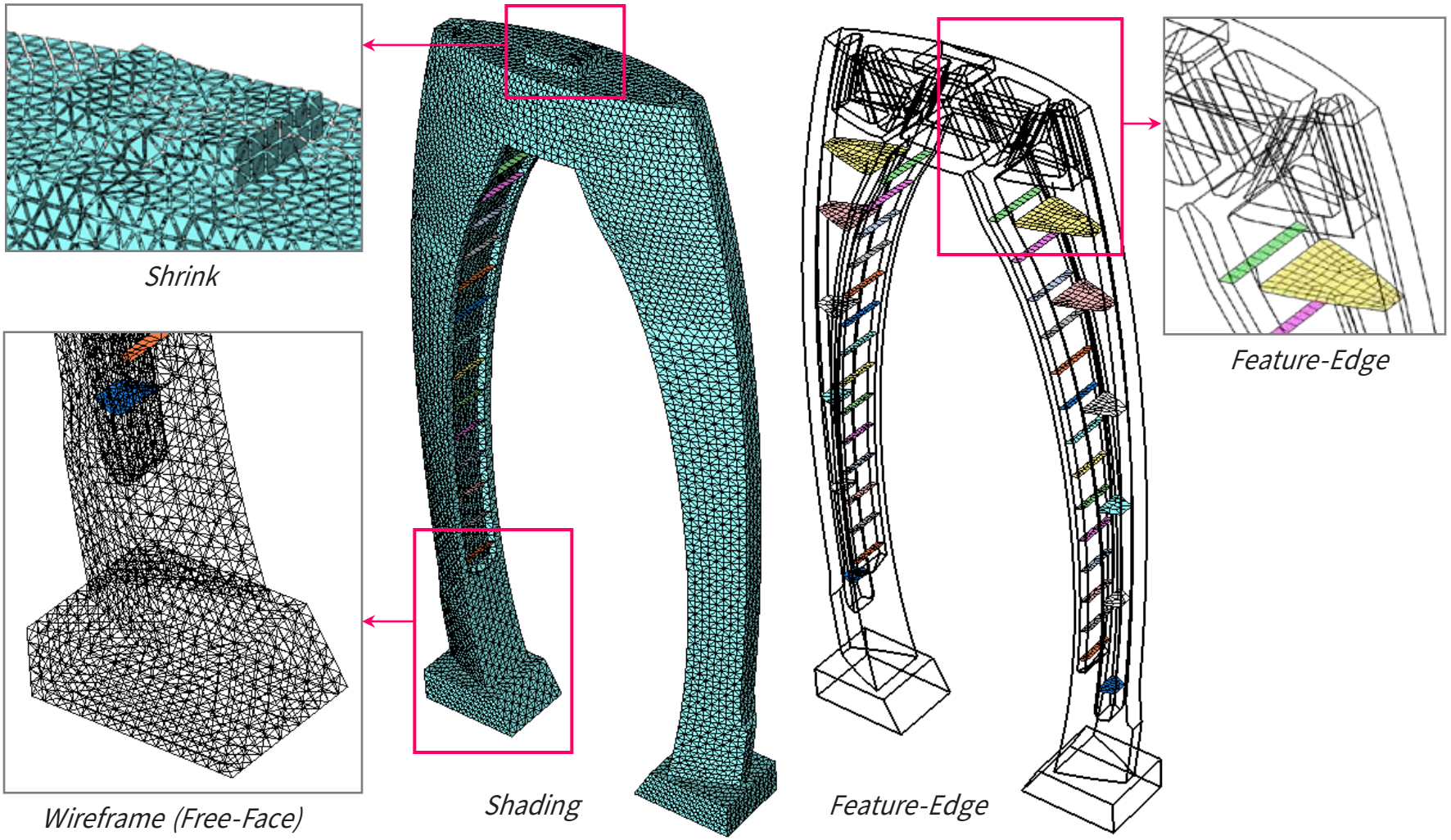
*Wireframe*

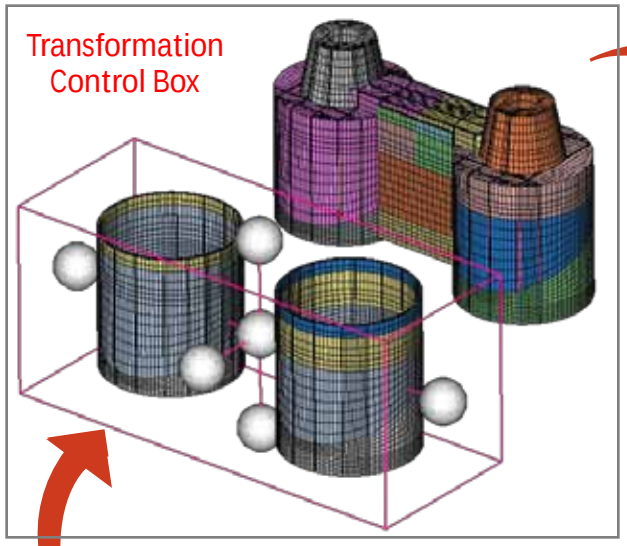


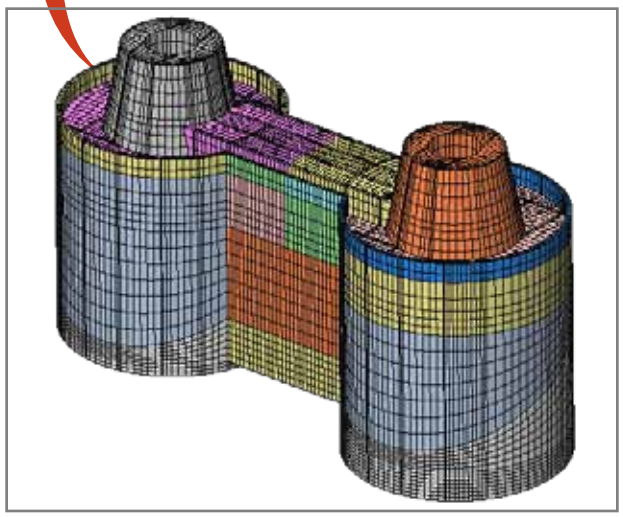
*Transparency*



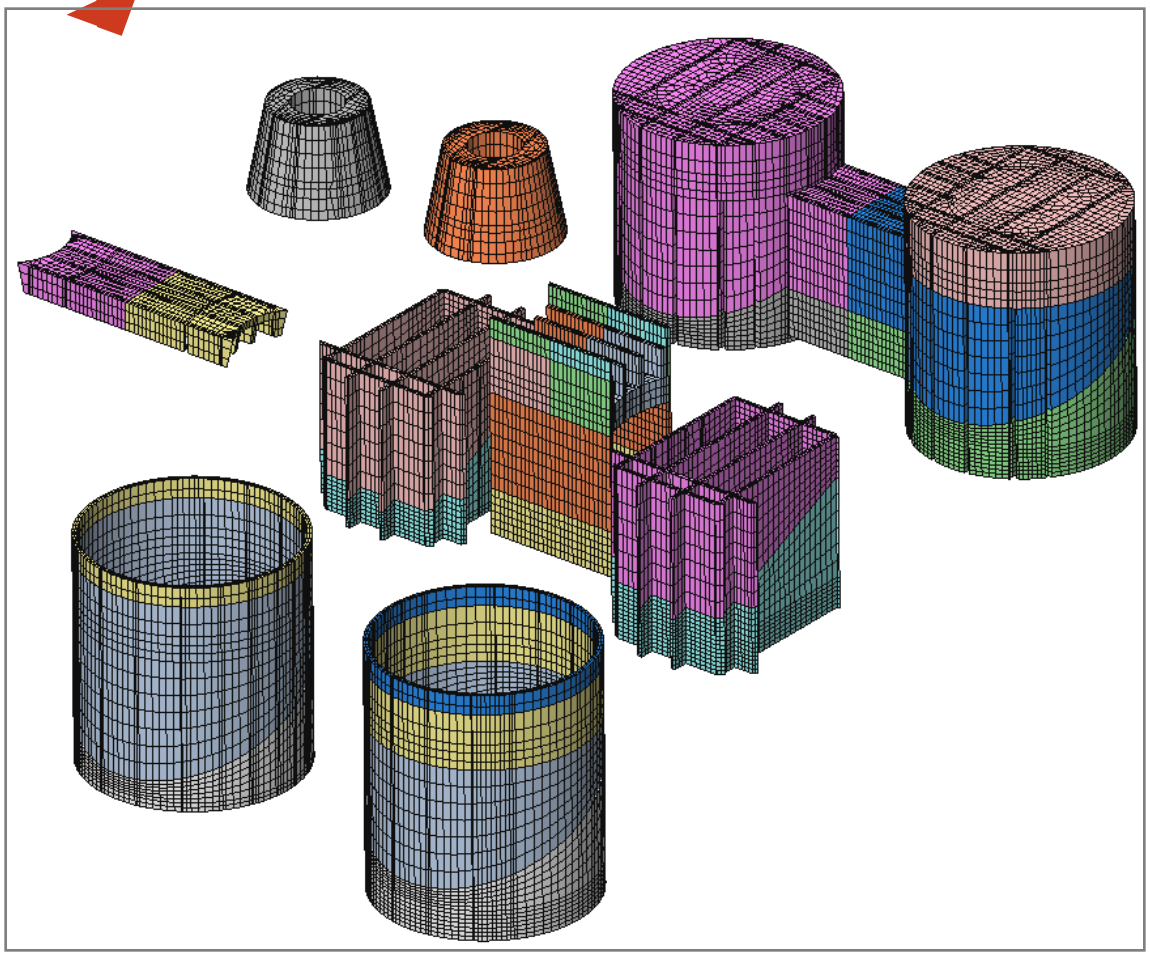
*Shading + Transparency*

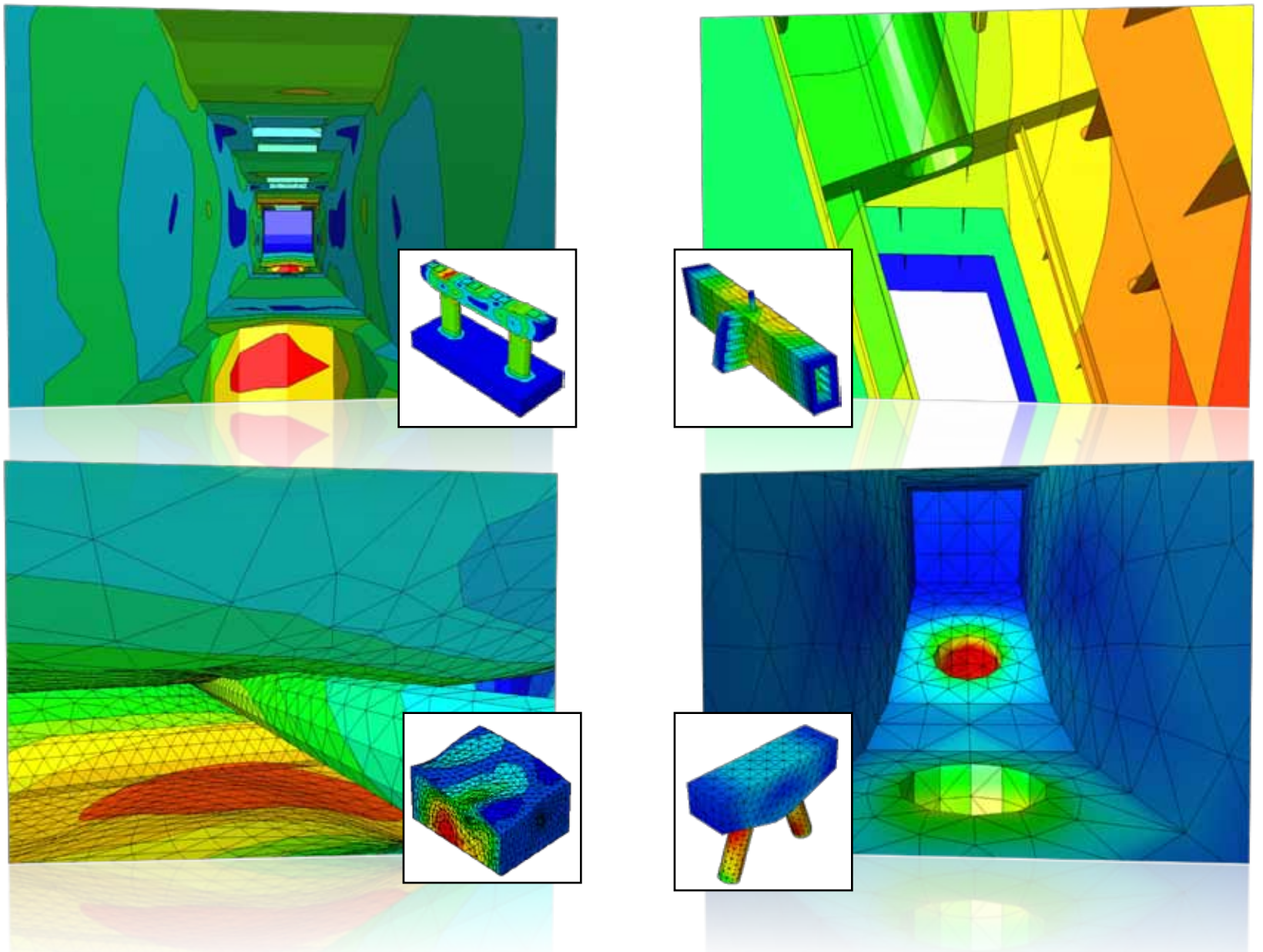

Shrink
Feature-Edge
Wireframe (Free-Face)
Shading
Feature-Edge



Virtual Transformation (Translation, Rotation, Scaling)
by Mouse Dragging





## Geometry Model Data

- **Import (Geometry)**
  - STEP, IGES
  - ACIS*, Parasolid*
  - SolidWorks*, Inventor*, etc.
  - AutoCAD DWG / DXF

  → '*' marked CAD interfaces are options.

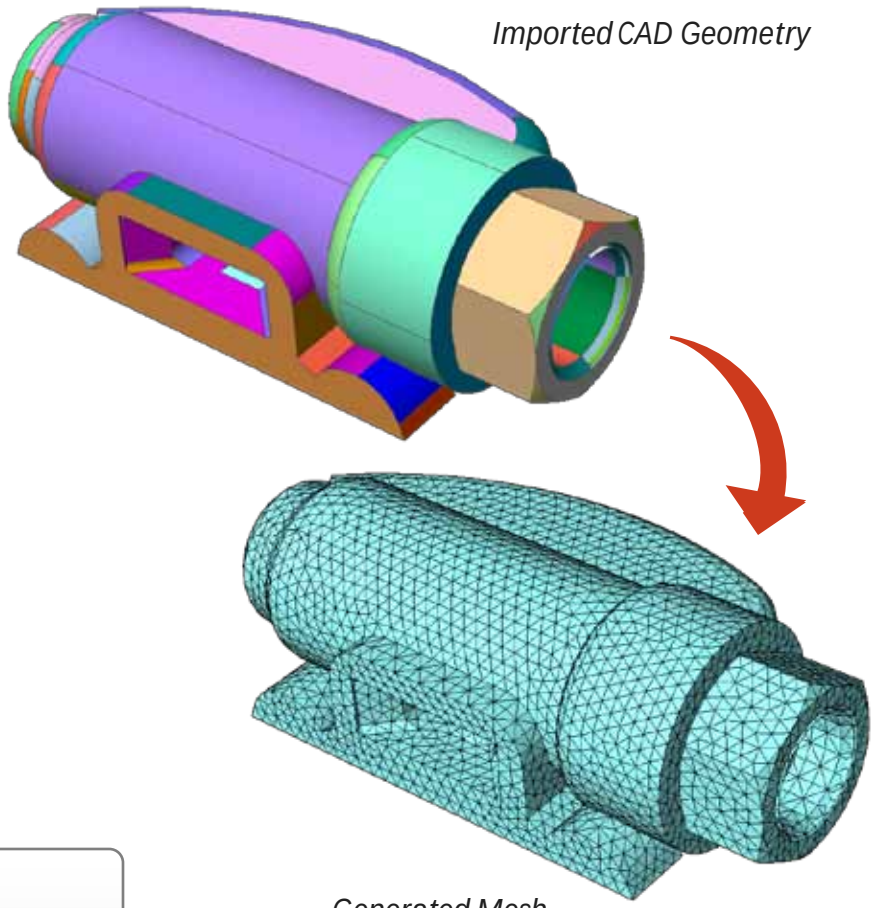
- **Export (Geometry)**
  - STEP, IGES

## Analysis Model Data

- **Import (Analysis Data)**
  - DIANA, MSC/NASTRAN
  - Neutral (Text)
- **Export (Analysis Data)**
  - MIDAS/Civil, MIDAS/Gen
  - Neutral (Text)

## Standards for CAD Data Exchange

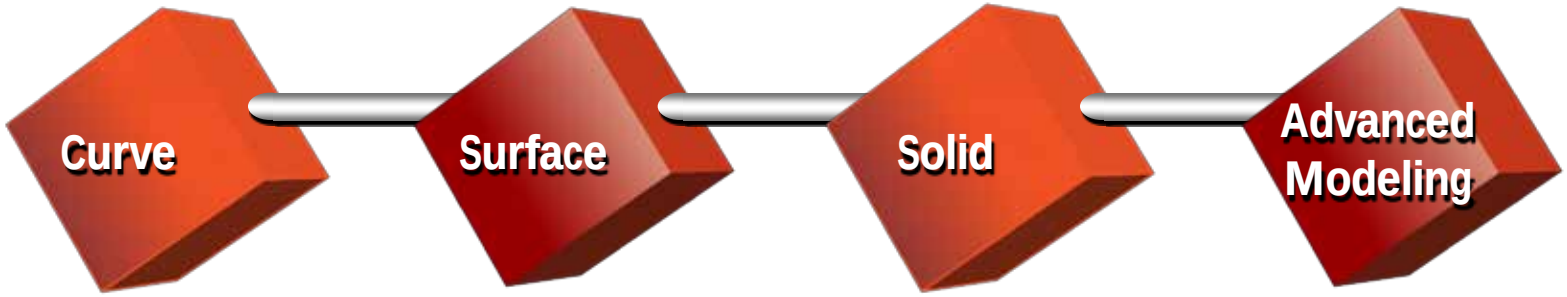
- STEP (**ST**andard for the **E**xchange of **P**roduct Model Data)
- IGES (**I**nitial **Gra**ph**ics** **E**xchange **S**pecification)



*Imported CAD Geometry*

*Generated Mesh*

# Geometry Modeling




- Line, Polyline
- Arc, Circle
- Polygon
- B-Spline
- Tunnel Section
- Fillet, Chamfer
- Trim, Extend
- Intersect
- Offset, Tangent
- Break, Merge

...

- Plane Patch
- Coons Patch
- NURBS Patch
- Grid Patch
- Vertex Patch
- Fillet, Chamfer
- Sew, Fuse
- Trim, Divide
- Extend
- Imprint

...

- Box, Wedge
- Cylinder, Cone
- Sphere, Torus
- Trim, Divide
- Embed
- Boolean Op. (Fuse, Cut, ...)
- Stitch Surfaces

...

- Extrude
- Revolve
- Loft
- Sweep
- Fillet, Chamfer
- Offset, Draft
- Shelling
- Local Prism
- Check, Repair
- Transform

...

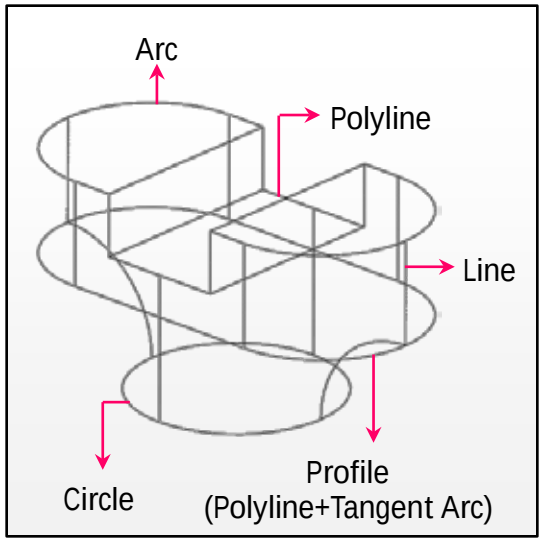
**Advanced modeling functions support both top-down and bottom-up approaches in surface & solid modeling.**

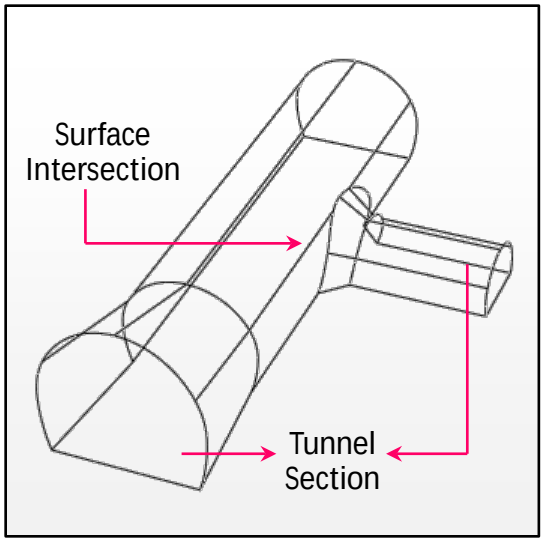
## Generation

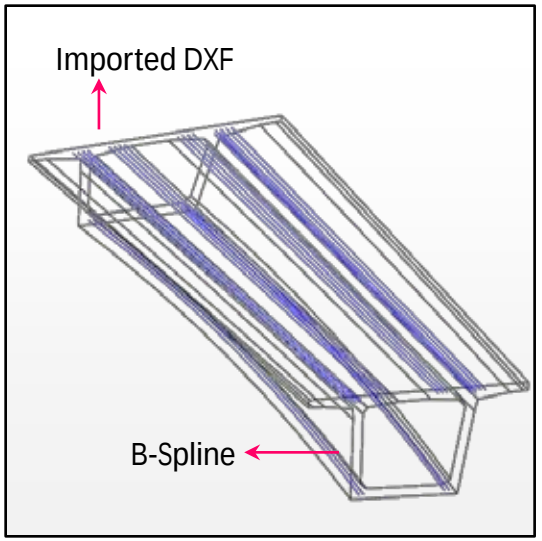
- Line
- Arc
- Circle
- Ellipse
- Parabola
- Hyperbola
- B-Spline
- Polyline
- Rectangle
- Polygon
- Profile
- Tunnel
- On-Surface Curve
- Shortest Path Line
- Surface Intersection
- Offset Curve
- Extrude Vertex
- Tangent Line

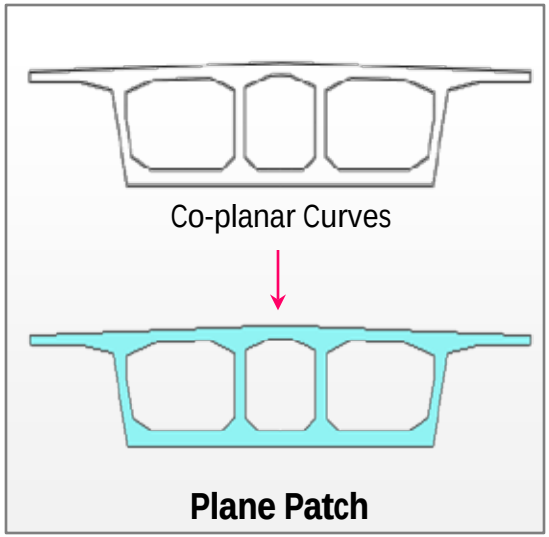
## Modification

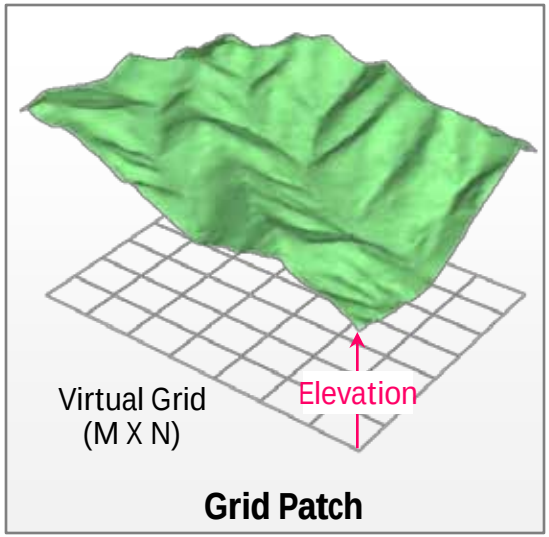
- Fillet / Chamfer
- Trim / Extend
- Merge / Break
- Intersect
- Align, Coincide
- Make Wire

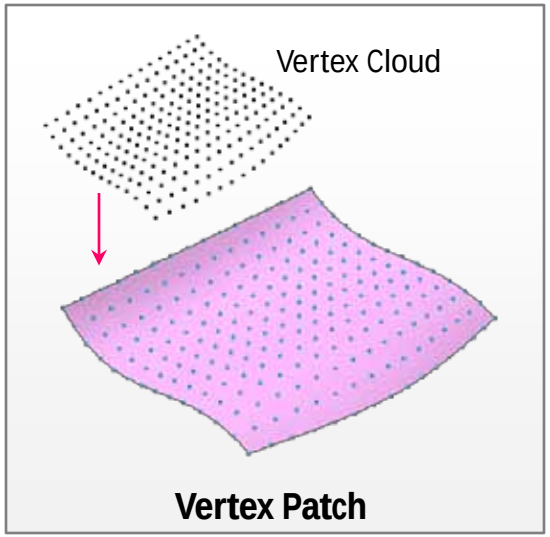


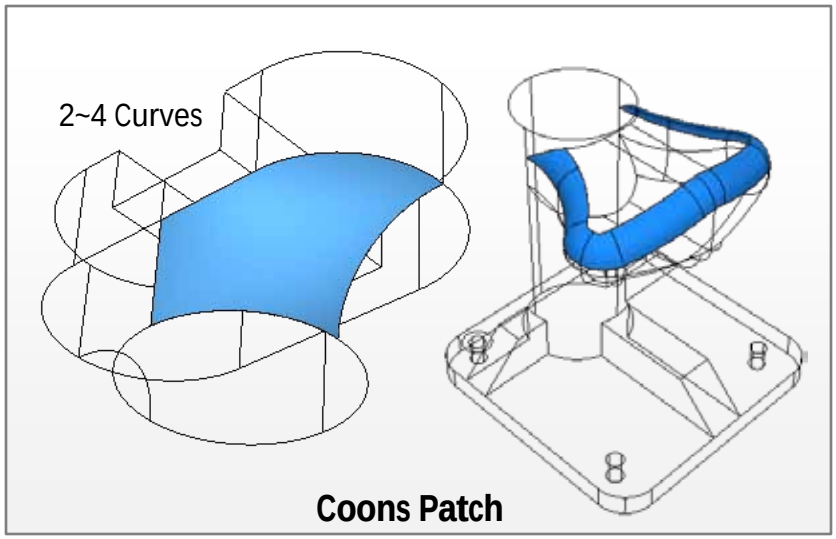



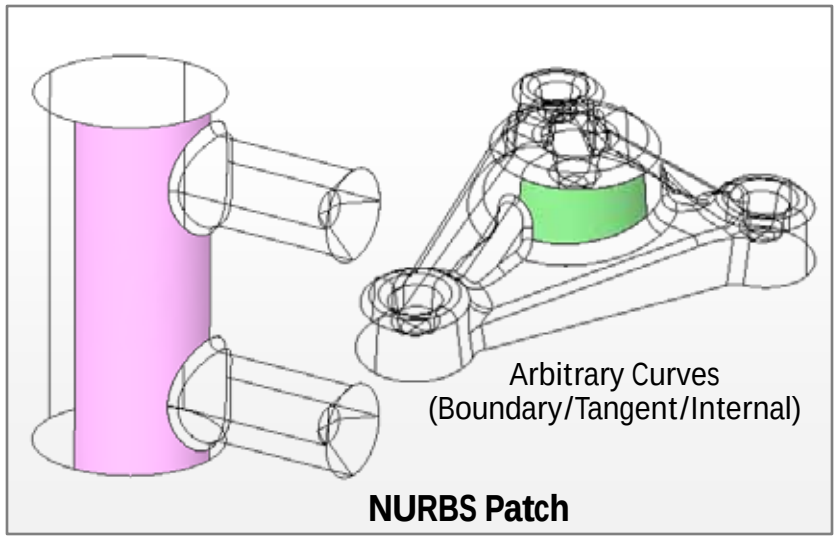



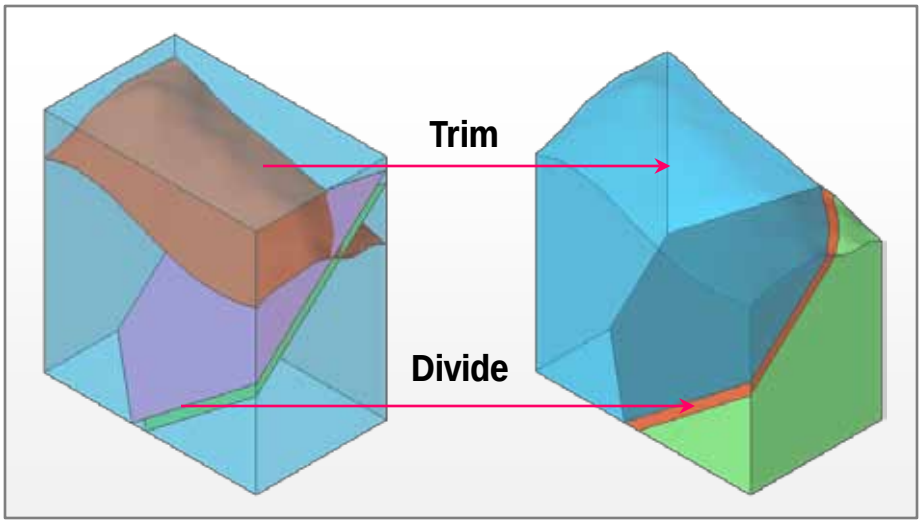

Co-planar Curves
Plane Patch

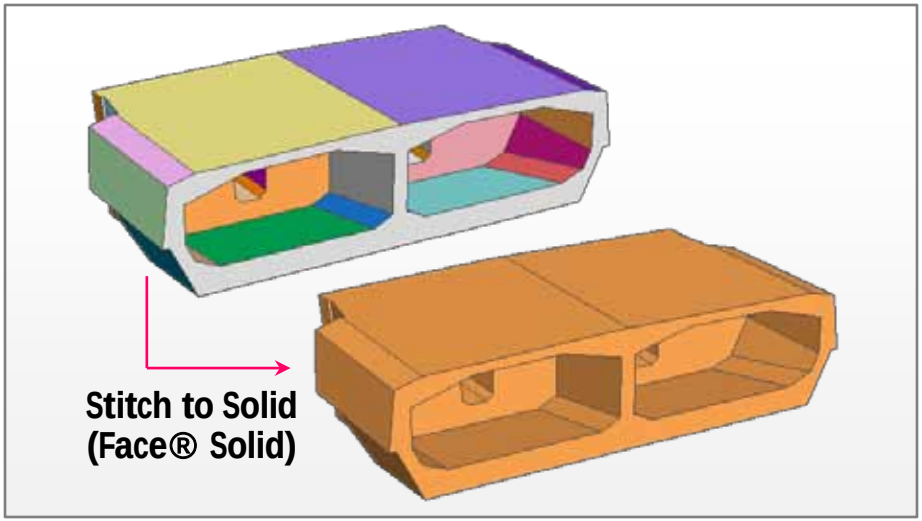

Virtual Grid
(M X N)
Elevation
Grid Patch


Vertex Cloud
Vertex Patch

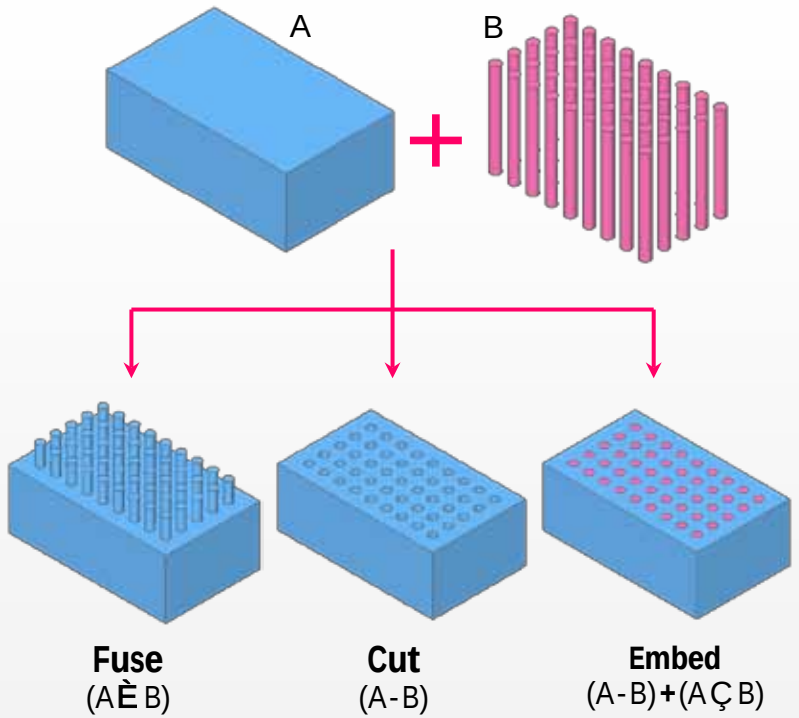

2~4 Curves
Coons Patch


Arbitrary Curves
(Boundary/Tangent/Internal)
NURBS Patch

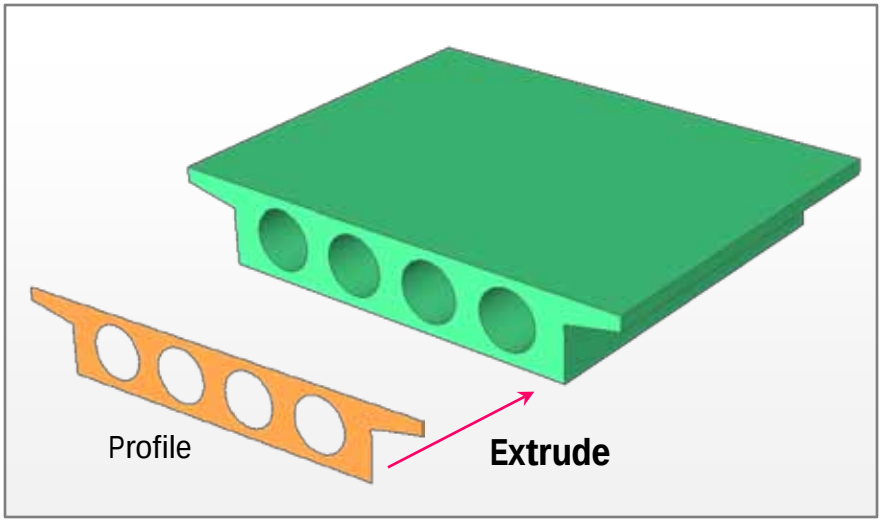


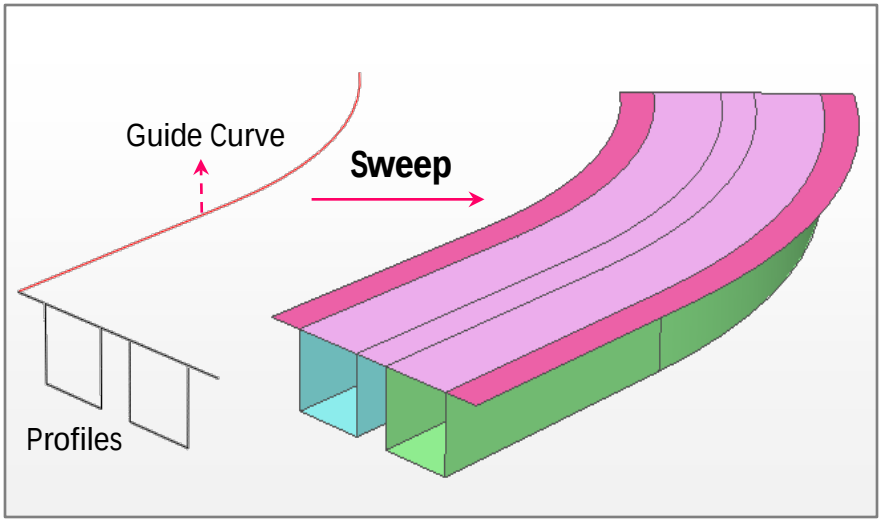



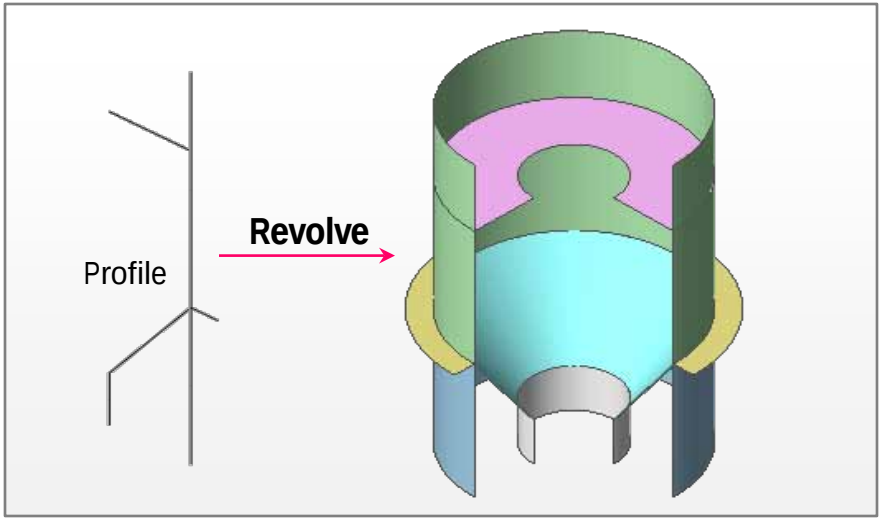

## Boolean Operation

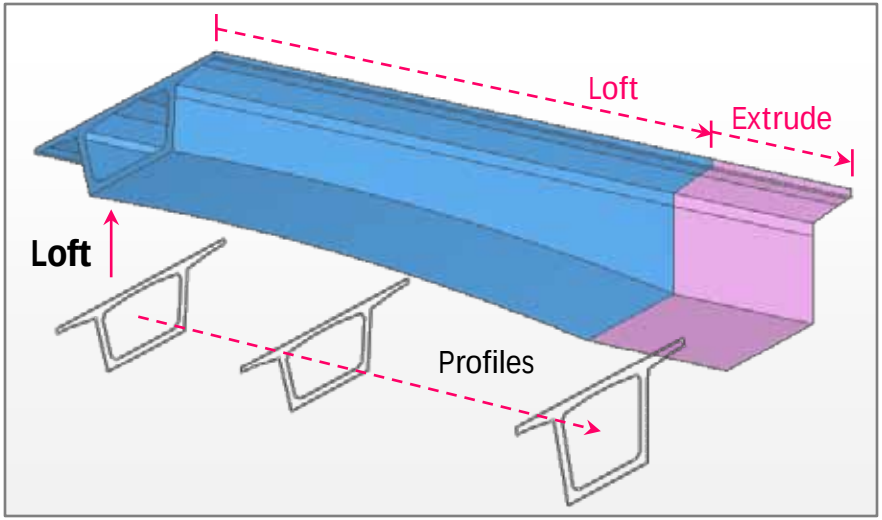


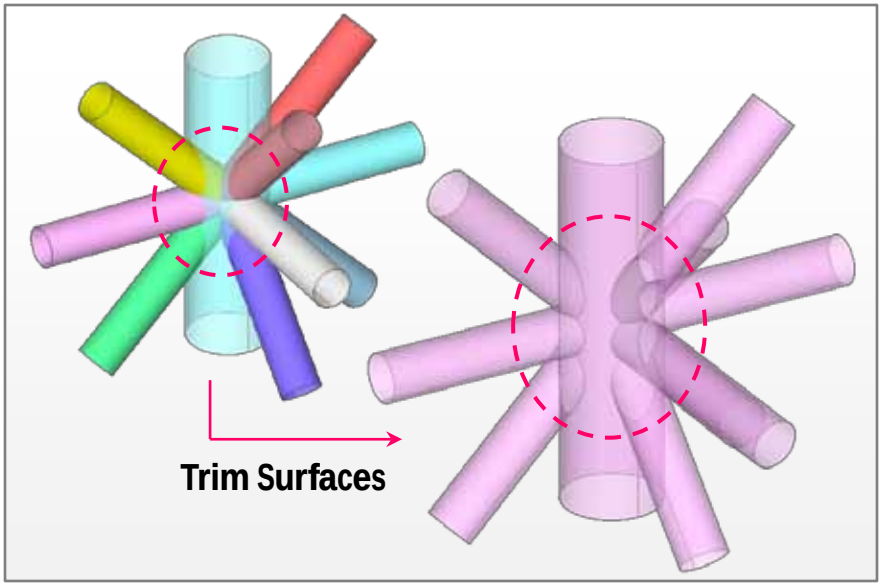

**Boolean Common (A Ç B) operation is also provided.**

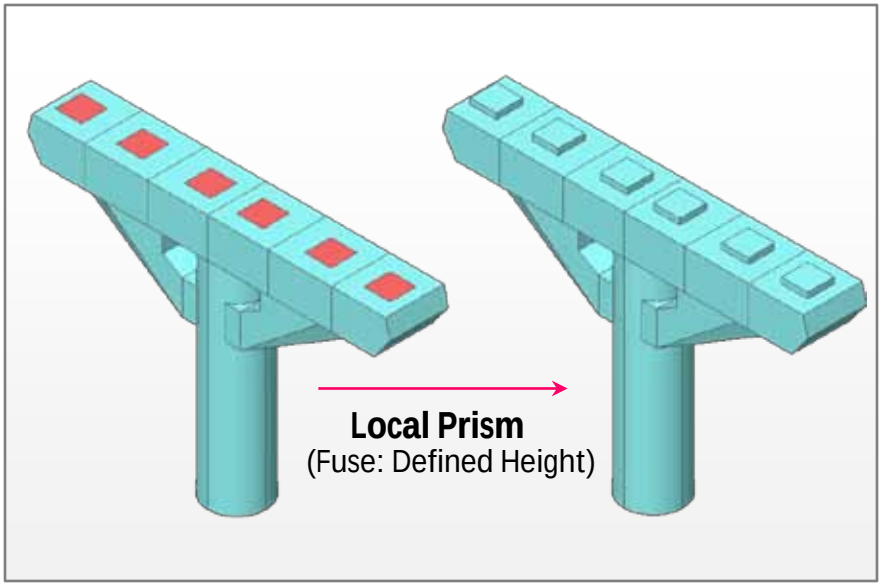

Profile
Extrude

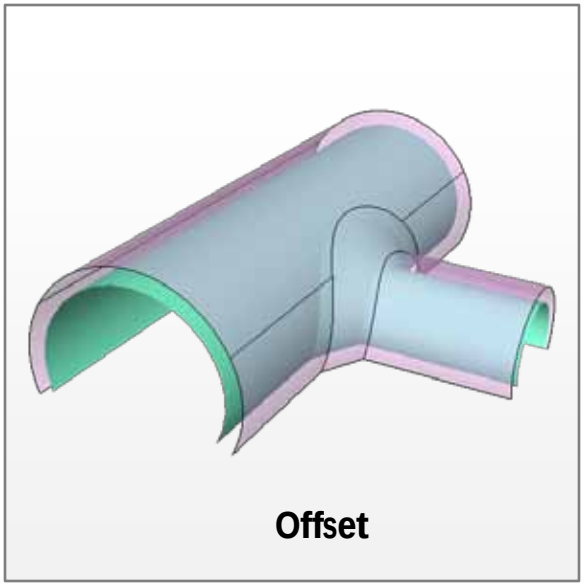

Guide Curve
Sweep
Profiles

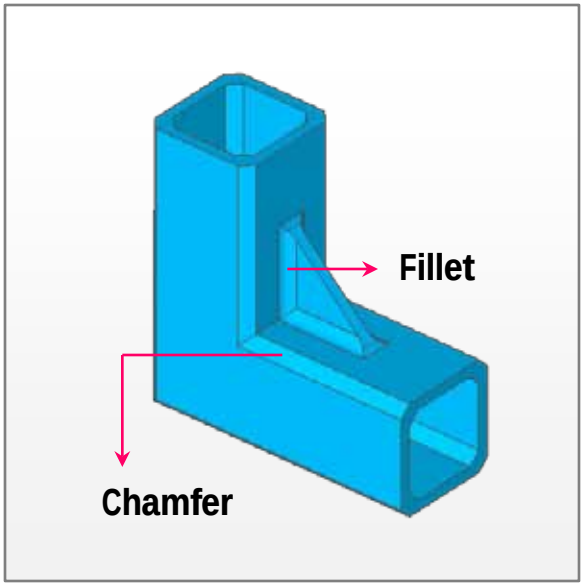

Profile
Revolve

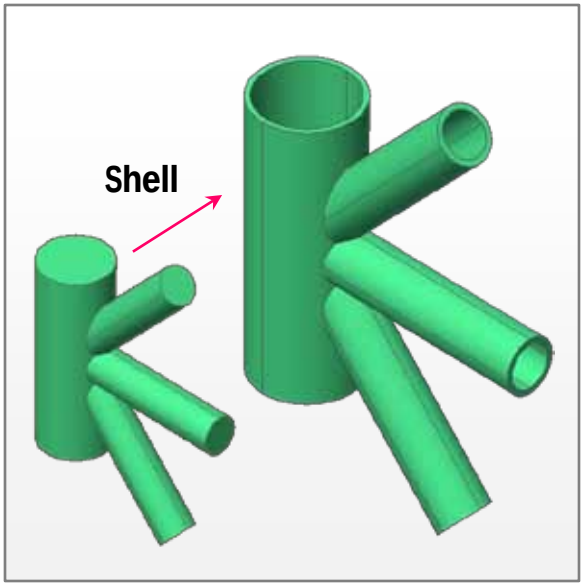

Loft
Extrude
Loft
Profiles


Trim Surfaces

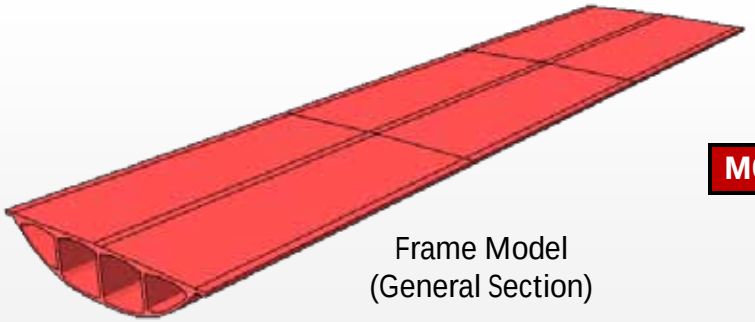

Local Prism
(Fuse: Defined Height)


Offset


Fillet
Chamfer


Shell

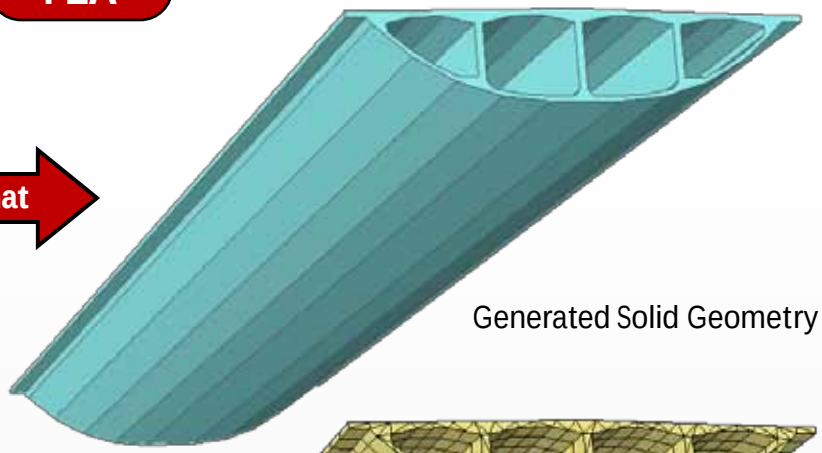
## Civil, Gen



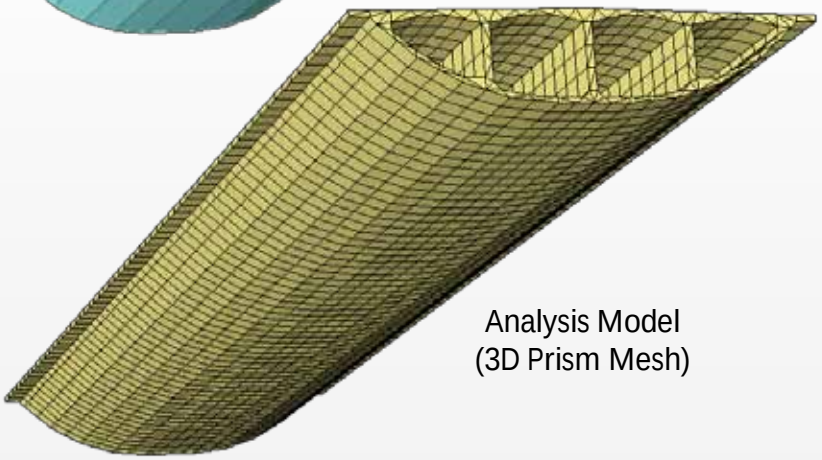
Frame Model
(General Section)

MCS Format

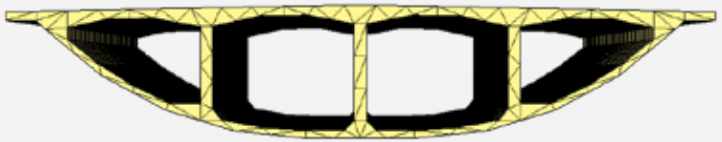
## FEA

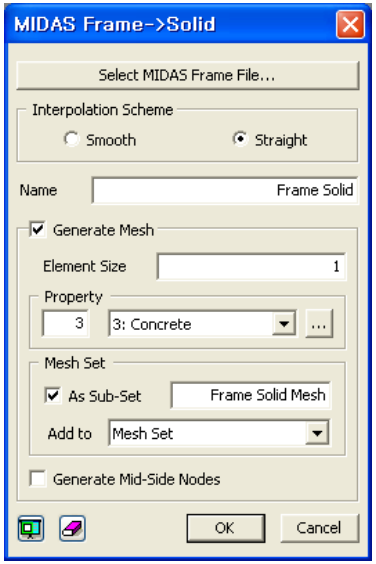


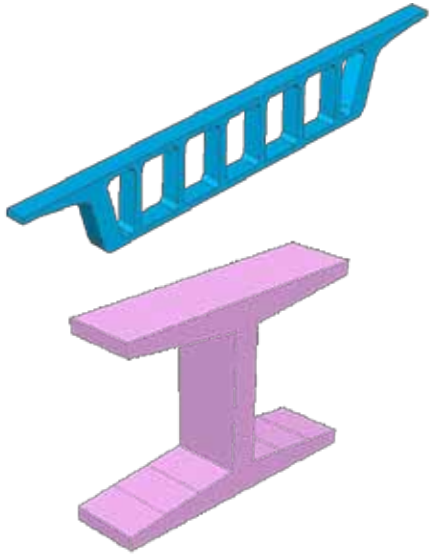
Generated Solid Geometry



Analysis Model
(3D Prism Mesh)

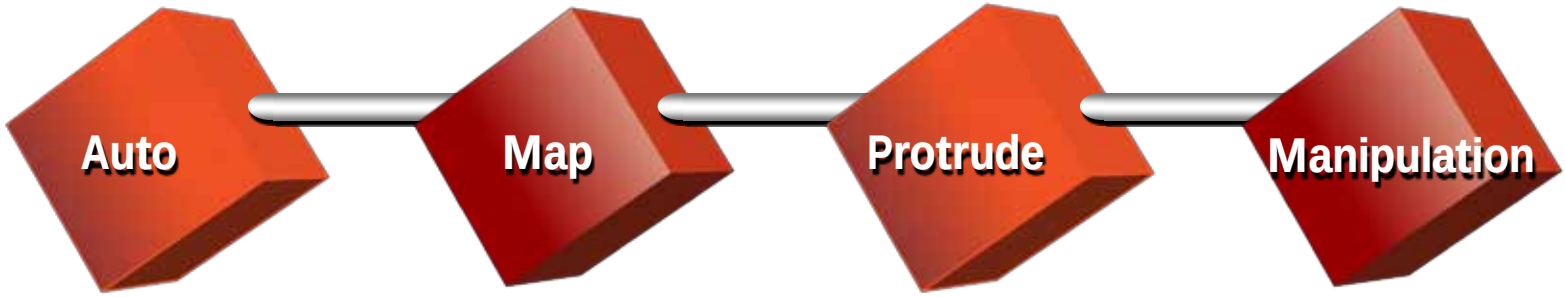




Frame® Solid Wizard automatically generates Solid Geometry & Mesh by importing Frame Model (*.MCS) from Civil and Gen.

# Mesh Generation




- Solid
- Surface
- Edge
- Planar Area
- 4-Curve Area
- 2D ® 3D

**Type**

- Quadrilateral
- Combined
- Triangle

- Solid
- Surface
- k-Curve Area
- k-Face Volume
- 4-Node Area

...

- Extrude
- Revolve
- Project
- Fill
- Sweep

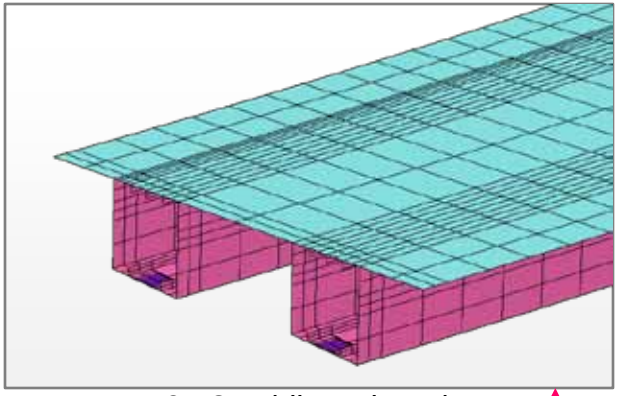
**Object**

- Geometry
- Element
- Node

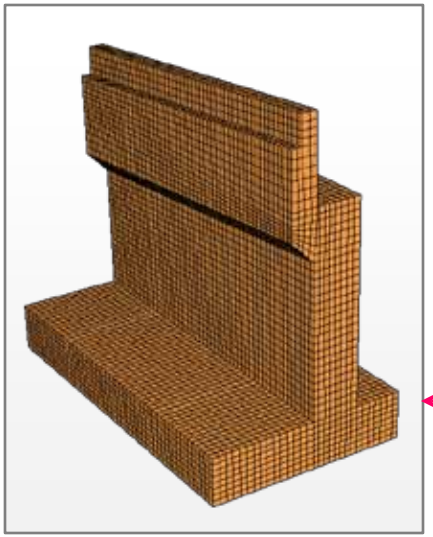
- Create
- Extract
- Connection
- Change Para.
- Smooth
- Divide
- Check
- Quality
- Merge
- Transform

...

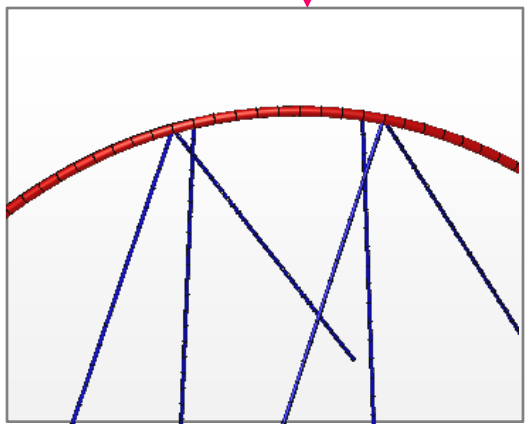
**Various of methods for generating Reinforcements and Interface Elements are provided. (auto & manual)**



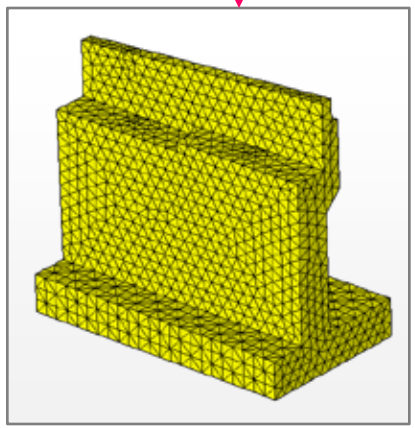
2D Quadrilateral Mesh



3D Hexahedral Mesh

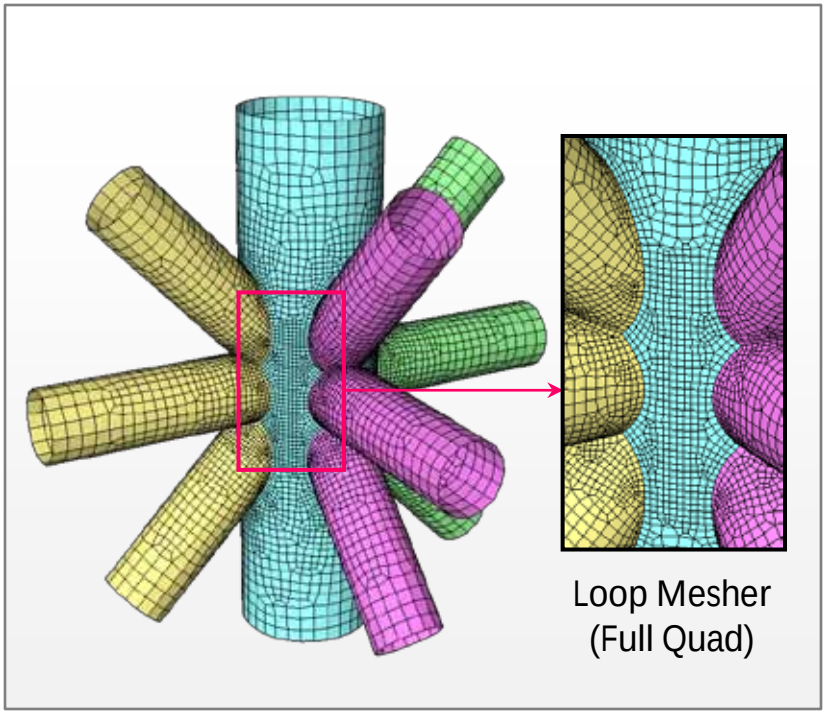


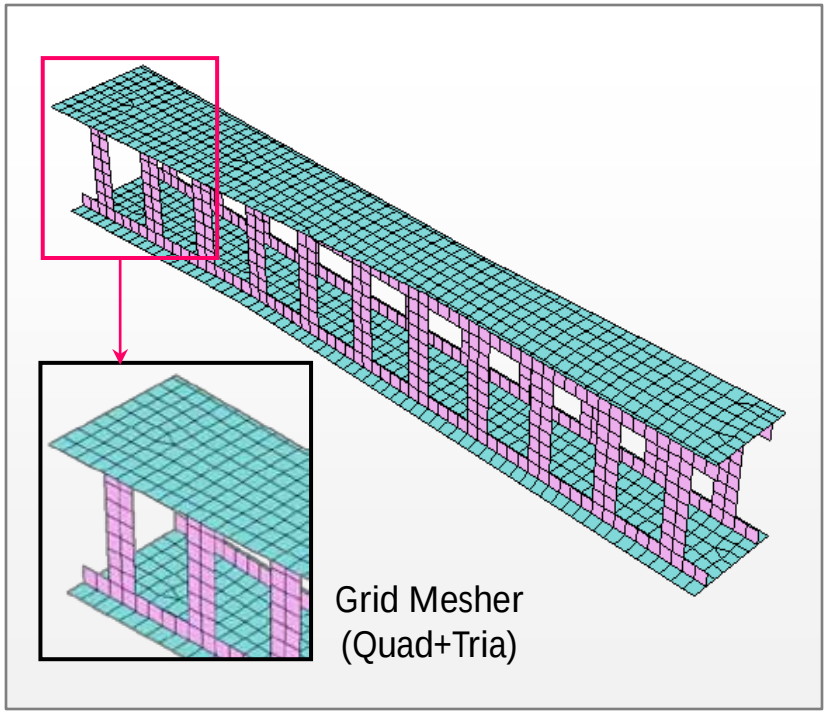
1D Linear Mesh



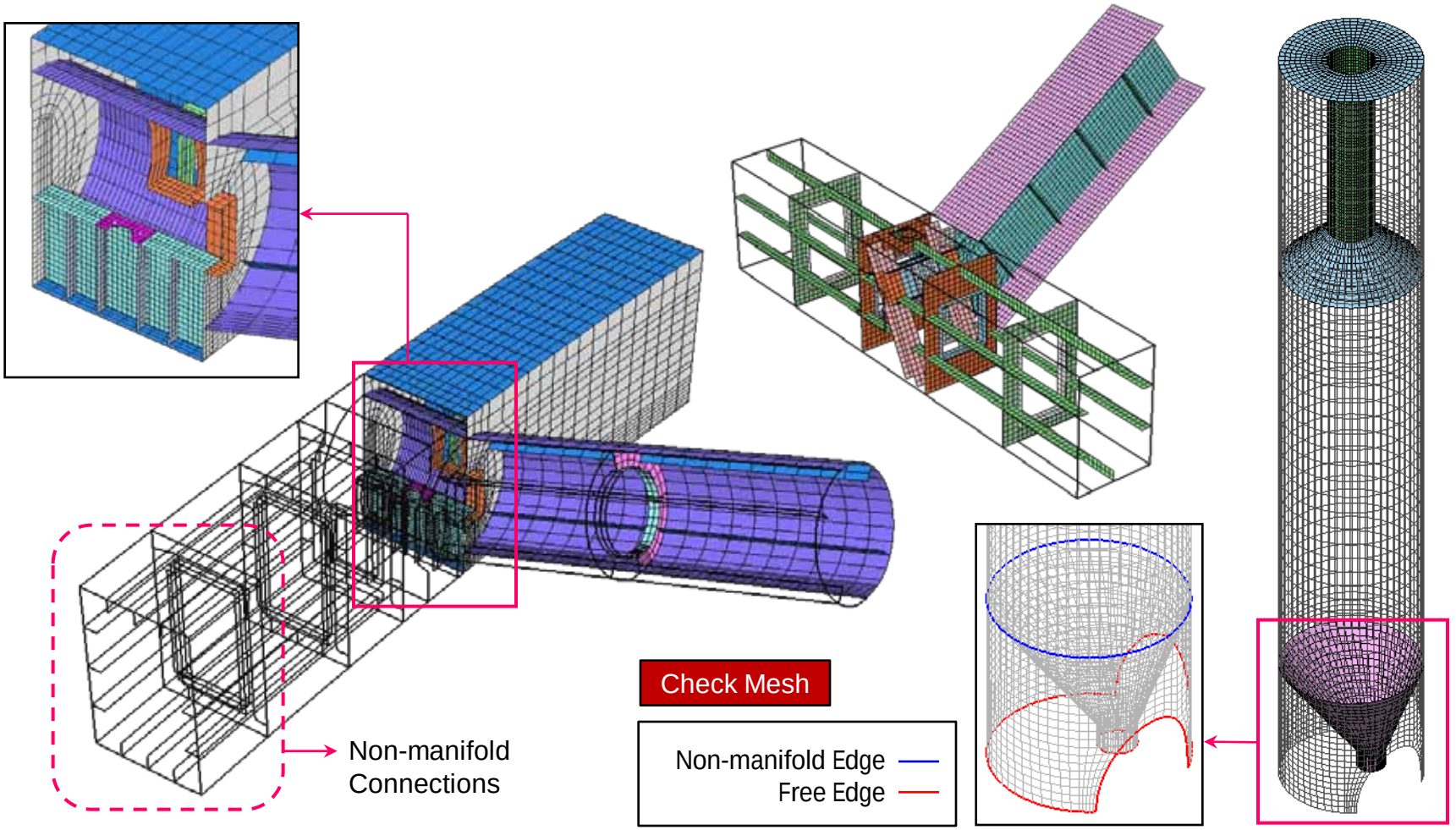
3D Tetrahedral Mesh

| | Regularity Uniformity | Boundary Sensitive | Orientation Insensitive | Sizing Control (< 1/2) | Internal Curve/Point |
|---|---|---|---|---|---|
| Loop Mesher | Ö | Ö | Ö | Ö | Ö |
| Grid Mesher | Ö | Ö | Ö | | Ö |
| Delaunay Mesher | Ö | Ö | Ö | Ö | Ö |

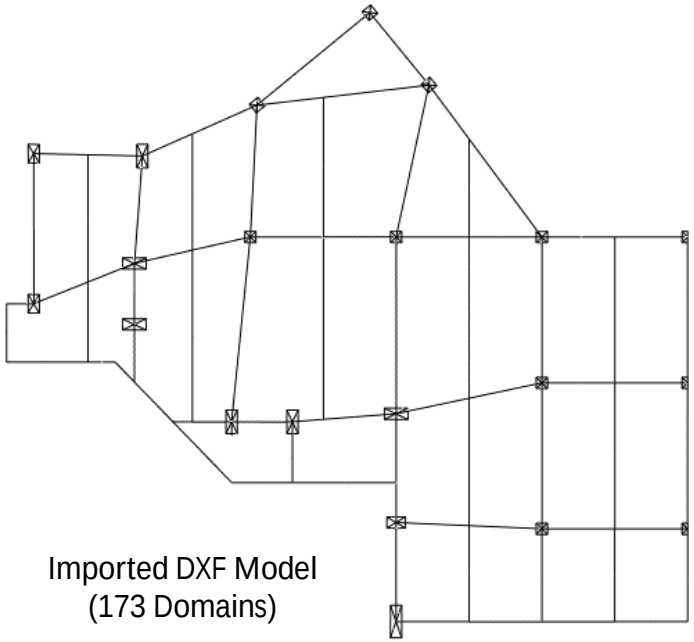


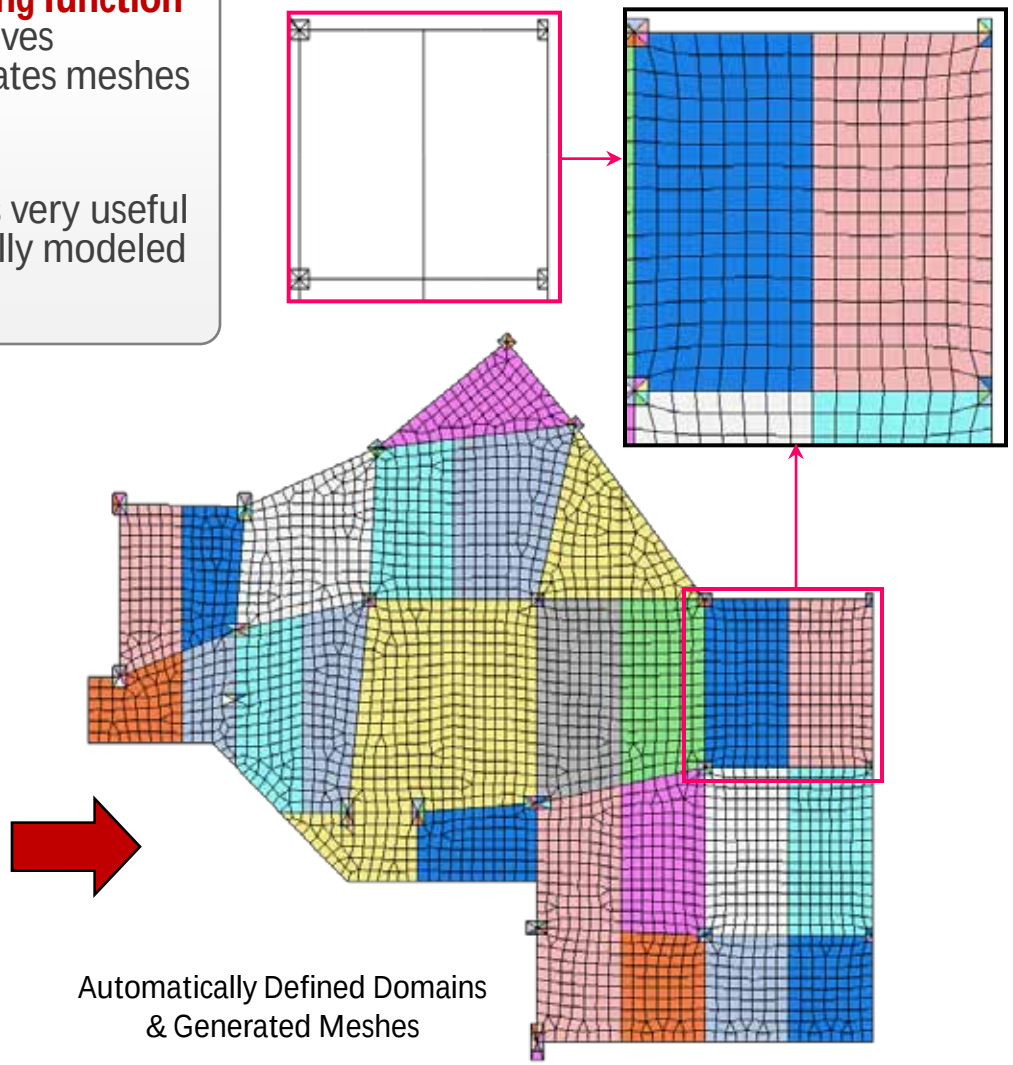
FEA provides a number of modeling and meshing functions for non-manifold surface models.



- FEA provides **automatic defining & meshing function** which defines mesh-able domains from curves (without creating surfaces) and then generates meshes for each domain.
- **Automatic defining & meshing function** is very useful for **complex 2D models** which were originally modeled in **AutoCAD**.

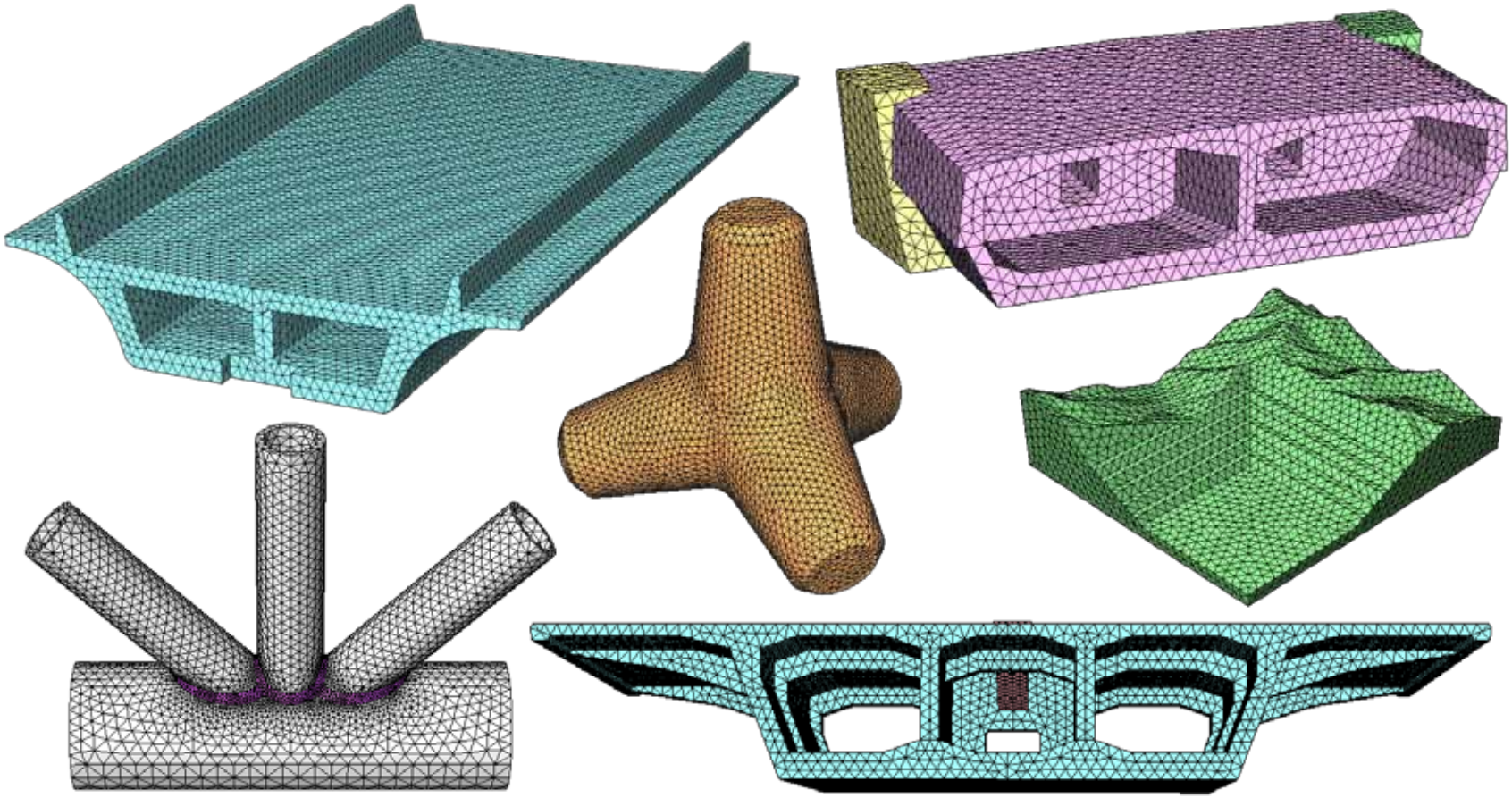


Imported DXF Model
(173 Domains)

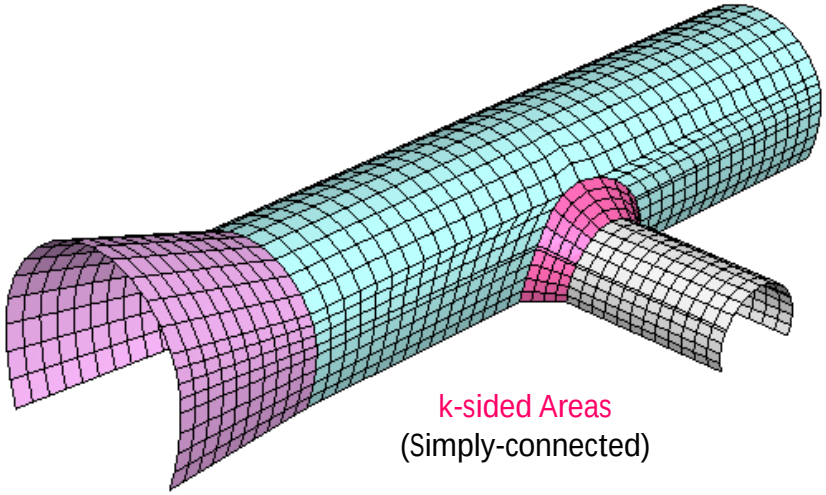


Automatically Defined Domains
& Generated Meshes

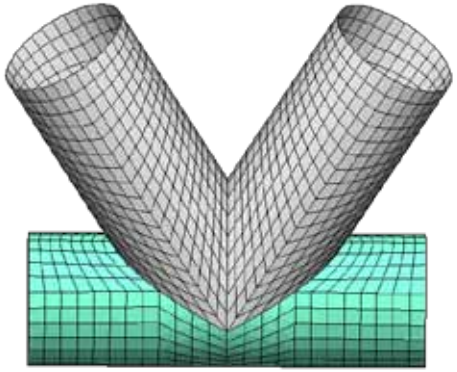
- FEA's **Tetra Mesher** auto-generates **tetrahedral solid mesh** with variable sizes in smooth transition. (**200,000 Tetra's/min**)
- FEA's **Tetra Mesher** is capable of including **holes, curves** and **points** that are present in/on solids.



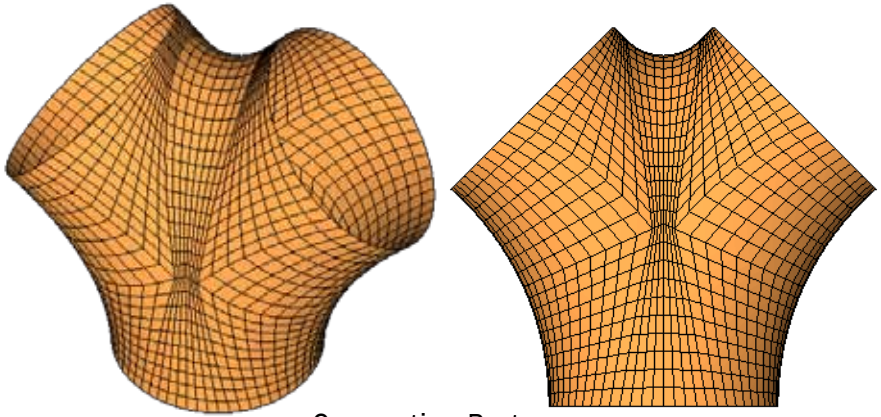
FEA's **Map Mesher** generates **structured (regular & orthogonal) mesh** both in surfaces and solids.



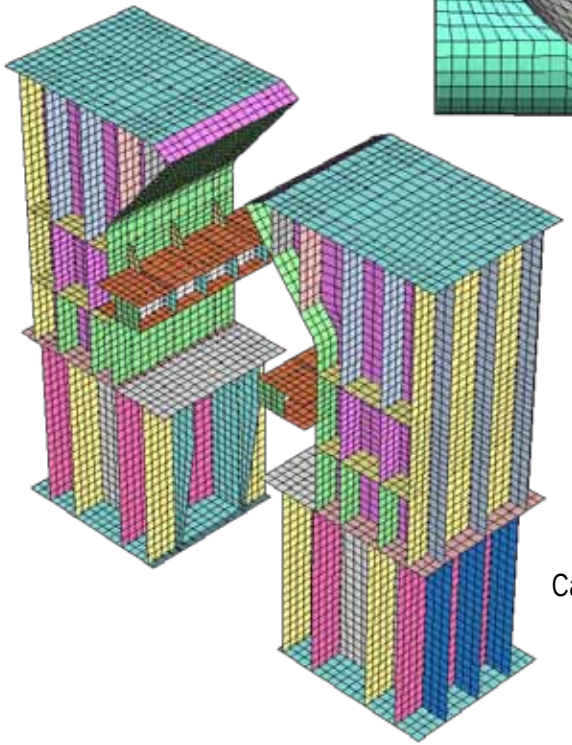
k-sided Areas
(Simply-connected)



Pipe Junction

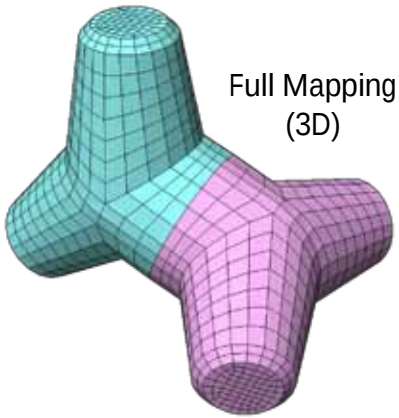


Connection Part

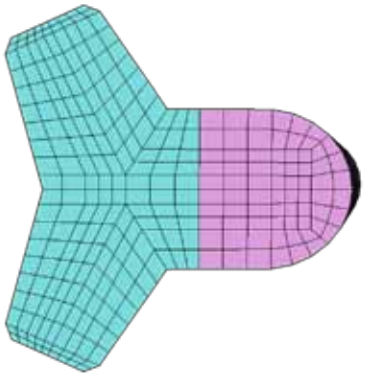


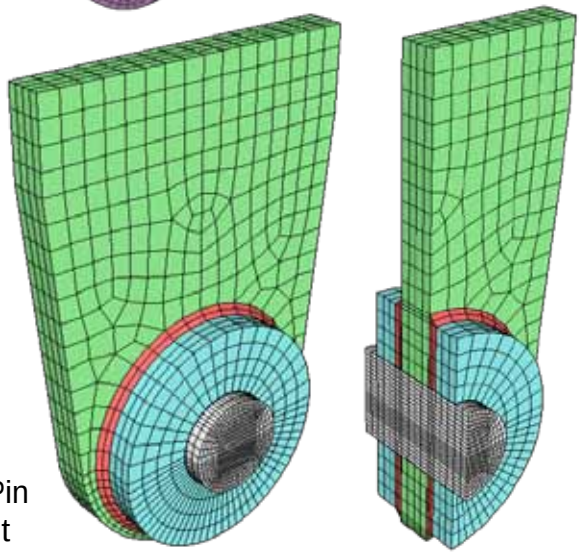
Cargo Carrier

**FEA's Solid Map Mesher generates hexa and/or penta mesh in simple solids by full mapping or combination (auto+map).**

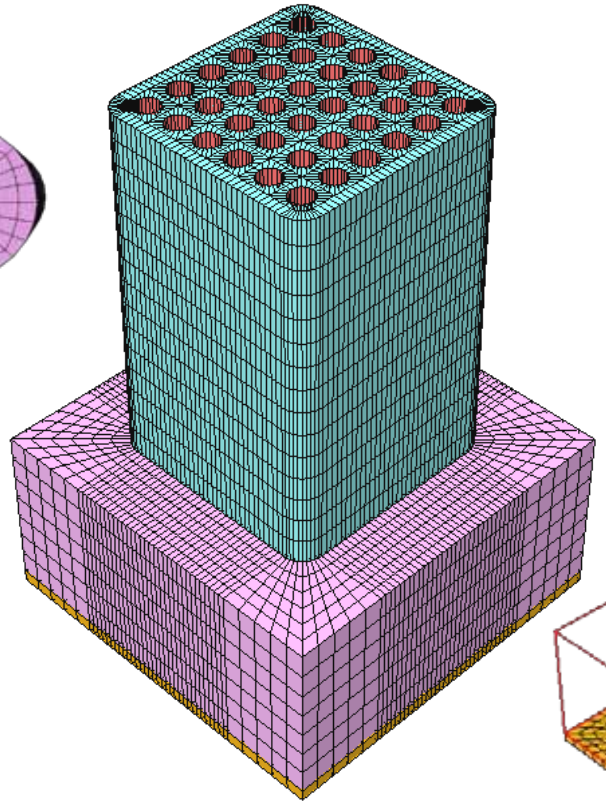


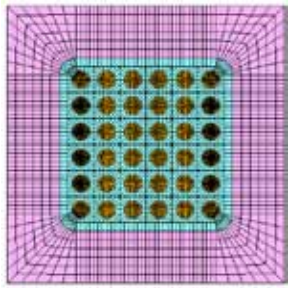
Full Mapping
(3D)

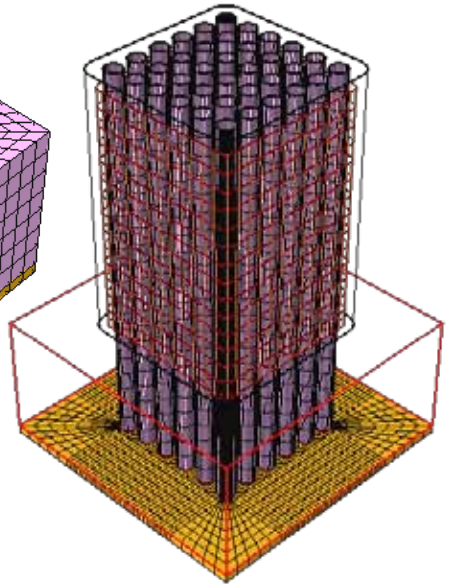




Lug-Pin
Joint

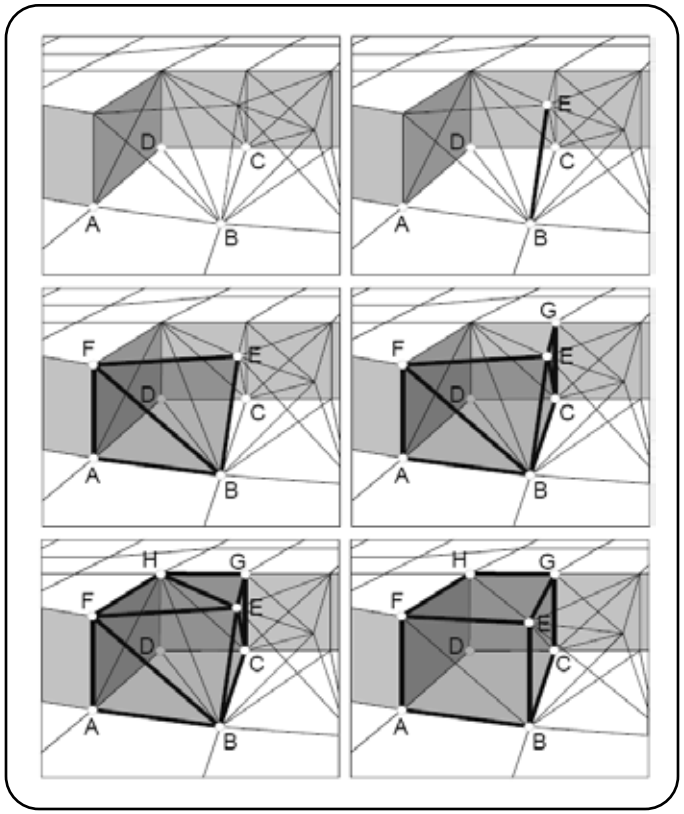




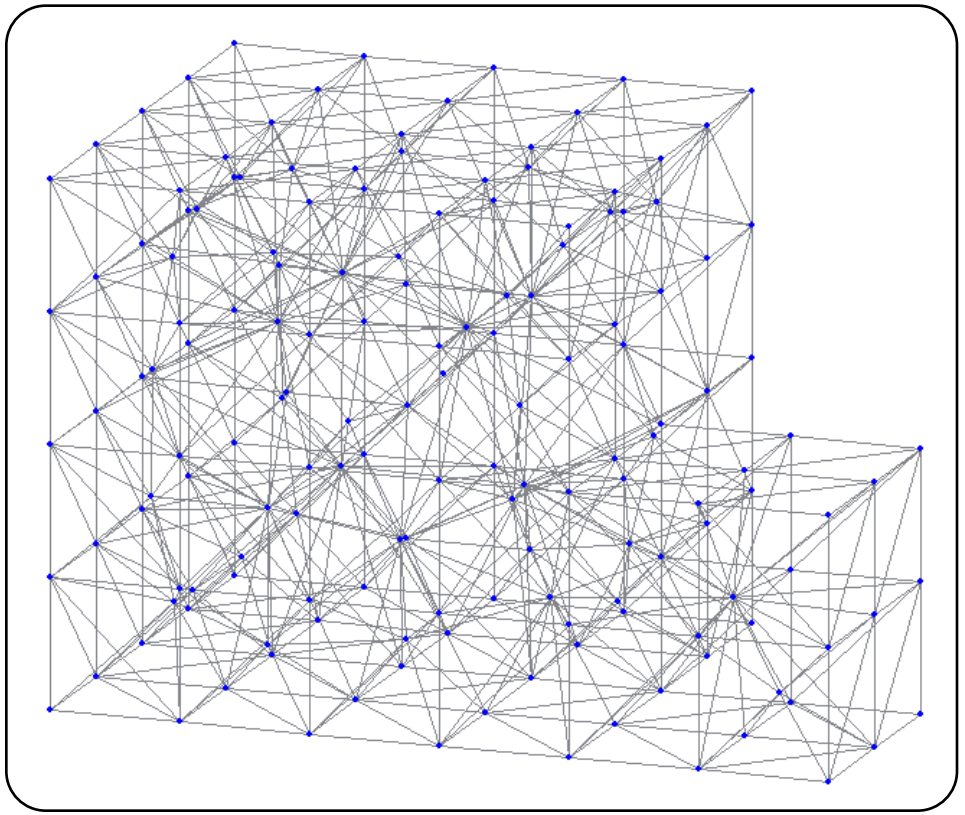


Pier (Pipe + Reinforcement Steel + Concrete)

- FEA is under implementation of **H-Morph Meshing** to generate **Hexa-dominant mesh**.
- **H-Morph** is a method to generate **boundary conforming, hexa-dominant mesh** for arbitrary solid geometries. (FEA uses **Q-Morph** and **H-Morph** algorithms proposed by S.Owen.)
- FEA will also provide **Prism Layer Meshing** function. (Outer:Prism – Inner:Tetra)

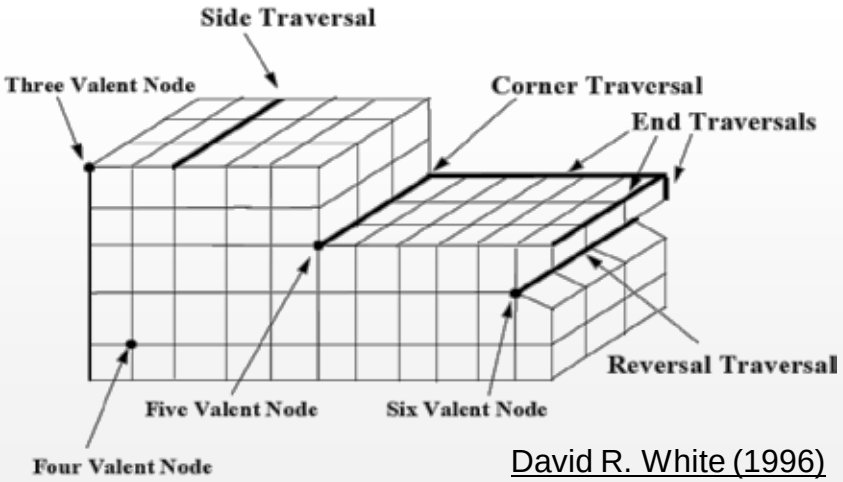



S.Owen (1999)

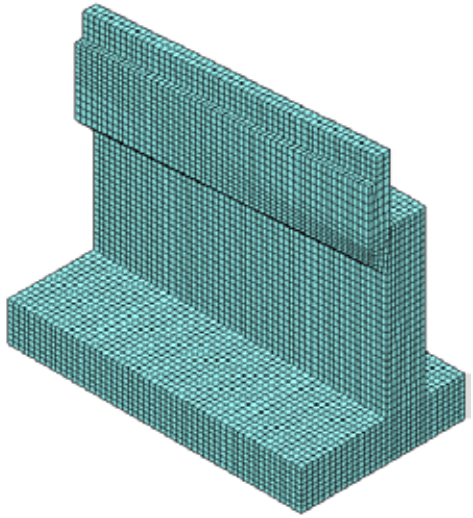


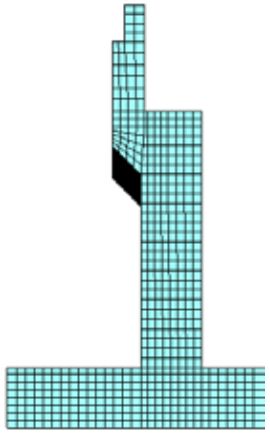
H-Morphing Procedure (Tetra® Hexa)

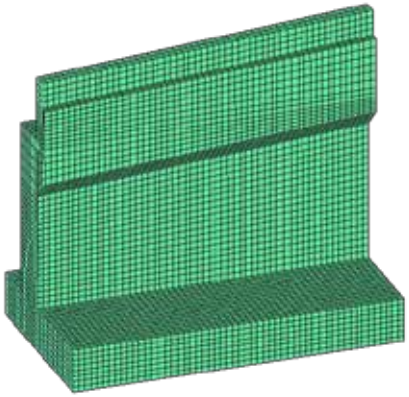
- FEA is under implementation of **Sub-mapped Meshing** functions for **pseudo-Cartesian geometries**.
- FEA adopts **Volume Sub-mapping** algorithms proposed by D.White and M.Whiteley.
- **Volume Sub-mapping** is enhanced 3D mapping technique which sub-divides geometry into volume mappable sub-regions.



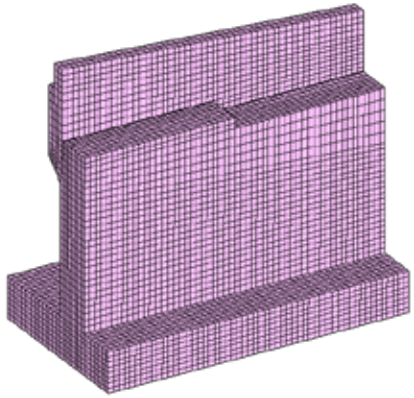

David R. White (1996)







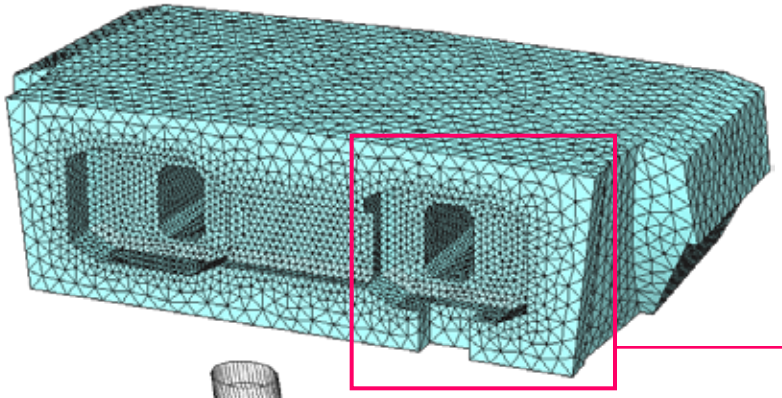
Front View

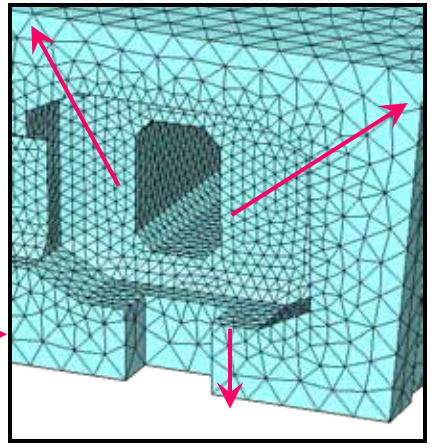


Rear View

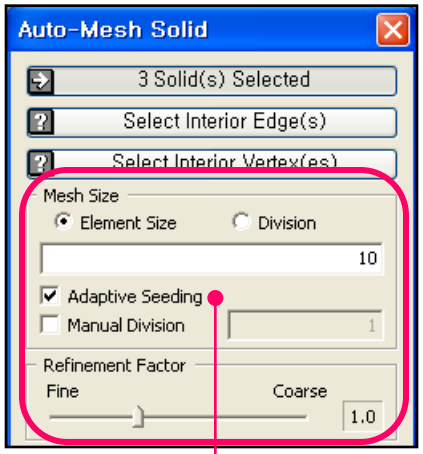
Pseudo-Cartesian shapes have interior and exterior angles that are close to π/2.

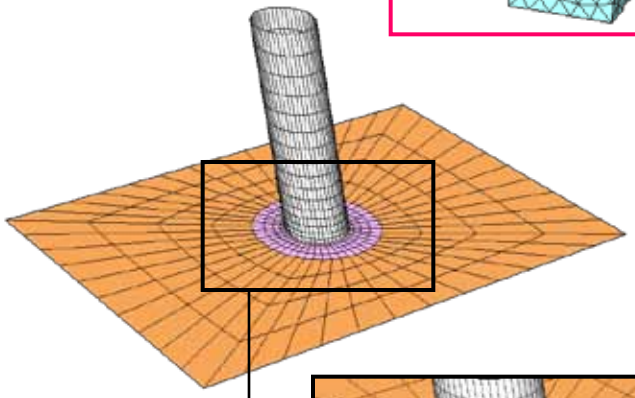
FEA provides various size control methods and **adaptive seeding function** based on **user-specified mesh size** and **geometric characteristics**.

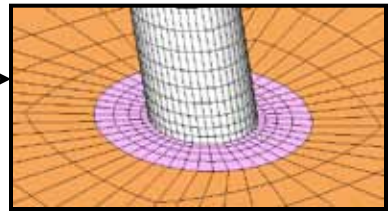




Smooth Transition



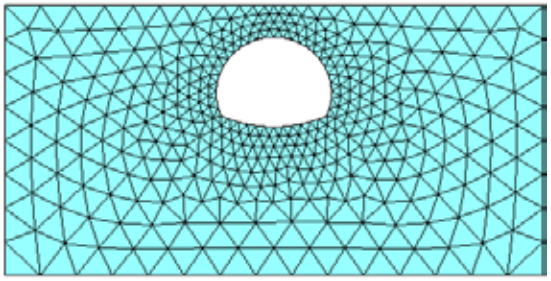



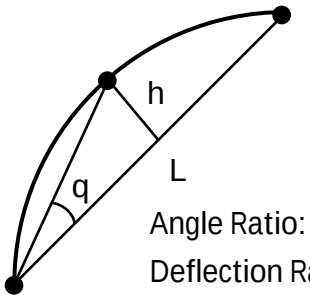


Biased Seeding
& Mapped Mesh

Linear & Symmetric Seeding

Coarse Fine Coarse

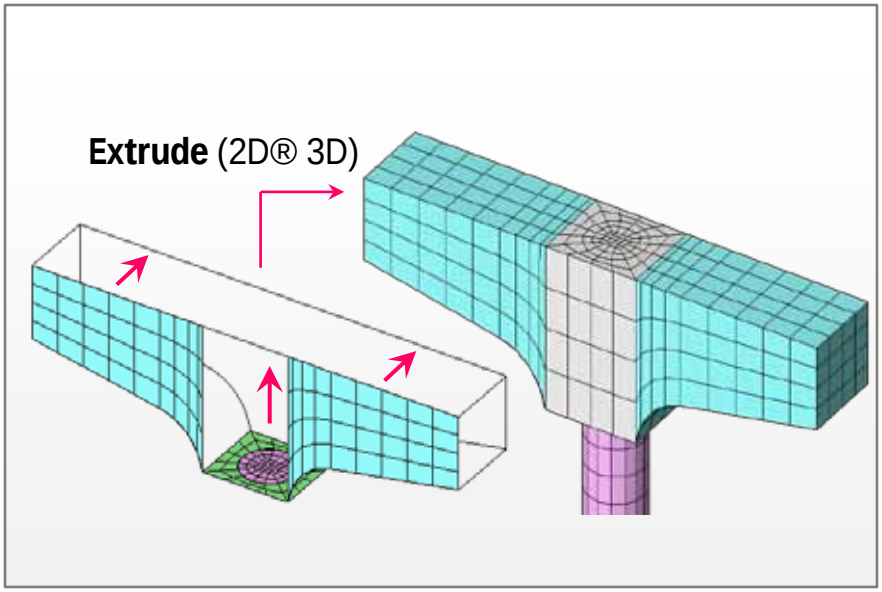


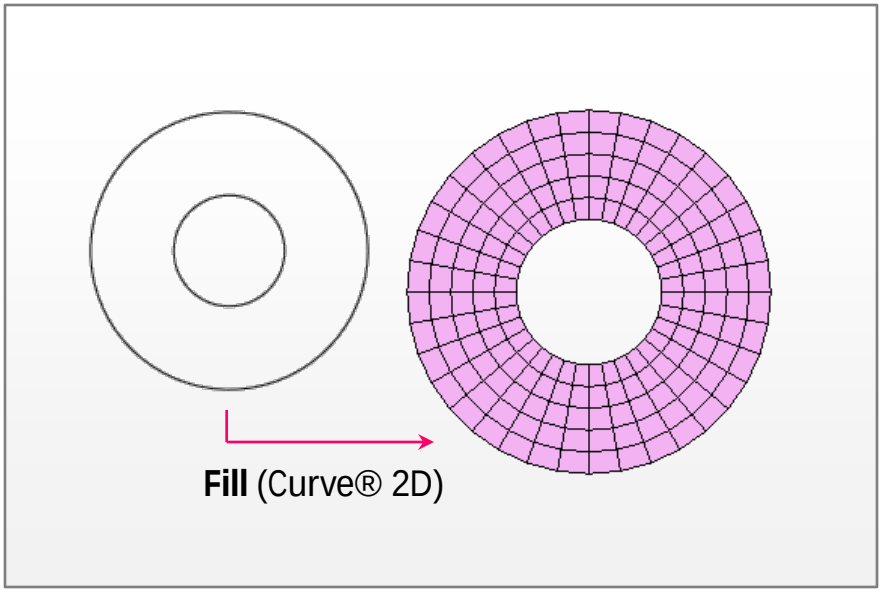


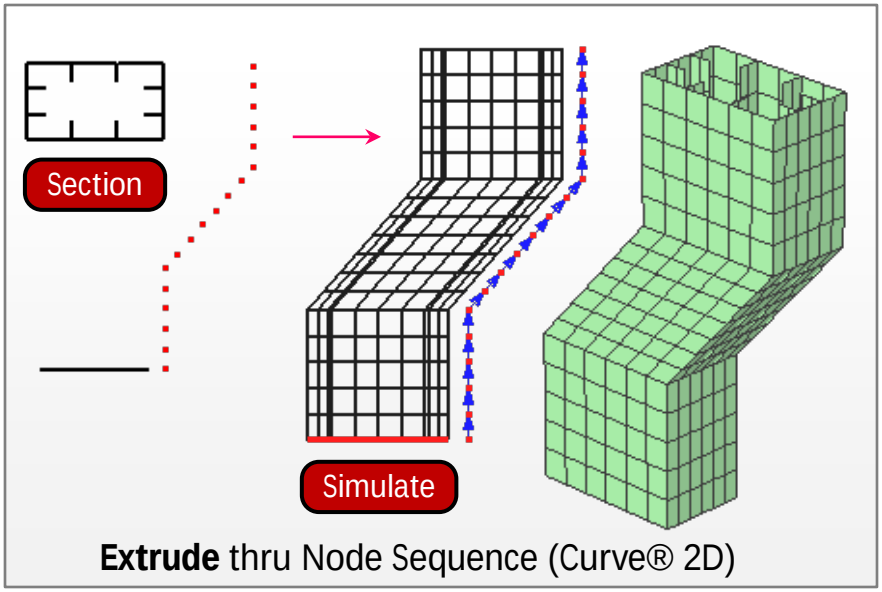

Angle Ratio: sin **q**

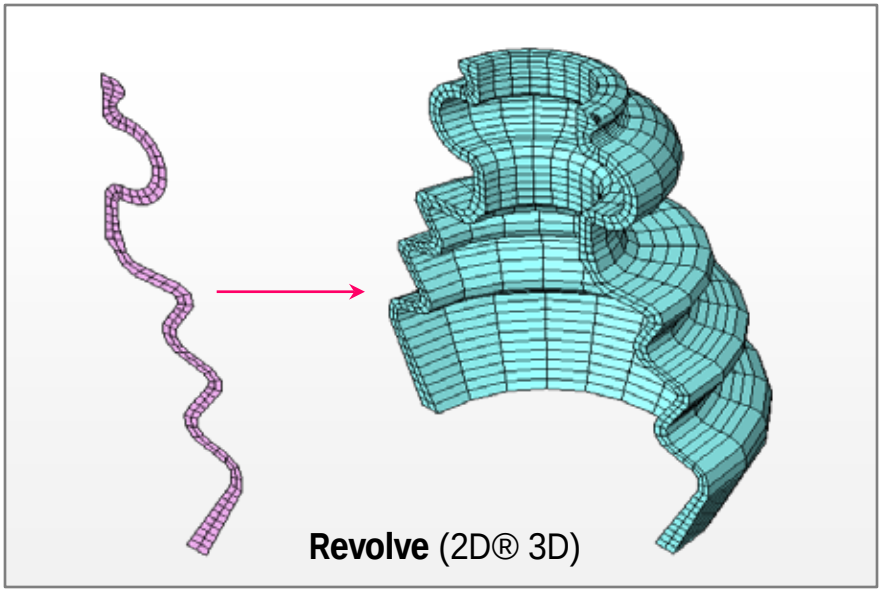
Deflection Ratio: h/L

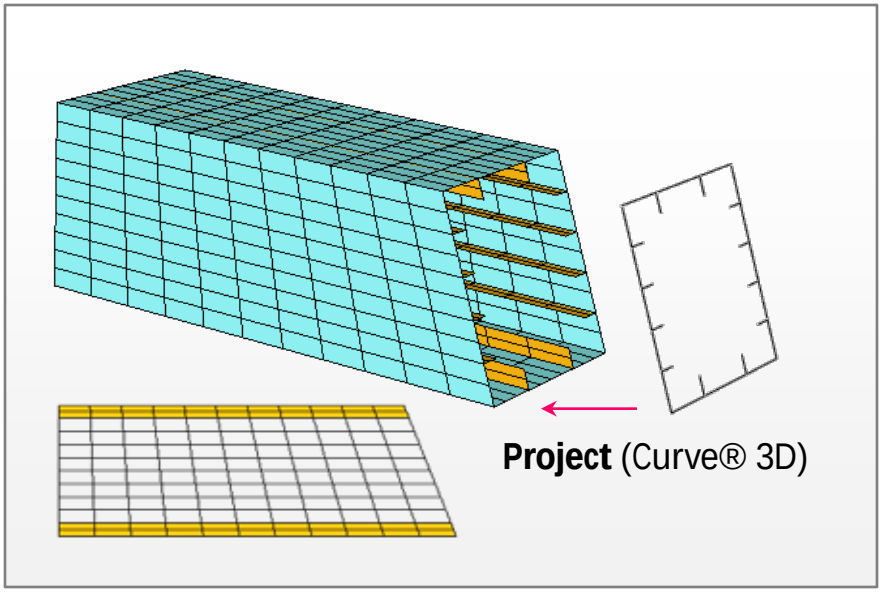
Adaptive Seeding

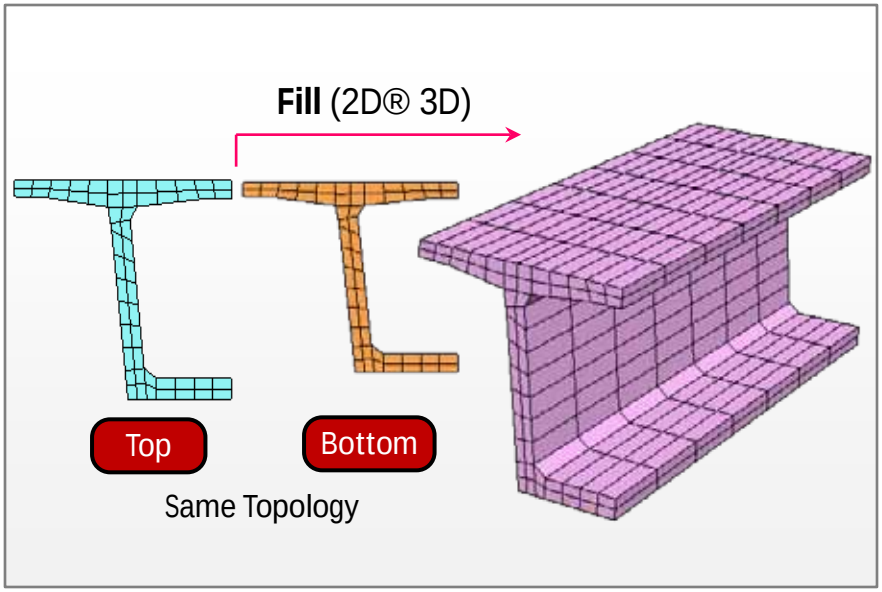

Extrude (2D® 3D)

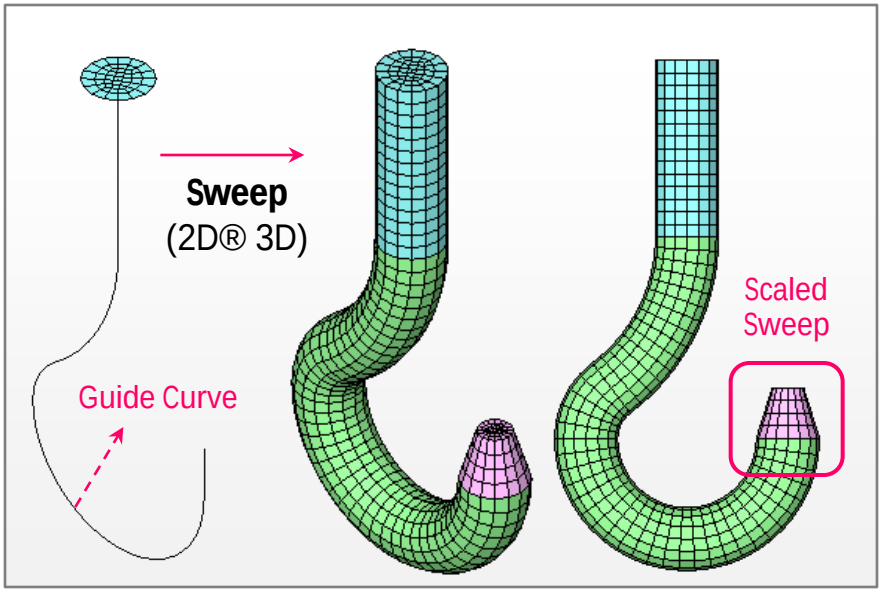

Fill (Curve® 2D)

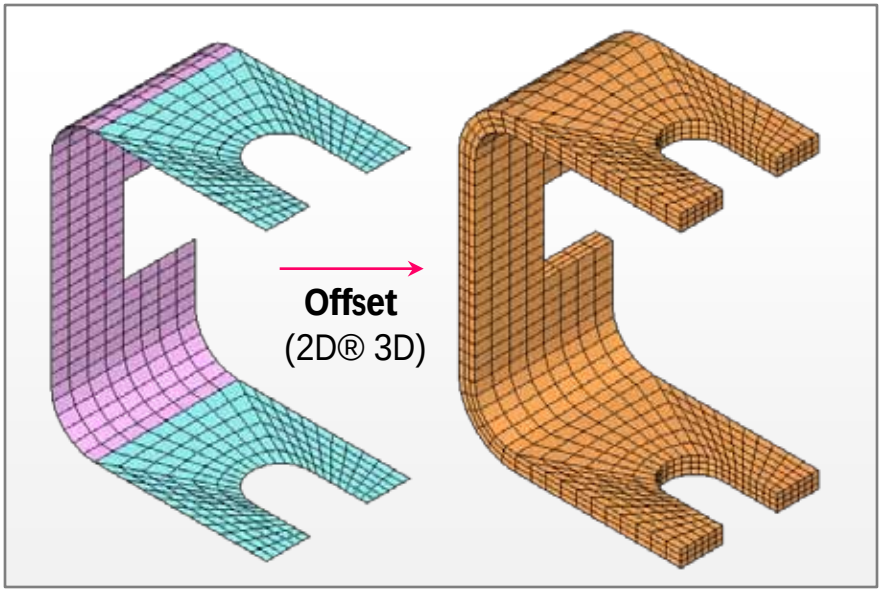

Section
Simulate
Extrude thru Node Sequence (Curve® 2D)


Revolve (2D® 3D)


Project (Curve® 3D)

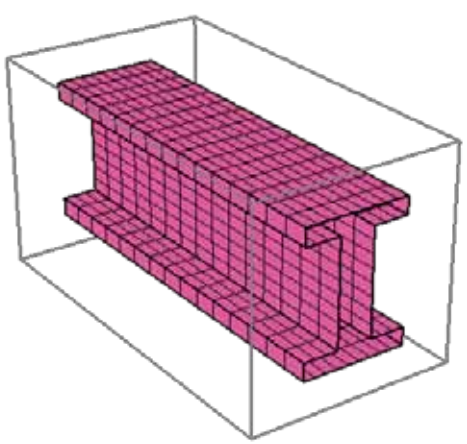

Fill (2D® 3D)
Top
Bottom
Same Topology

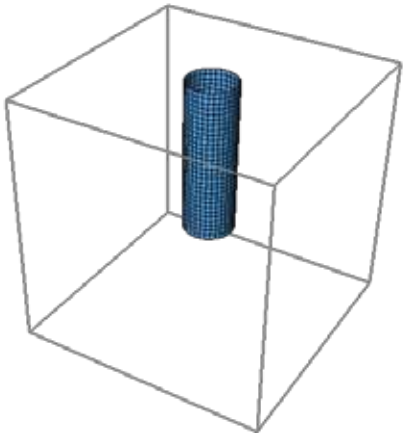

Sweep
(2D® 3D)
Guide Curve
Scaled
Sweep

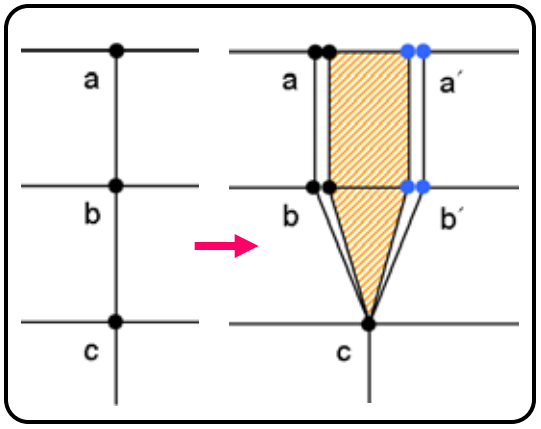

Offset
(2D® 3D)

## Generation Method

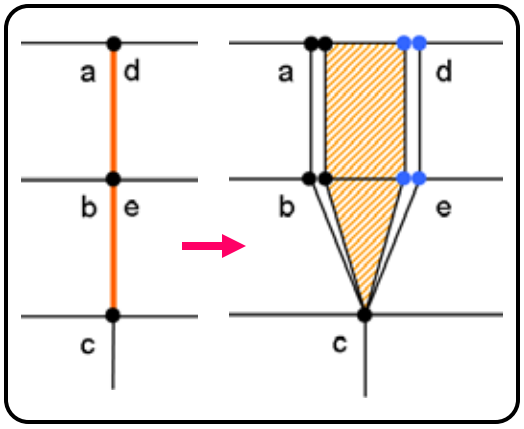
- Select Nodes
- Input Node IDs
- Extract from Element Boundary
- Extract from Free-Faces
- Insert Both Sides of Beam/Plate
- Covert Elements



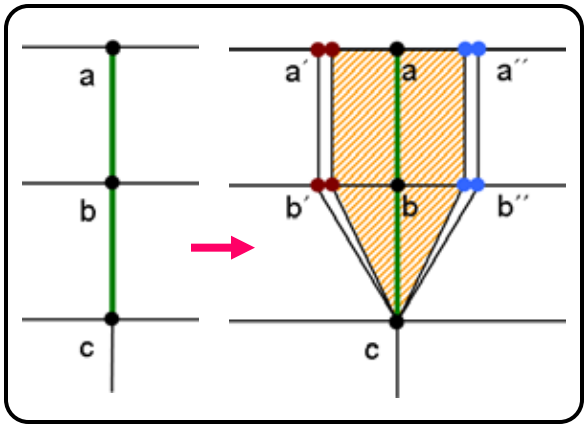





Select Nodes
Input Node IDs



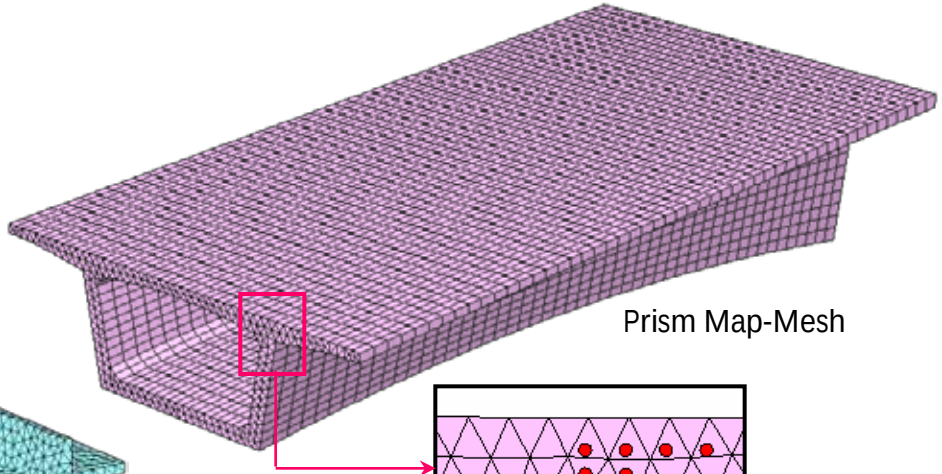

Extract from Element Boundary
Extract from Free-Faces



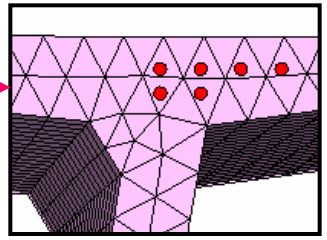

Insert Both Sides of Beam/Plate

## Modeling Method

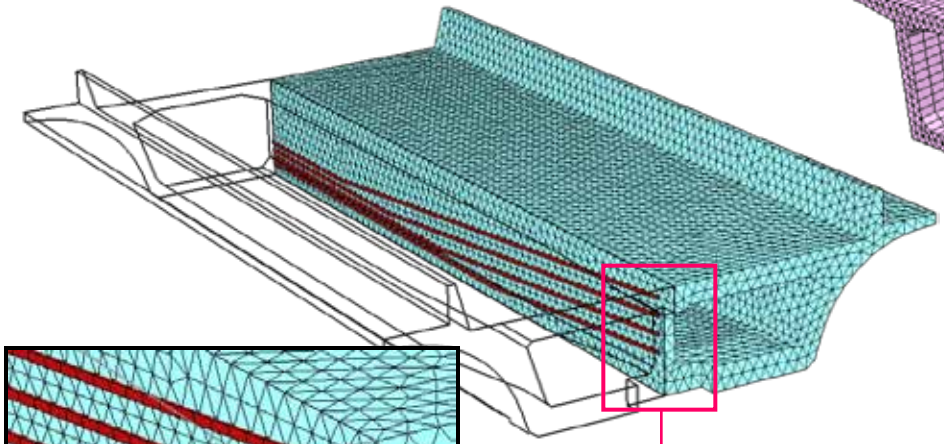
- Embedded Bar (In-compatible Mesh)
- Truss (Compatible Mesh) + Interface (Slip, Friction)



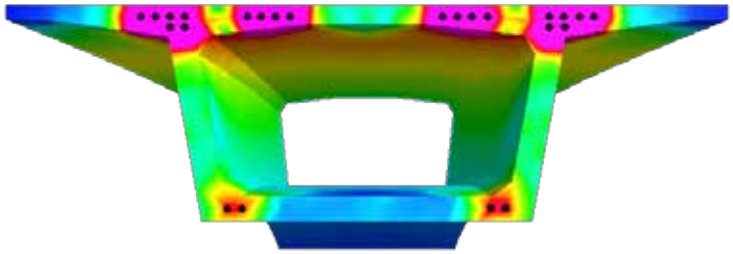
Prism Map-Mesh



Embedded Bar (Incompatible)



Truss + Interface
(Compatible)



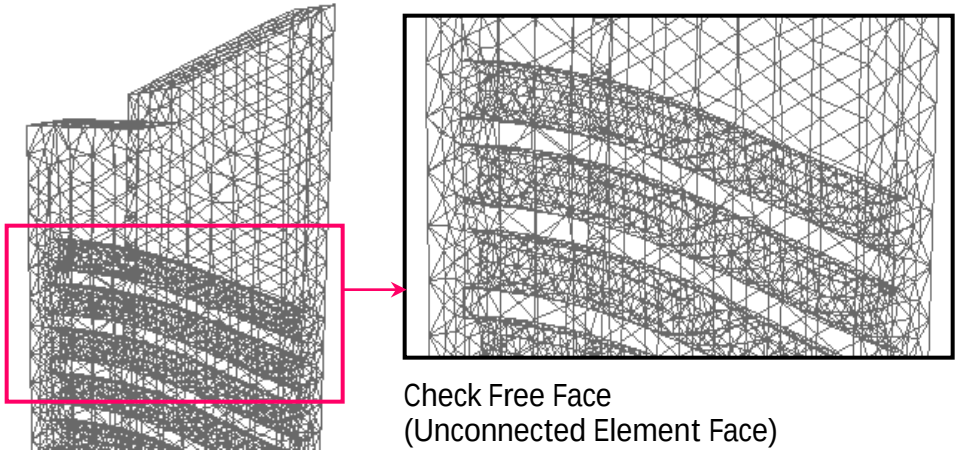
Analysis Result

## Check & Verify

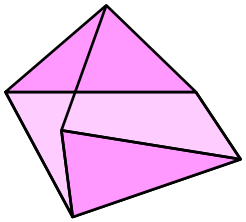
- Free Edges
- Free Faces
- Manifold Edges
- Non-manifold Edges
- Check & Align ECS

## Quality Assurance

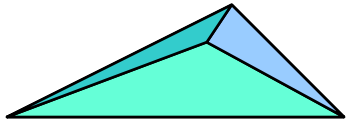
- Aspect Ratio
- Skew Angle
- Taper (2D)
- Warpage (2D)
- Jacobian Ratio
- Twist
- Collapse (Tetra)
- Length / Area



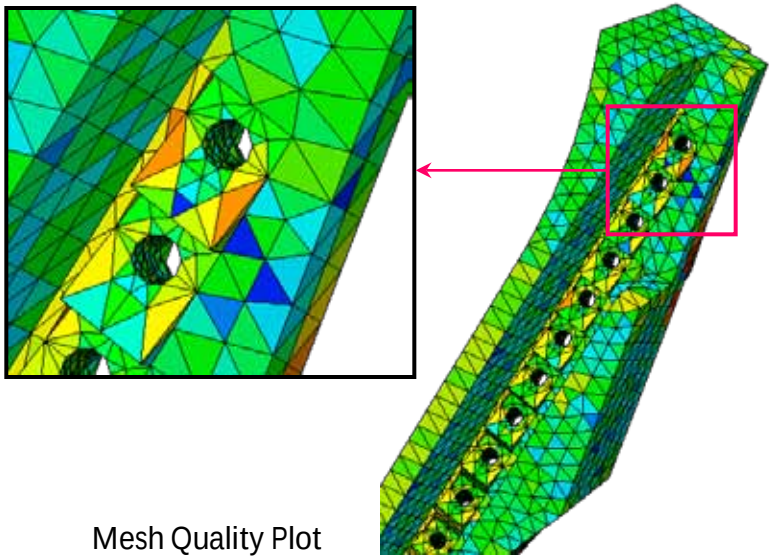
Check Free Face
(Unconnected Element Face)



Twisted Penta



Collapsed Tetra
(Near Zero Volume)



Mesh Quality Plot

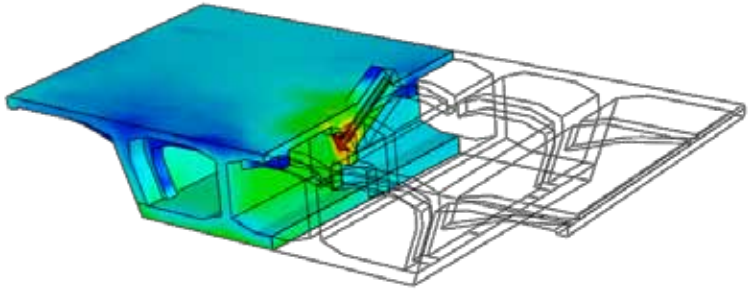
# Analysis

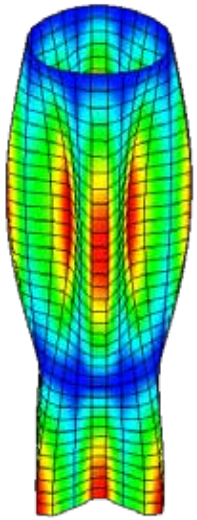
- Static Analysis
- Construction Stage Analysis
- Moving Load Analysis

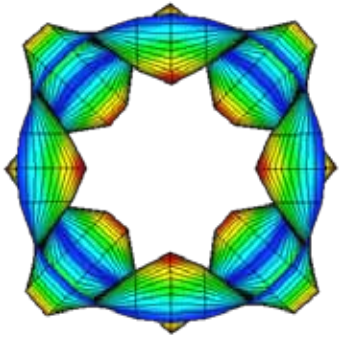
- Modal Analysis
- Linear Buckling Analysis
- Transient / Frequency / Response Spectrum Analysis

- Material / Geometry Nonlinearity Analysis
- Interface Nonlinearity Analysis
- Reinforcement Analysis
- Cracking Analysis
- Static/Explicit Contact Analysis

- Heat Transfer Analysis
- Fatigue Analysis
- Fluid Dynamics Analysis







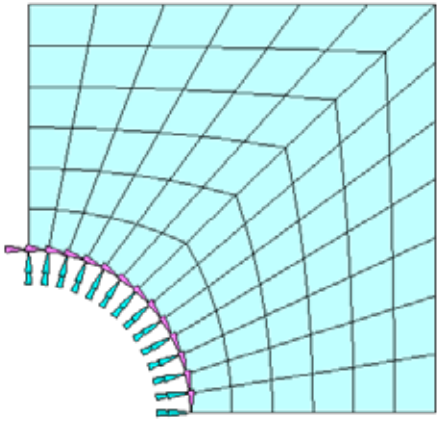
| Category | Elements | | Order | Remark |
|---|---|---|---|---|
| **Structural** | **1D** | Truss (Gap / Hook / Cable) | 1st | Total Lagrangian |
| | | Beam | 1st | Total Lagrangian |
| | **2D** | Plane Stress (Qaud / Tria) | 1st, 2nd | Total/Updated Lagrangian |
| | | Plane Strain (Quad / Tria) | 1st, 2nd | Total/Updated Lagrangian |
| | | Axisymmetry (Quad / Tria) | 1st, 2nd | Total/Updated Lagrangian |
| | | Plate (Quad / Tria) | 1st, 2nd | Total/Updated Lagrangian |
| | | Shell (Quad / Tria) | 1st, 2nd | Total/Updated Lagrangian |
| | **3D** | Brick / Wedge / Tetra | 1st, 2nd | Total/Updated Lagrangian |
| **Nonstructural** | **Connection** | General Link | - | - |
| | | Rigid Link | - | - |
| | **Mass Spring** | Point | - | - |
| | | Matrix | - | - |
| | **Interface** | 3D Point | - | - |
| | | 2D | 1st, 2nd | - |
| | | 3D (Quad / Tria) | 1st, 2nd | - |
| **Reinforcement** | Embedded Bar | | 1st, 2nd | - |
| | Embedded Grid (Quad / Tria) | | 1st, 2nd | - |
| **Heat Transfer** | 1D, 2D, 3D, Cooling Pipe, Thermal Link | | 1st, 2nd | - |

## Loadings

- Body Force
- Force / Moment
- Mass
- Displacement
- Pressure
- Beam Load
- Pre-stress
- Temperature

## Boundary Conditions

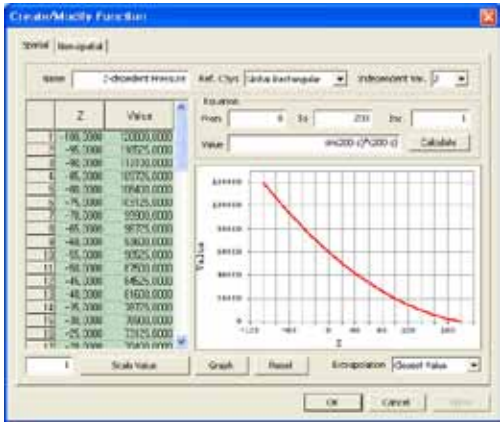
- Constraint
- Multi-Point Constraint
- Contact Conditions
- Convection
- Radiation

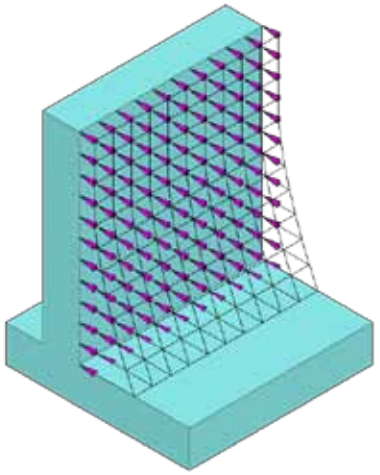


Constraint based-on CSys.

## Velocity / Acceleration

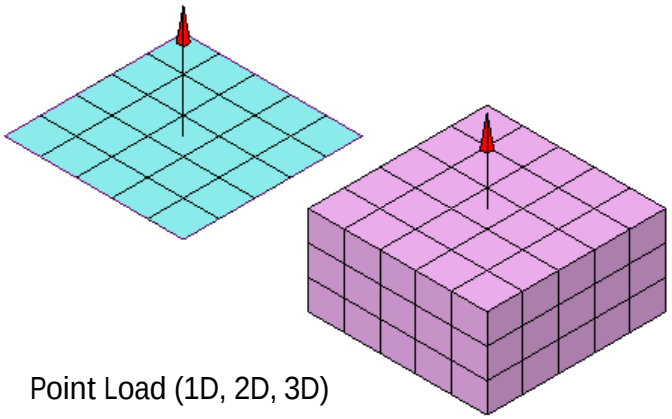
- Heat Generation
- Heat Flux
- Time Forcing Function
- Time Varying Load
- Ground Acceleration
- Response Spectrum Function



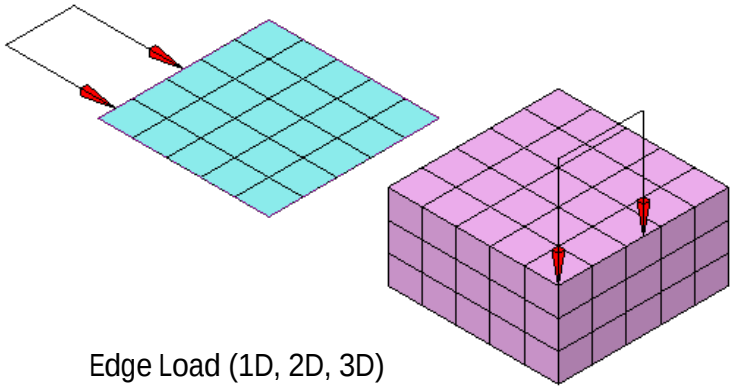


Spatially Varying Pressure (Function Applied)

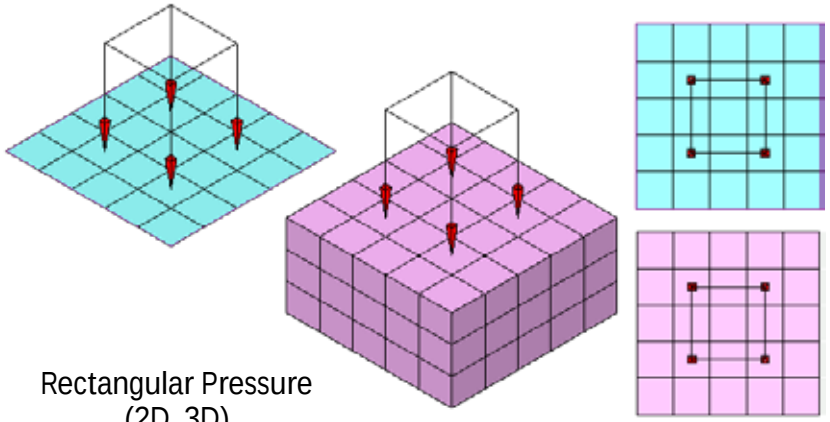
FEA provides **arbitrary loading** function which can be applied to **arbitrary locations/areas regardless of node and/or element connection**.



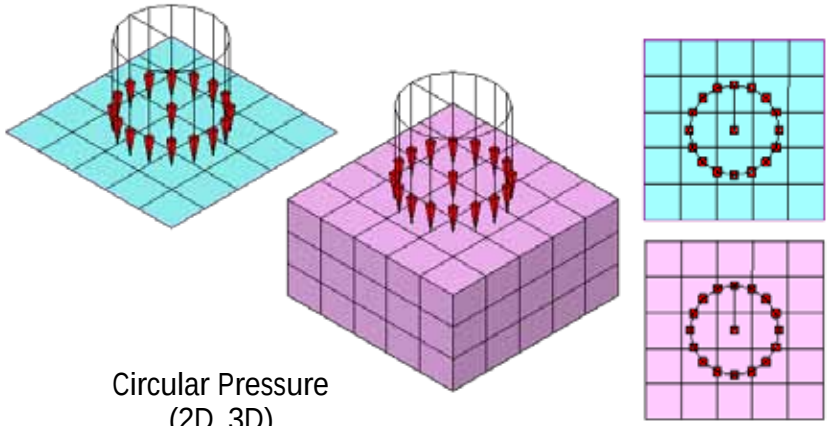
Point Load (1D, 2D, 3D)



Edge Load (1D, 2D, 3D)

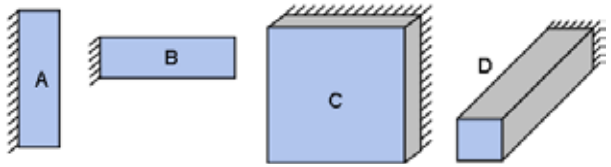


Rectangular Pressure
(2D, 3D)



Circular Pressure
(2D, 3D)

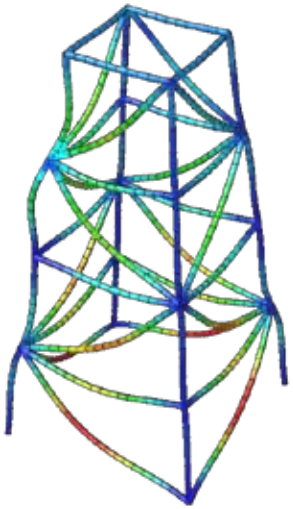
- **Linear Static Analysis**
  - Multiple Load Cases
  - Result Combination and Transformation
- **Equation Solvers**
  - Direct Solvers
    - Multi-frontal Sparse Gaussian Solver (Default)
    - Skyline Solver
  - Iterative Solvers
    - Preconditioned Conjugate Gradient
    - Generalized Minimal Residual

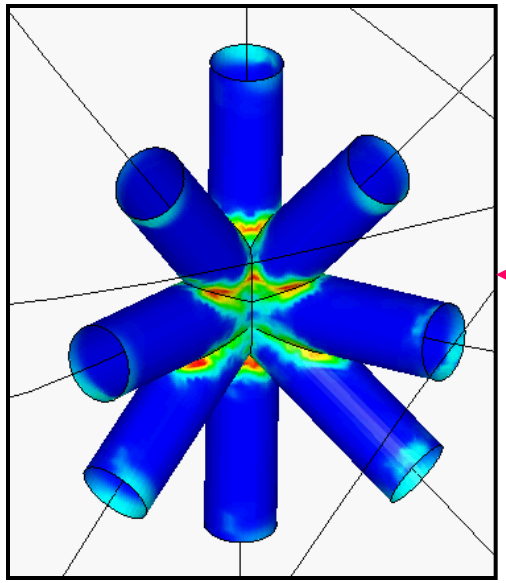


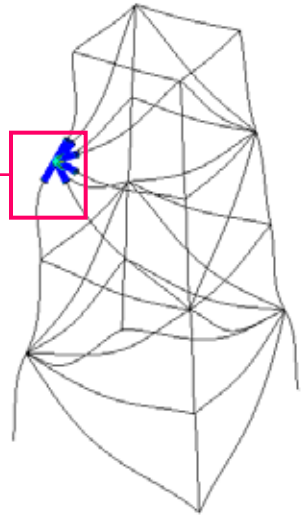

| | | Model A | Model B | Model C | Model D |
|---|---|---|---|---|---|
| Element Type | | Plate | Plate | Solid | Solid |
| No. of Elements | | 30,000 | 30,000 | 125,000 | 40,000 |
| No. of DOF's | | 180,600 | 181,800 | 390,150 | 132,300 |
| Solution Time [sec] | Multi-frontal | 35 | 41 | 3,244 | 262 |
| | PCG | 179 | 188 | 817 | 139 |

Net Solution Times (Pentium IV 3GHz, 1GB RAM)

*Offshore Platform / Steel Frame Composed of Cylindrical Jackets (Plate + Frame)*



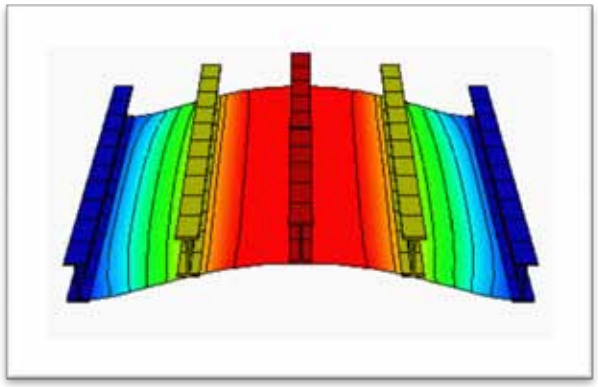




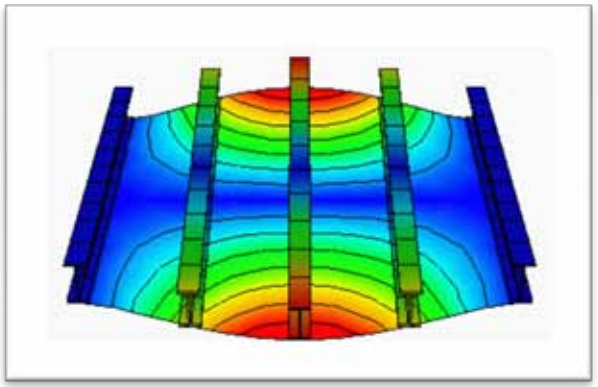
*Stress Distribution of Jacket*

- **Modal Analysis**
  - Lanczos Method
  - Subspace Iteration
  - Ritz Vector

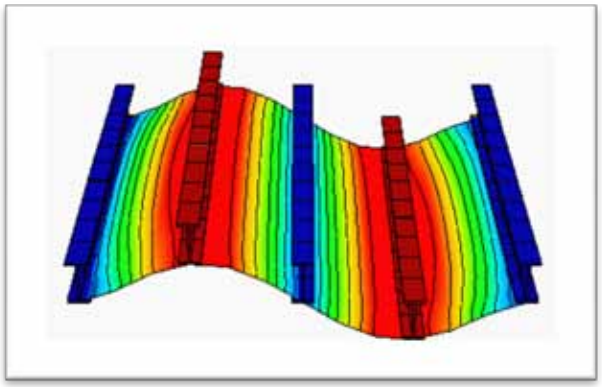
- **Linear Buckling Analysis**
  - Critical Buckling Modes
  - Buckling Modes
  - Load Combination



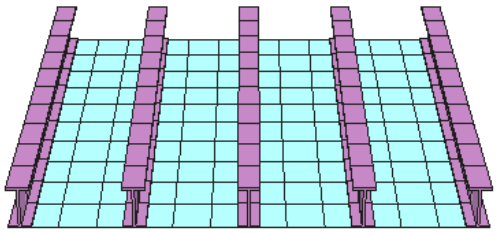
*1st Mode (64.58 Hz)*



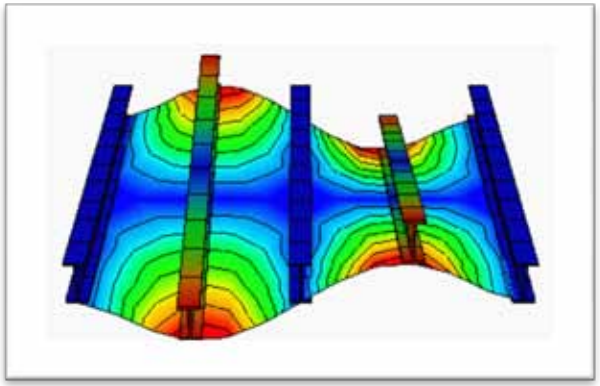
*2nd Mode (106.05 Hz)*



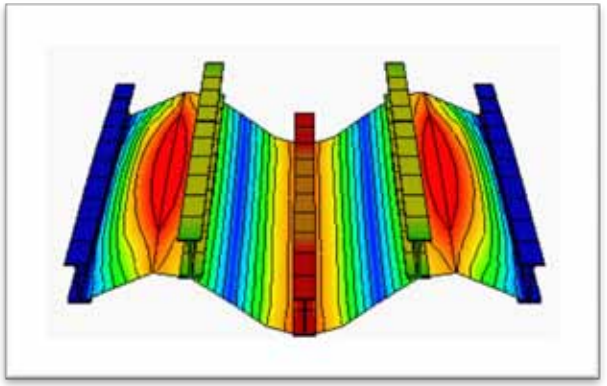
*3rd Mode (208.96 Hz)*



*Simply Supported Stiffened Plate (Plate + Beam)*



*4th Mode (270.00 Hz)*



*5th Mode (440.58 Hz)*

## n Transient Response Analysis

Direct Transient Response

Modal Transient Response

Time Forcing Function DB

(54 Earthquake Acceleration Records)

Nonlinear Analysis

Boundary Nonlinear Analysis

(Damper, Viscous Boundary, etc.)

## n Frequency Response Analysis

Direct Frequency Response

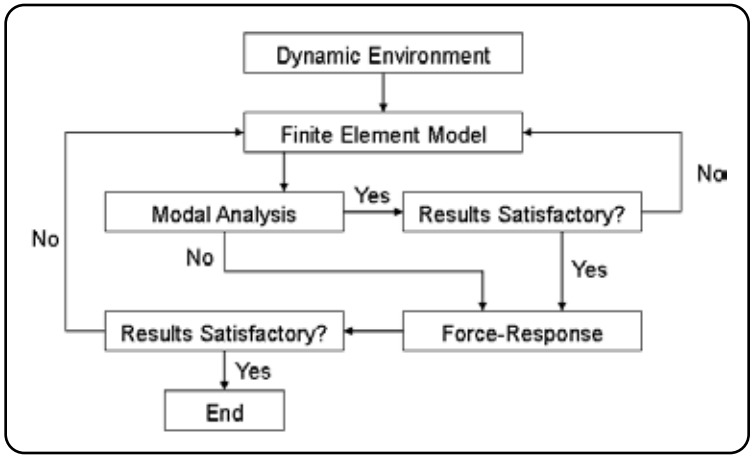
Modal Frequency Response

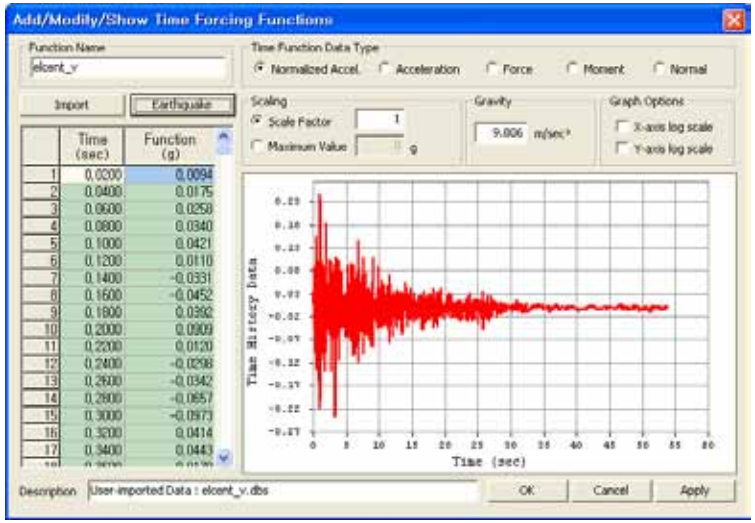
Frequency-dependent Excitation

## n Spectrum Response Analysis

SRSS, CQC,ABS

Design Spectrum DB

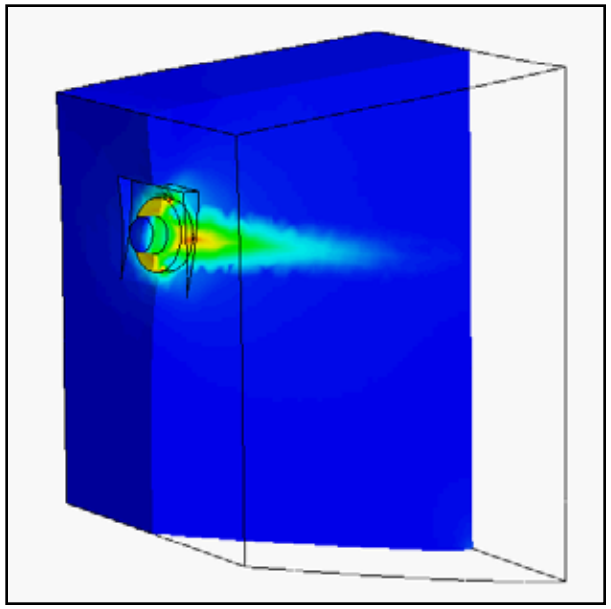


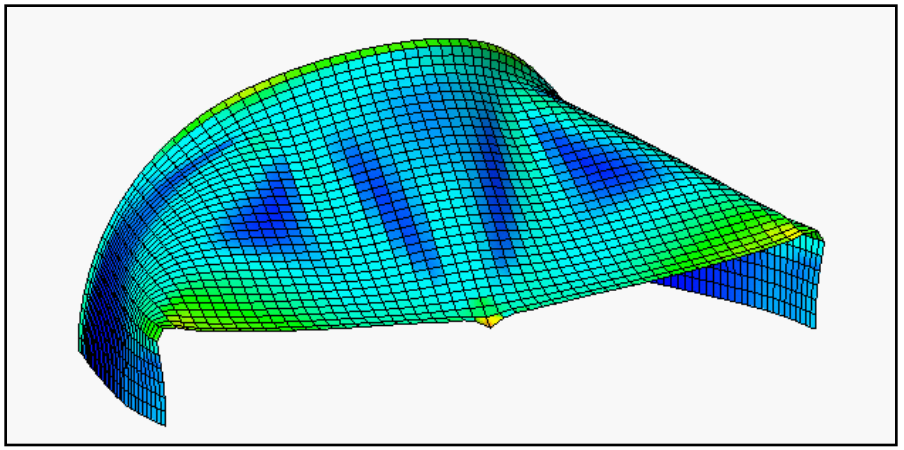

*Time Forcing Function*

- **Material Models**
  - von Mises
  - Tresca
  - Mohr-Coulomb
  - Drucker-Prager
  - Rankine
  - User-Supplied Material

- **Nonlinear Behaviors**
  - Hardening (Iso/Kinematic/Mixed)
  - Softening
- **Iteration Method**
  - Full Newton-Raphson
  - Modified Newton-Raphson
  - Arc-Length Method
  - Constant Stiffness
  - Displacement Control

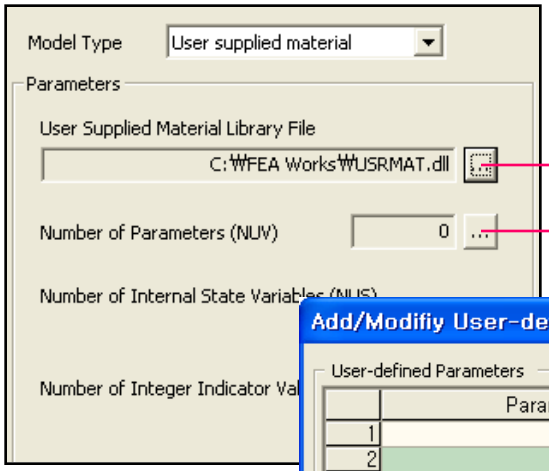


*Tendon Anchorage (Solid) - von Mises*



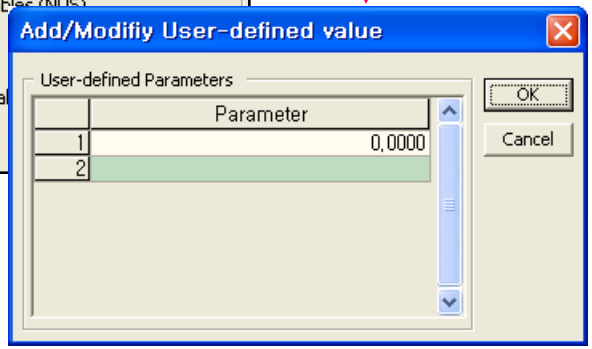
*Pinched Cylinder (Plate) – von Mises Material & Geometry Nonlinear Analysis*

- In FEA, users can use their own defined material models via Fortran-coded library file.
- FEA's user-supplied material model supports nonlinear elastic and elasto-plastic behaviors.
- User-supplied material can be used seamlessly with all elements which allow material nonlinear behaviors.




USM Dialog

USRMAT.DLL




User-defined Parameters Input Dialog

```
!***********************************************************************
!     USER SUPPLIED MATERIAL SUBROUTINE
!***********************************************************************
      SUBROUTINE USRMAT( EPS0, DEPS, NS, IELEMEN, INTPT, COORD,          &
                         SE, ITER, USRVAL, NUV, USRSTA, NUS, IUSRIND,    &
                         NUI, SIG, STIFF,ID)

      IMPLICIT NONE

      !DEC$ ATTRIBUTES DLLEXPORT::USRMAT

      INTEGER, INTENT(IN)    :: NS
      INTEGER, INTENT(IN)    :: IELEMEN
      INTEGER, INTENT(IN)    :: INTPT
      INTEGER, INTENT(IN)    :: ITER
      INTEGER, INTENT(IN)    :: ID
      INTEGER, INTENT(IN)    :: NUV
      INTEGER, INTENT(IN)    :: NUS
      INTEGER, INTENT(IN)    :: NUI
      REAL*8,  INTENT(IN)    :: EPS0(NS)
      REAL*8,  INTENT(IN)    :: DEPS(NS)
      REAL*8,  INTENT(IN)    :: COORD(3)
      REAL*8,  INTENT(IN)    :: SE(NS, NS)
      REAL*8,  INTENT(INOUT) :: SIG(NS)
      REAL*8,  INTENT(INOUT) :: STIFF(NS, NS)
      REAL*8,  INTENT(INOUT) :: USRSTA(NUS)
      REAL*8,  INTENT(IN)    :: USRVAL(NUV)
      INTEGER, INTENT(INOUT) :: IUSRIND(NUI)

      INTEGER :: I, J
      REAL*8  :: EMOD, EPS(NS)

      SIG(1:NS) = 0.D0
      EMOD      = USRVAL(1)
      EPS(1:NS) = EPS0(1:NS) + DEPS(1:NS)
!-----------------------------------------------------------------------
!        TOTAL STRESS
!-----------------------------------------------------------------------
      SIG(1) = EMOD * EPS(1) + 1000.D0 * EMOD * EPS(1)**2
      SIG(2) = EMOD * EPS(2) + 1000.D0 * EMOD * EPS(2)**2
      SIG(3) = EMOD * EPS(3) + 1000.D0 * EMOD * EPS(3)**2
      SIG(4) = (EMOD * EPS(4)) / 2.D0
      SIG(5) = (EMOD * EPS(5)) / 2.D0
      SIG(6) = (EMOD * EPS(6)) / 2.D0
!-----------------------------------------------------------------------
!        MATERIAL STIFFNESS MATRIX
!-----------------------------------------------------------------------
      STIFF(1,1) = EMOD + 2000.D0 * EMOD * EPS(1)
      STIFF(2,2) = EMOD + 2000.D0 * EMOD * EPS(2)
      STIFF(3,3) = EMOD + 2000.D0 * EMOD * EPS(3)
      STIFF(4,4) = 0.5D0 * EMOD
      STIFF(5,5) = 0.5D0 * EMOD
      STIFF(6,6) = 0.5D0 * EMOD

      RETURN

      END
!***********************************************************************
```

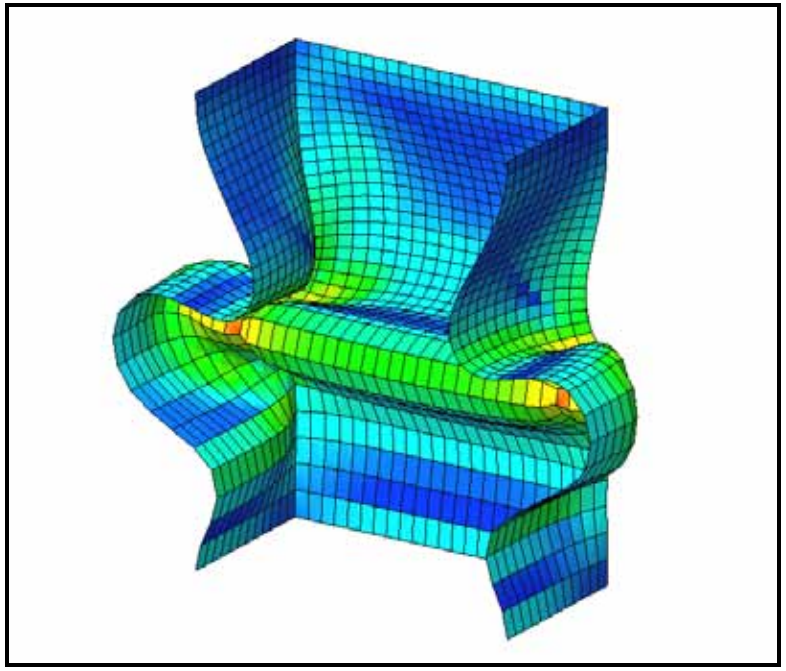
Input: **Strain**

Output: **Total Stress**, **Stiffness Matrix**

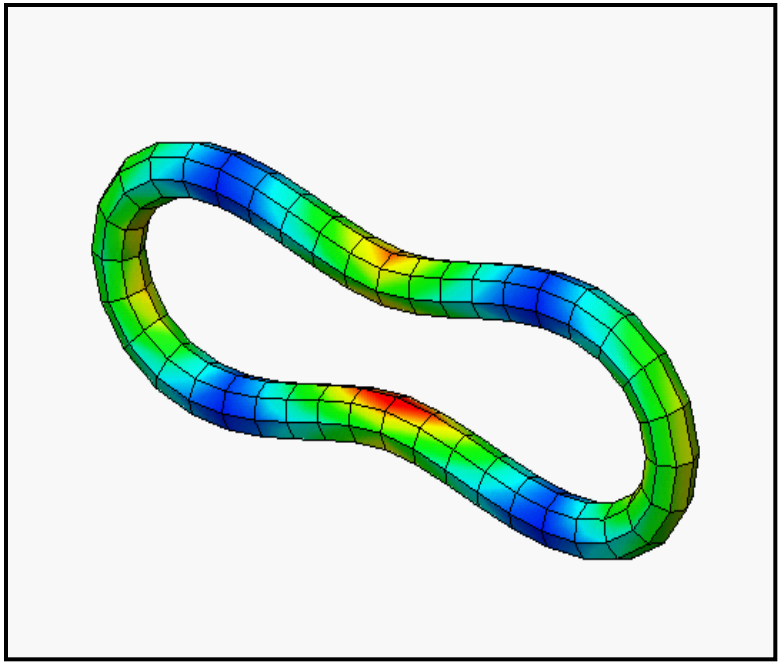
*<Ex> Nonlinear Elastic Material for Solid Element*

- **Methods**
  - Updated Lagrangian
  - Total Lagrangian
  - Co-rotational

- **Iteration Method**
  - Full Newton-Raphson
  - Modified Newton-Raphson
  - Arc-Length Method
  - Constant Stiffness
  - Displacement Control

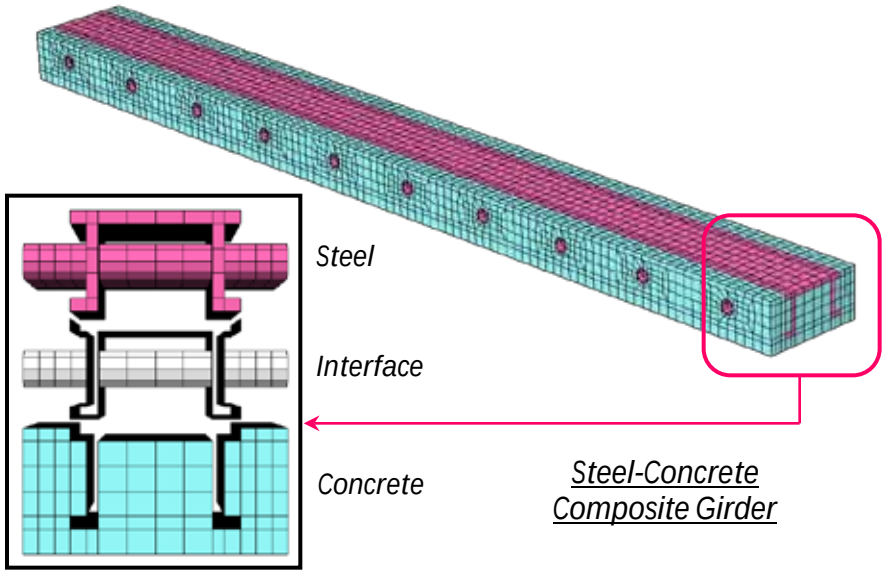


*Rectangular Tube (Plate) – Co-rotational*

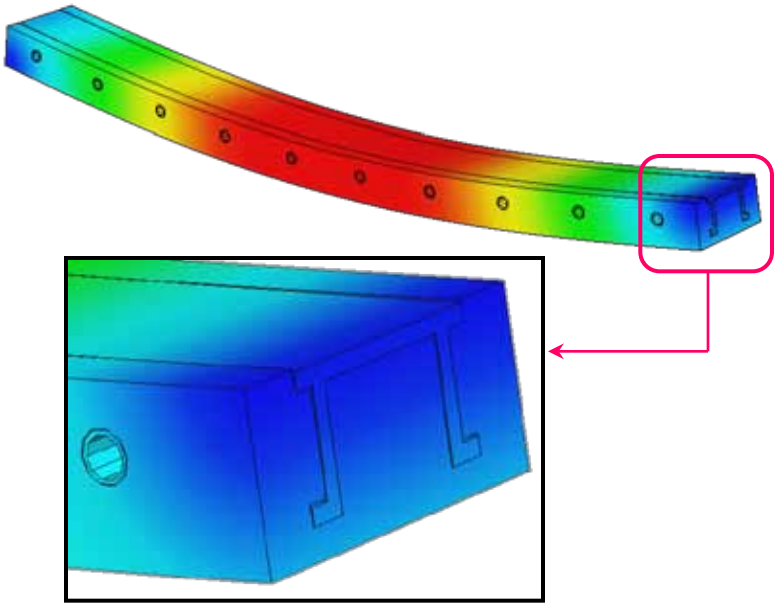


*Ring (Solid) – Total Lagrangian*

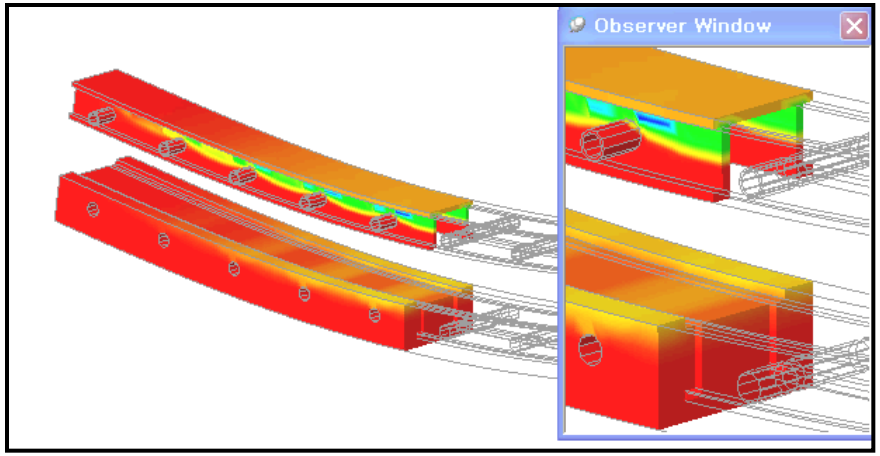
- **Interface Models**
  - Coulomb Friction
  - Discrete Cracking
  - Crack Dilatancy
  - Bond-Slip
  - Combined (Cracking-Shearing-Crushing)




*Steel-Concrete Composite Girder*



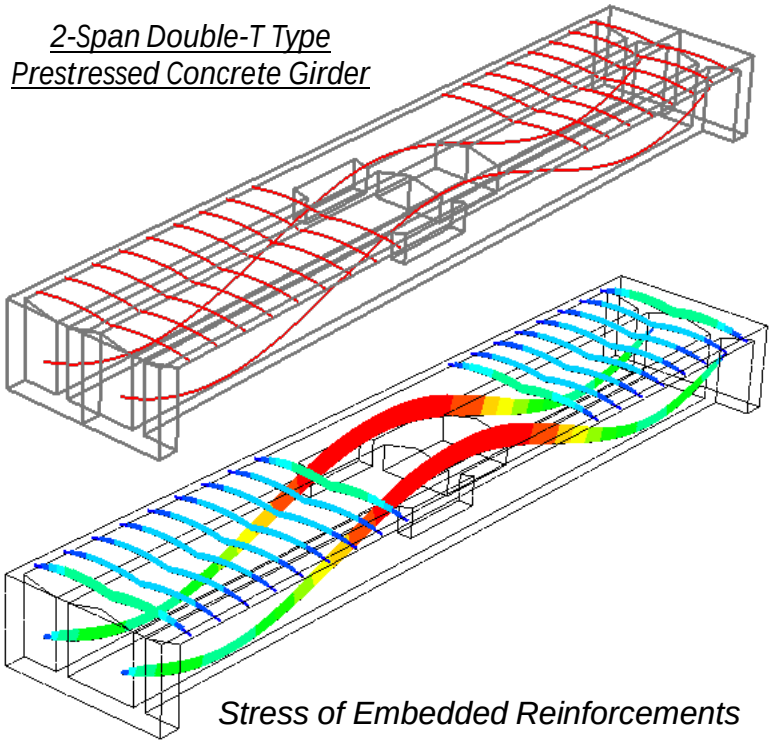
*Deformation (Discontinuity btwn Steel & Concrete)*



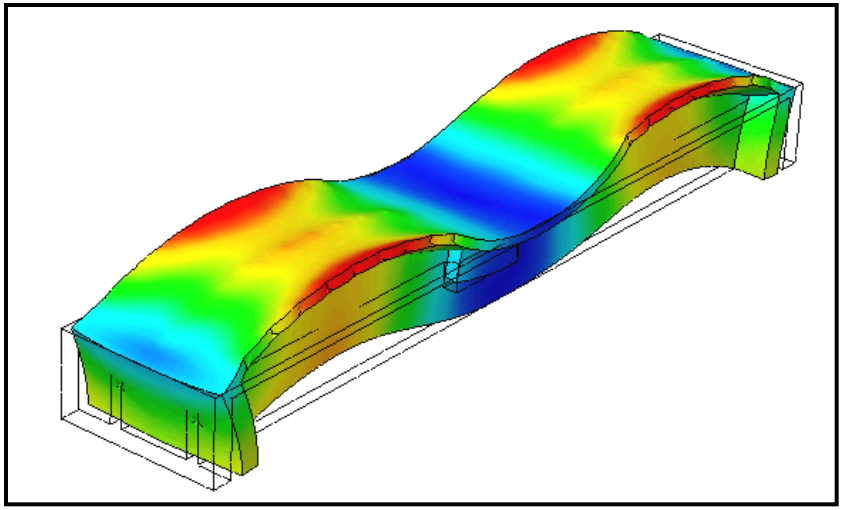

*Principal Stress (Virtually Transformed & Clipped View)*

- **Reinforcements**
  - Embedded Bar/Grid (Bonded/Unbonded)
  - Truss + Interface (Slip/Friction)

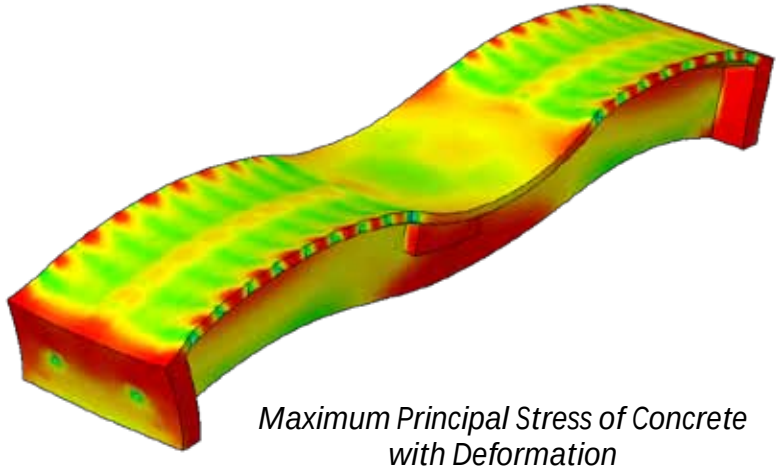
*2-Span Double-T Type Prestressed Concrete Girder*



*Stress of Embedded Reinforcements*



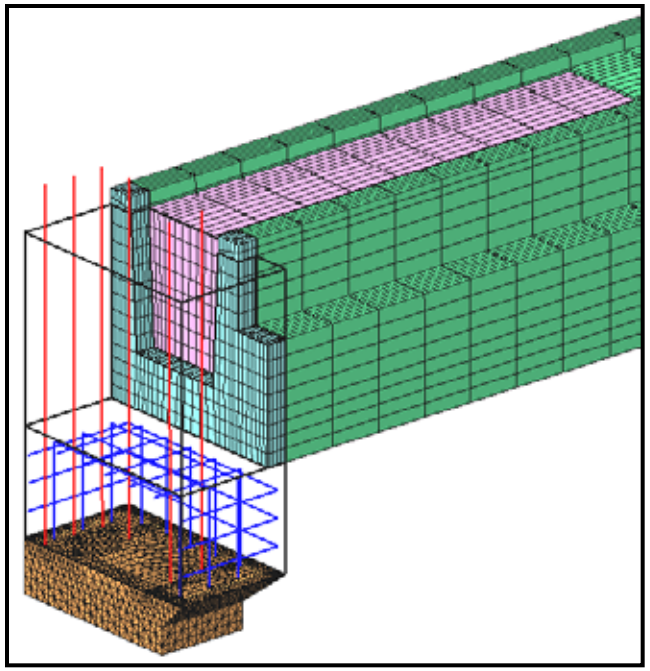
*Deformation*



*Maximum Principal Stress of Concrete with Deformation*

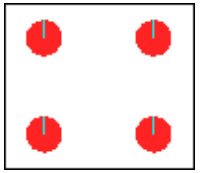
- **Cracking Models**
  - Total Strain Crack
  - Smeared
  - Crack Index

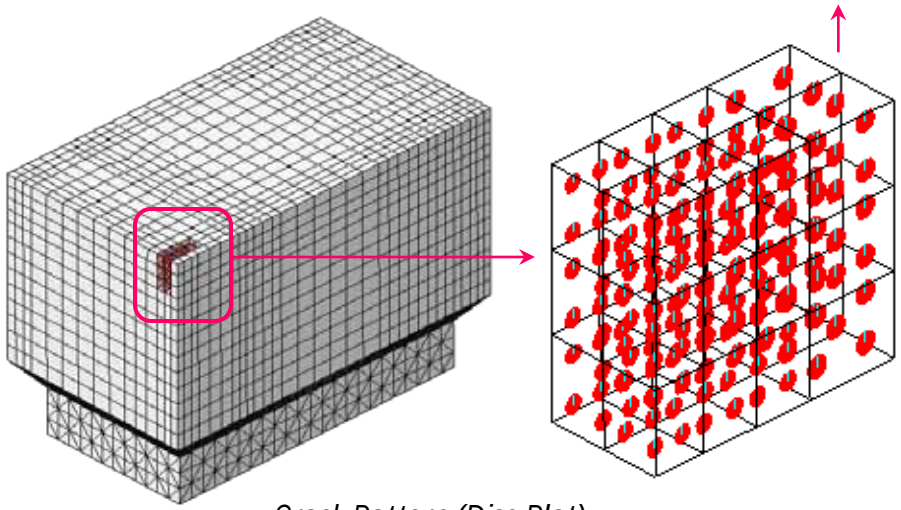
- **Results**
  - Crack Pattern (Crack Stress/Strain)
  - Element Status
    - Cracking : Partially/Fully Open, Closed, Not Yet
    - Plasticity : Previously Plastic, Elastic, Plastic, Critical
    - Contact : No Contact, Slip, Stick



*Steel Reinforced Concrete Bracket*

- Symbols at Gauss Points
- Disc Normal: Opening Direction
- Disc Color : Magnitude
- Line : Shearing Direction

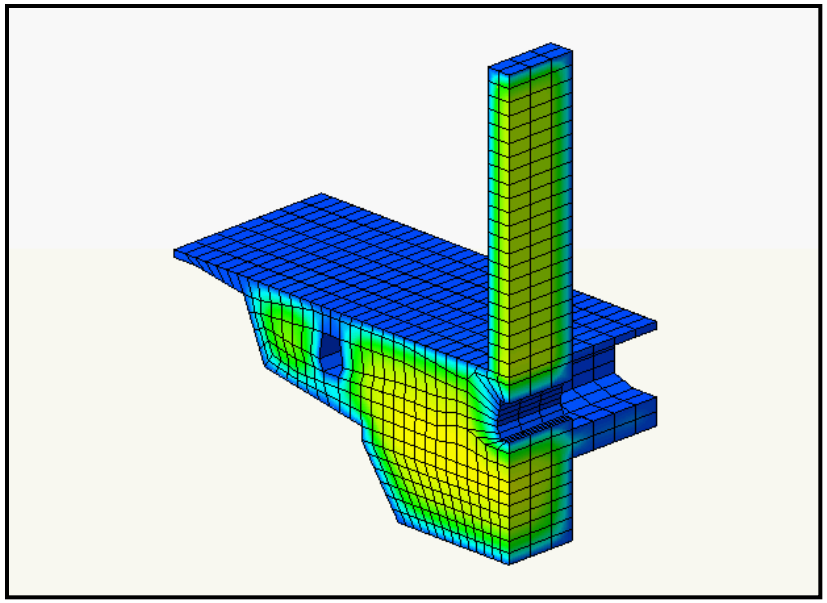




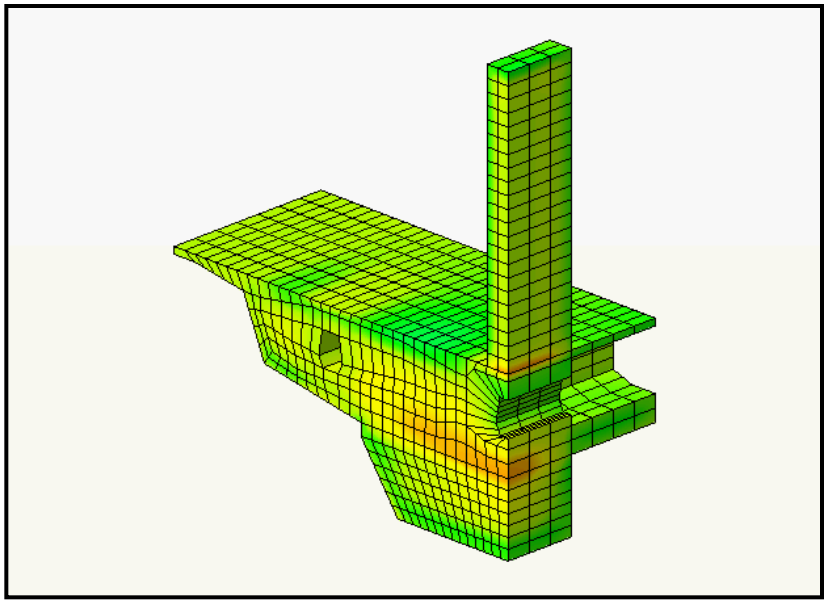
*Crack Pattern (Disc Plot)*

- **Visco-Elastic Models**
  - Kelvin
  - Maxwell
  - Creep-Shrinkage (Design Code)
  - Temperature-Dependent Material

- **Heat Transfer**
  - Steady-State
  - Transient
  - Conduction, Convection, Radiation
  - Pipe Cooling



*Pier Table (Construction Stage) - Temperature*



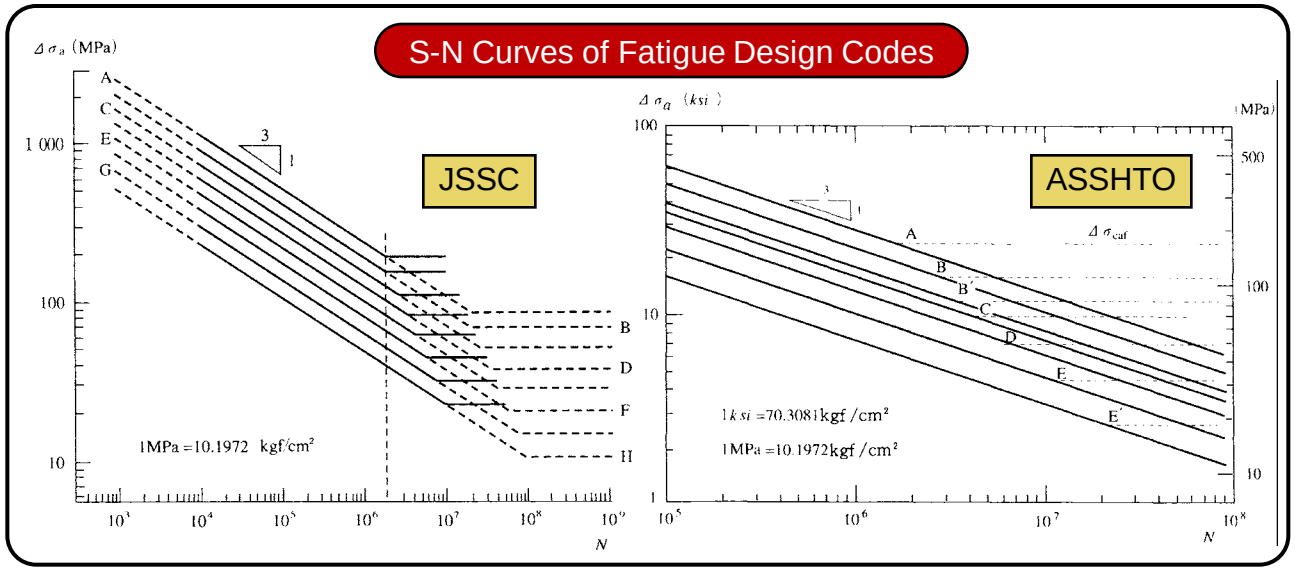
*Pier Table (Construction Stage) - Stress*

- **Methods and Parameters**
  - S-N Method (Stress-Life)
  - E-N Method (Strain-Life)
  - Load / Stress History
  - Rainflow Counting
  - Mean Stress Corrections
  - Stress Concentration Factor
  - Modifying Factors

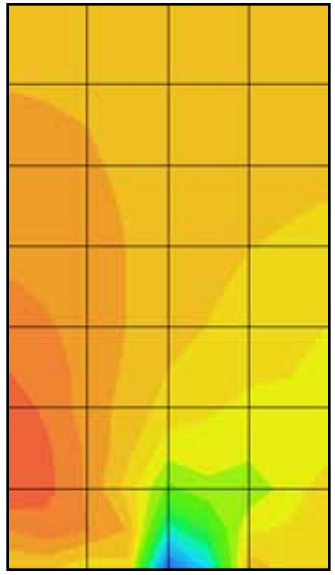
- **Calculation Objects**
  - Boundary Nodes Only (Default)
  - Nodes of Selected Mesh Sets

- **Results**
  - Cycles to Failure
  - Safety Factor
    (Cycles to Failure / Desired Repetition)

S-N Curves of Fatigue Design Codes




*Contour Plot of Cycles*



MQC System

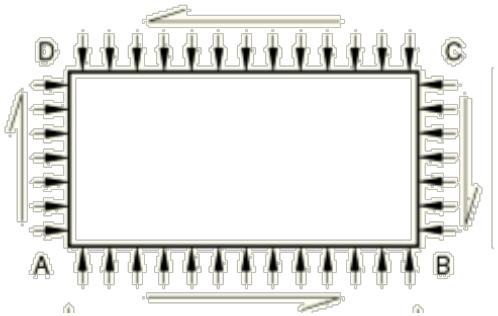
## Verification of Element Formulation (In Development Stage)

| | | |
|---|---|---|
| 1 | Single Element Test | Verify Stiffness Matrix (Simplest Check) |
| 2 | Patch Test | Verify Stability (Element Shape & Configuration) |
| 3 | Refined Mesh Test | Verify Convergence (Mesh Division vs. Stress) |
| 4 | Eigenvalue Test | Verify Mass Matrix (using Lumped Mass) |
| 5 | Benchmark Test | NAFEMS, NASTRAN, DIANA, ABAQUS, etc. |

## System Test (After Development Stage)

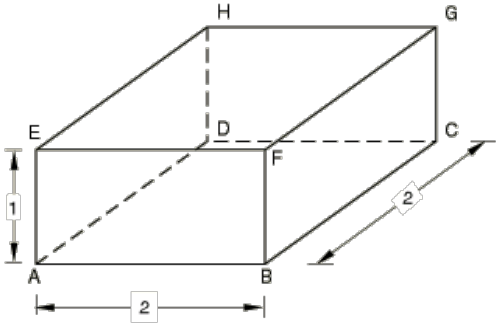
| | | |
|---|---|---|
| 6 | Coverage Analysis | Verify Full Coverage of Test Problems |
| 7 | Regression Test | Automated Test (Over 1,000 Problems Weekly) |

## Single Element Test




- Pure Compression & Shear
- Pure Bending

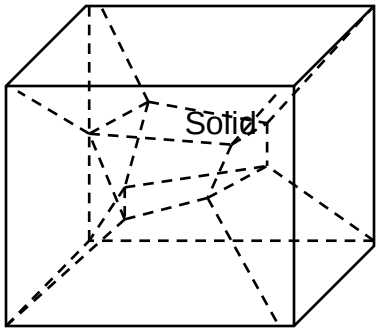
® Constant Stress (OK)




- Pure Compression & Shear

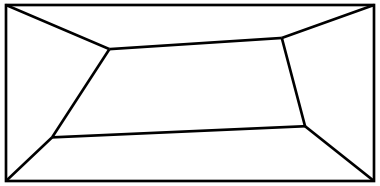
® Constant Stress (OK)

## Patch Test




- Dimension
  Lx = Ly = Lz = 1
- Pure Compression & Shear
  Ux = 10-3 (2x+y+z) / 2
  Uy = 10-3 (x+2y+z) / 2
  Uz = 10-3 (x+y+2z) / 2

® Constant Stress (OK)



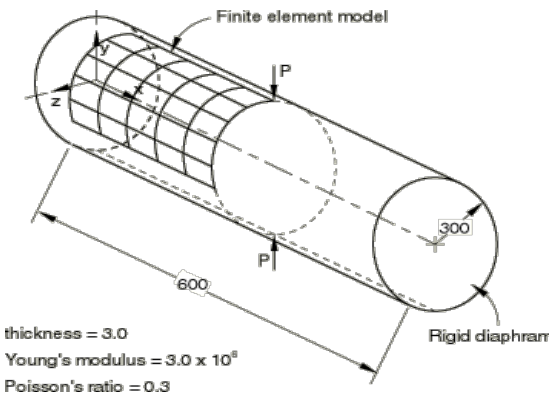
Plate

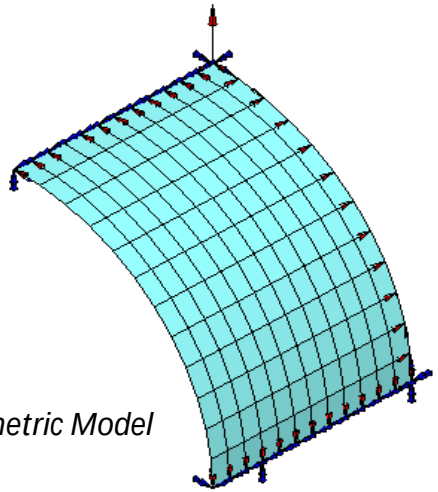
- Dimension
  Lx = 0.24, Ly = 0.12
- <1> Membrane
  Ux = 10-3 (x+y) / 2
  Uy = 10-3 (y+x) / 2
- <2> Bending (Transverse)
  Uz = 10-3 (x2+xy+y2) / 2
  Rx = 10-3 (y+x/2)
  Ry = -10-3 (x+y/2)

® Constant Stress (OK)

All constant stress values are always checked and verified!

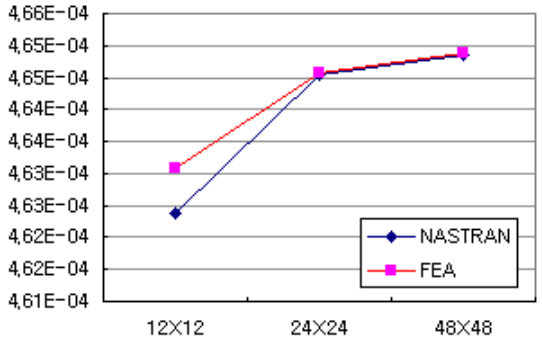
## Pinched Cylindrical Shell



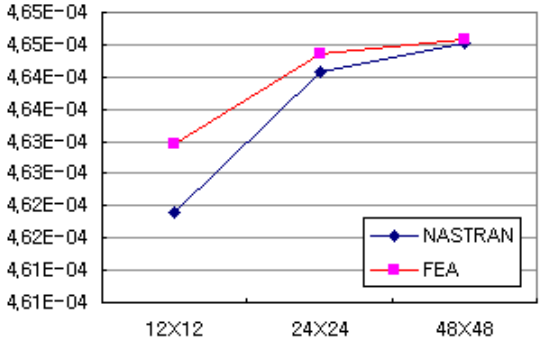



*Symmetric Model*

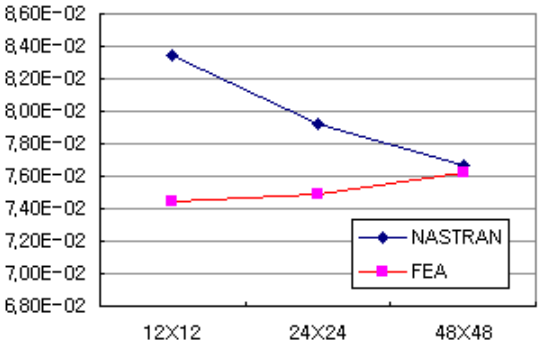
### Deflection (Shear-On)



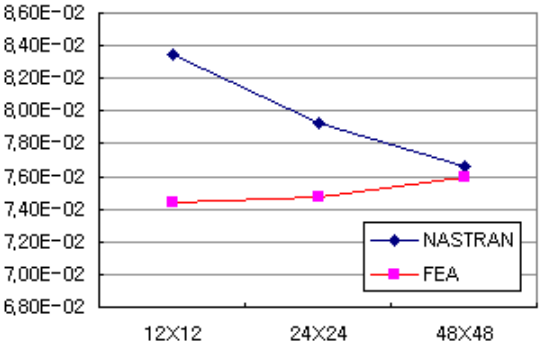

### Deflection (Shear-Off)




### von-Mises (Shear-On)



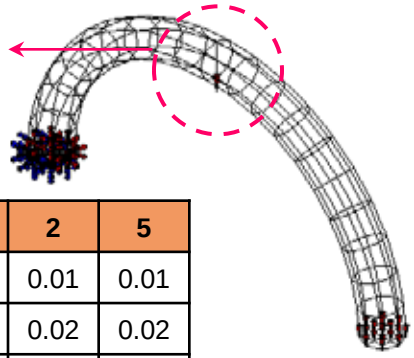

### von-Mises (Shear-Off)




- Theoretical deflection is $4.5197X10^{-4}$.
- FEA shows superior and monotonic convergence in various mesh divisions.

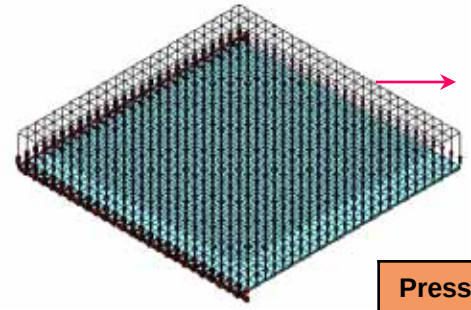
## Geometry Nonlinearity (Solid, T.L.)

Nodal Force = 1, 2, 5



| | Force | 1 | 2 | 5 |
|---|---|---|---|---|
| Error Norm [%] | Hexa | 0.01 | 0.01 | 0.01 |
| | Penta | 0.02 | 0.02 | 0.02 |
| | Tetra | 0.02 | 0.02 | 0.02 |

Displacement Relative Error Norm w.r.t. DIANA

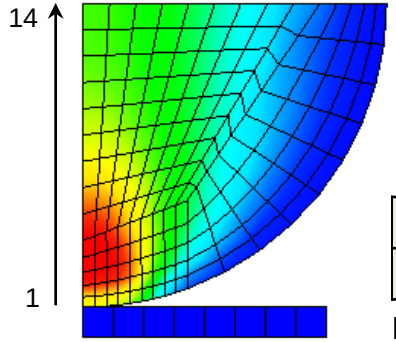


Pressure = 1, 2, 5

| | Pressure | 1 | 2 | 5 |
|---|---|---|---|---|
| Error Norm [%] | Hexa | 0.01 | 0.02 | 0.02 |
| | Tetra | 0.01 | 0.02 | 0.01 |

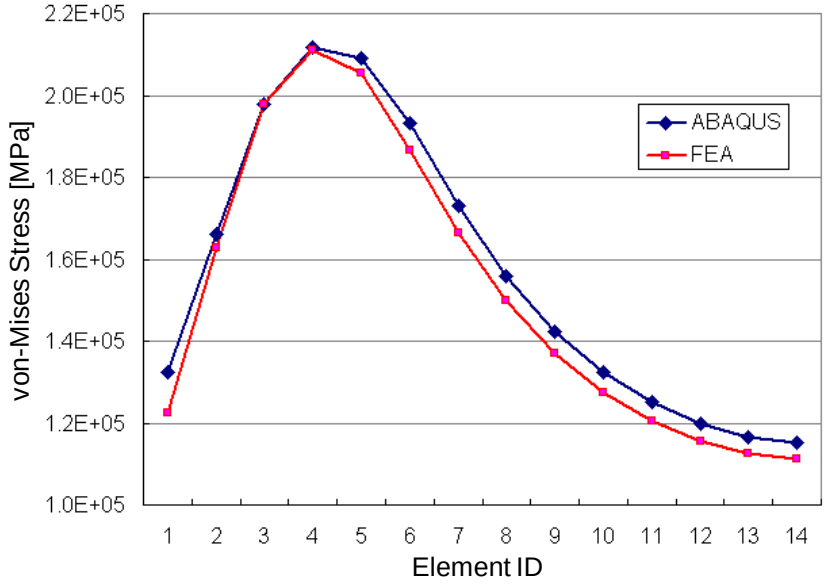
Displacement Relative Error Norm w.r.t. DIANA

## NAFEMS (CGS-3): Hertzian Contact

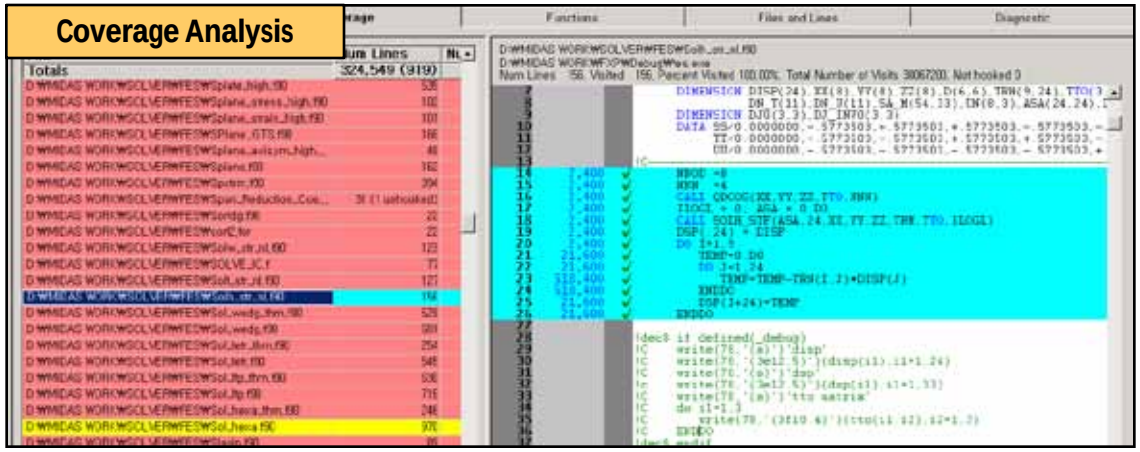



| | |
|---|---|
| ABAQUS | 21,169 [MPa] |
| FEA | 21,120 [MPa] |

Maximum Stress (E-ID: 4)



## Coverage Analysis

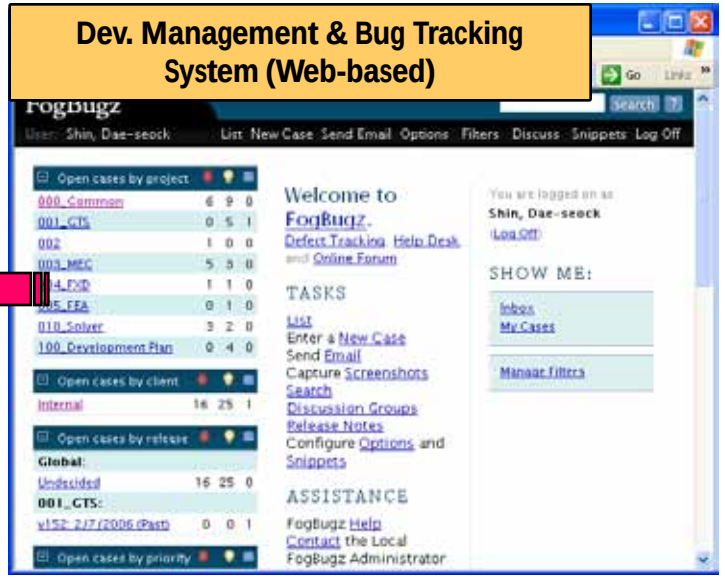


Counts the number of visits in execution to assure all code lines have been tested.

- Test problems are continuously augmented reflecting the result of coverage analysis.
- All test problems are automatically analyzed for regression prevention every week.

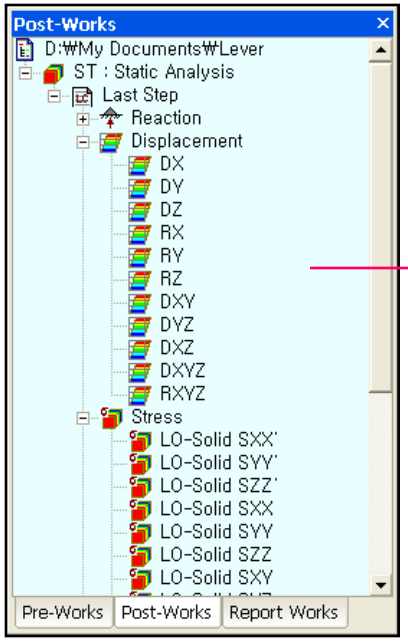

Manages and traces new features / bugs / supports with full revision history.

## Dev. Management & Bug Tracking System (Web-based)

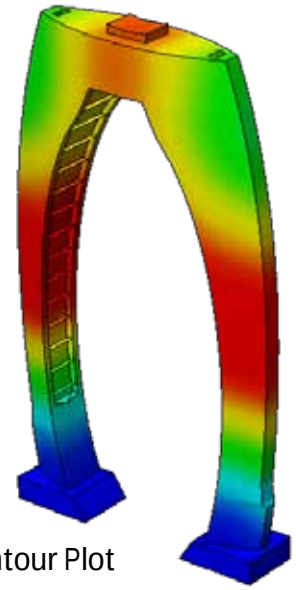


# Post-processing

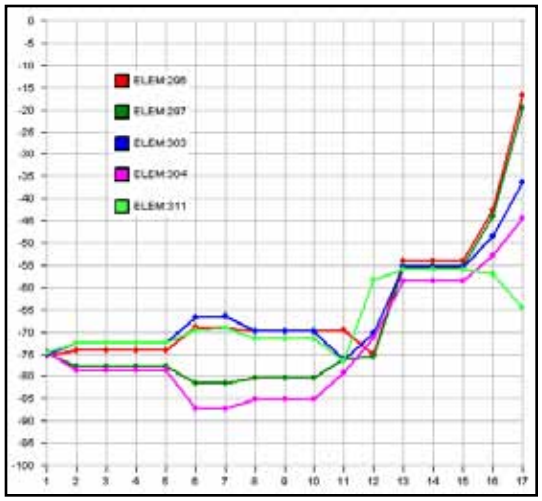
- **Complete Support for Visualization and Interpretation**
  - Flexible User-control on Legends, Colors, Fonts, Magnification, etc.
  - Multiple Plots, Graphs and Tables in Multiple Windows
  - Deformed Shape Combined with Undeformed Shape (including Mode Shape)
  - Local Plots defined by Geometrical Topology or User-selection
  - Contour Plots and Animations (AVI)
  - Iso-value Lines (2D) and Surfaces (3D)
  - Clipping Planes and Slice Lines/Planes
  - Partitioned Plots
  - History Plots in Various Graphs and Animations (AVI)
  - Result Values in MS-Excel compatible Tables
  - Result Probe and Extraction
  - Result Extraction for Construction Stage Analysis and Time History Analysis
  - Screen-shots in WMF, BMP, PNG Picture Formats
  - State-of-the-art Reports Generated by XML and HTML




Works Tree



Contour Plot



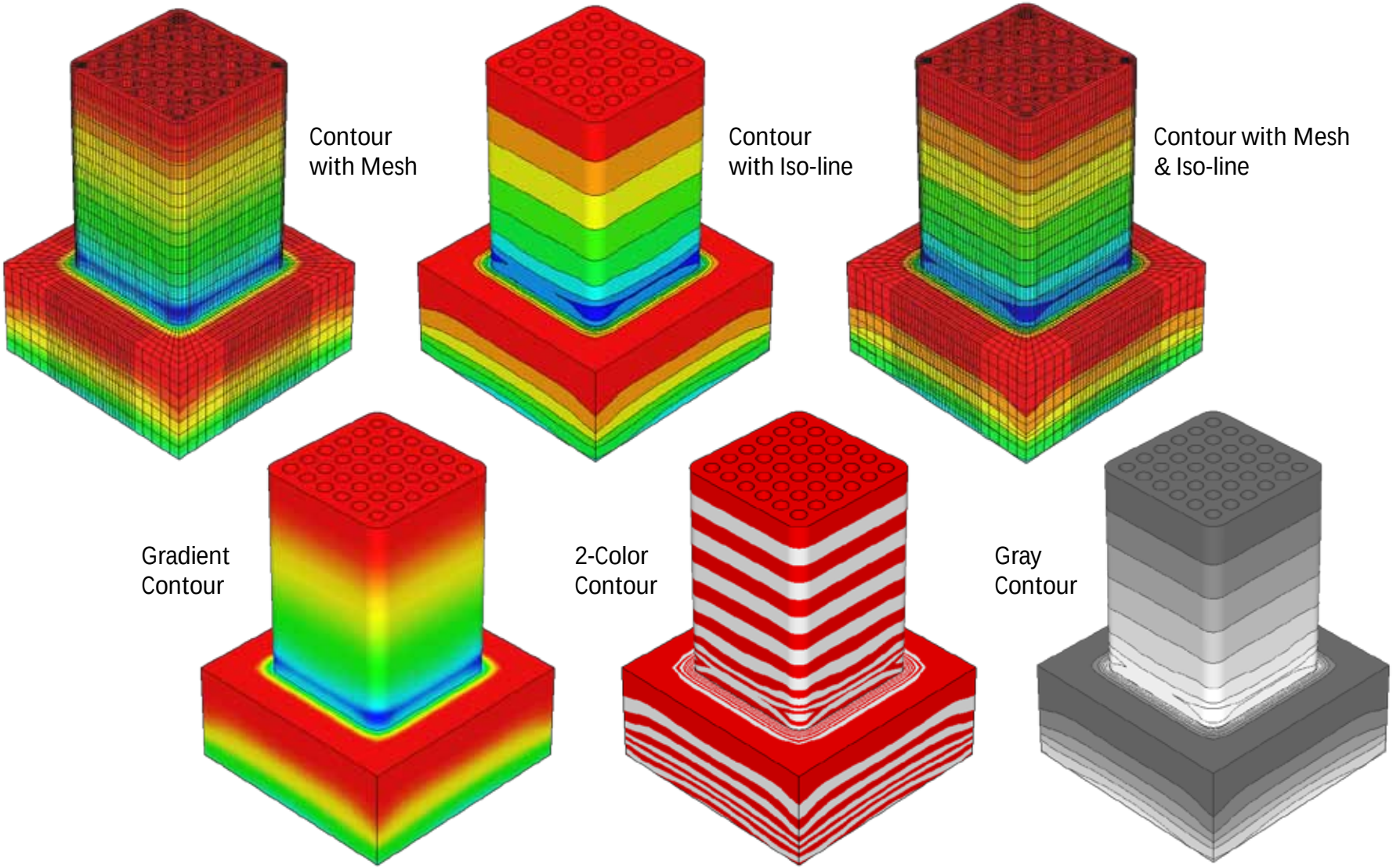

Result Graph

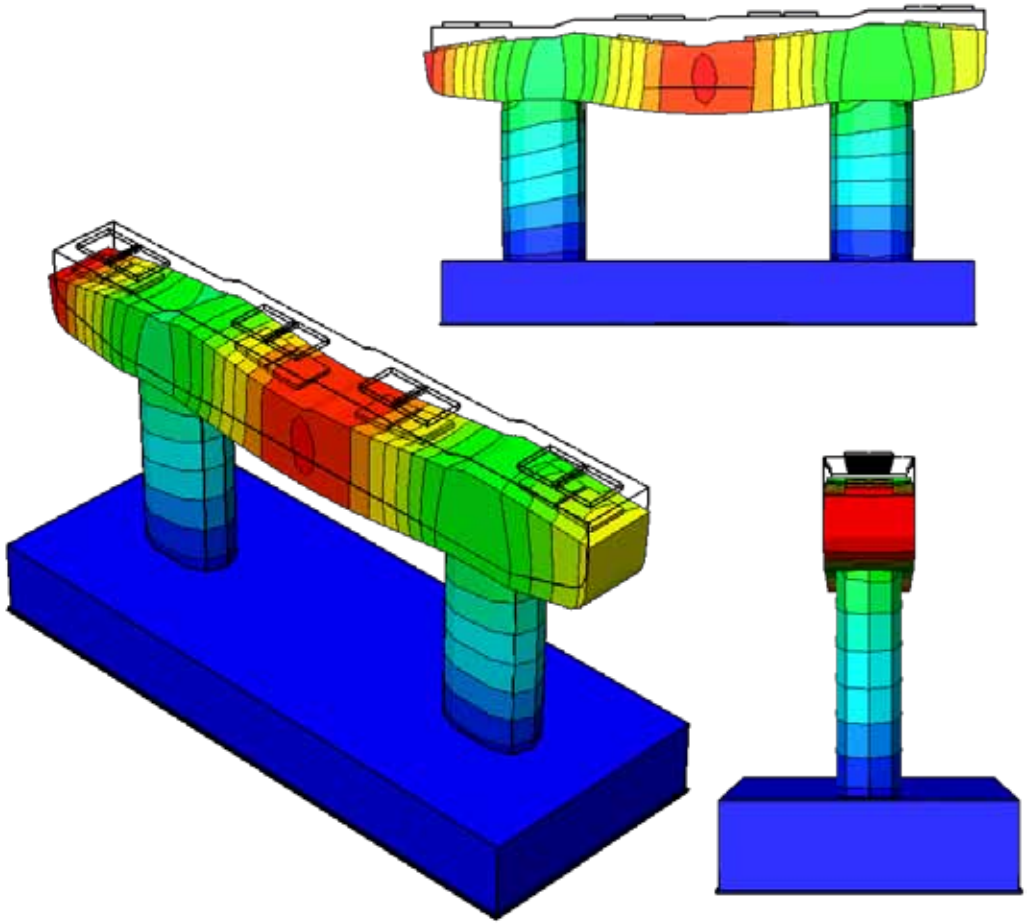
| Node | T1 | T2 | T3 |
|---|---|---|---|
| 1 | 0.004394 | 0.000727 | -0.004332 |
| 2 | 0.004824 | -0.002044 | -0.004367 |
| 3 | 0.006663 | -0.004990 | -0.004402 |
| 4 | 0.003325 | 0.000601 | -0.003268 |
| 5 | 0.003477 | -0.001071 | -0.003307 |
| 6 | 0.004475 | -0.002950 | -0.003352 |
| 7 | 0.002358 | 0.000509 | -0.002299 |
| 8 | 0.002311 | -0.000262 | -0.002296 |
| 9 | 0.002561 | -0.001090 | -0.002311 |
| 10 | 0.000667 | 0.000349 | -0.000564 |
| 11 | 0.007416 | -0.002552 | -0.006962 |
| 12 | 0.004516 | 0.000760 | -0.004451 |

Result Table

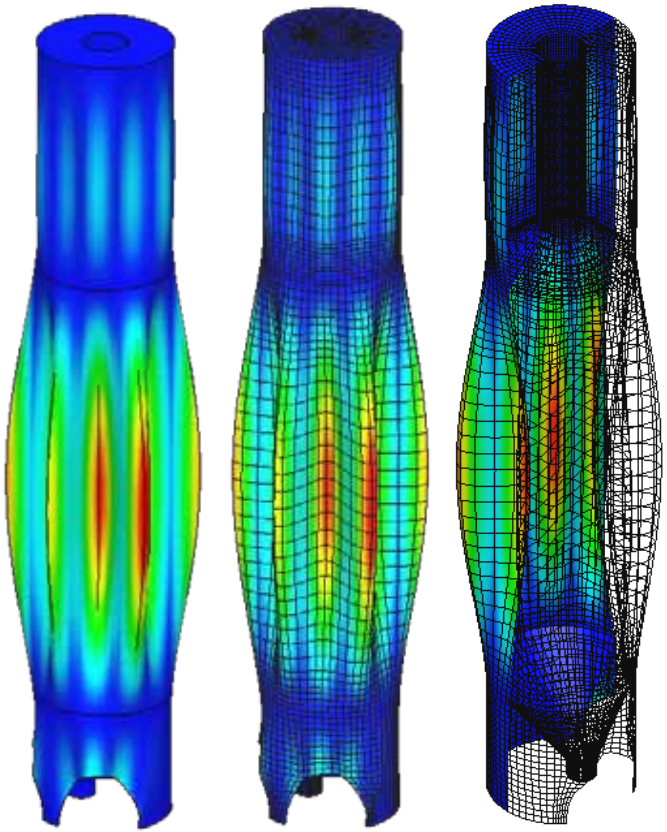
MS-Excel

| | A | B | C | D |
|---|---|---|---|---|
| 1 | 1 | 0,004394 | 0,000727 | -0,004332 |
| 2 | 2 | 0,004824 | -0,002044 | -0,004367 |
| 3 | 3 | 0,006663 | -0,00499 | -0,004402 |
| 4 | 4 | 0,003325 | 0,000601 | -0,003268 |
| 5 | 5 | 0,003477 | -0,001071 | -0,003307 |
| 6 | 6 | 0,004475 | -0,00295 | -0,003352 |
| 7 | 7 | 0,002358 | 0,000509 | -0,002299 |

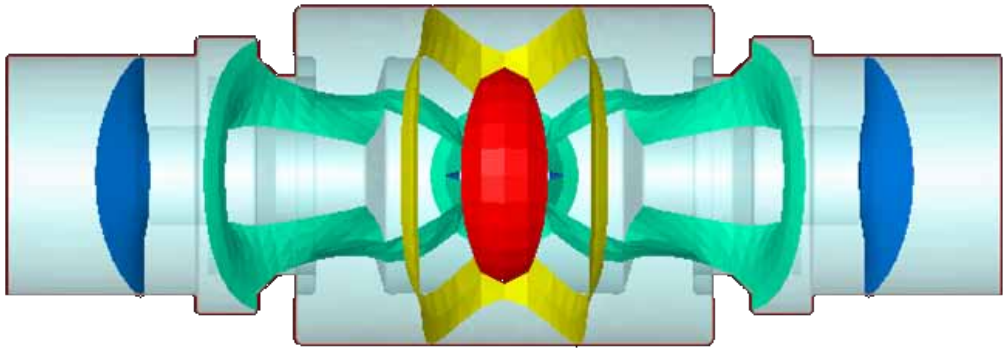

Contour
with Mesh
Contour
with Iso-line
Contour with Mesh
& Iso-line
Gradient
Contour
2-Color
Contour
Gray
Contour



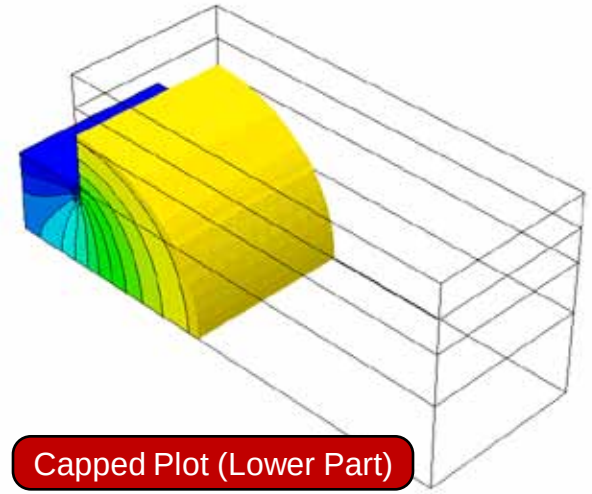
Deformed Contour with Original Shape
(Static Analysis)



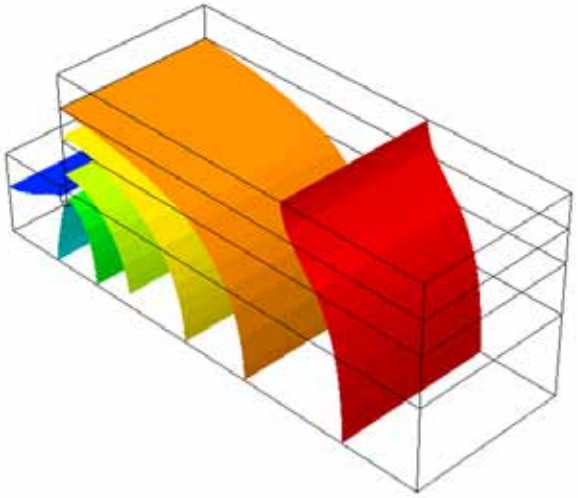
Mode Shapes
(Stability Analysis)



Iso-Surface in Transparent Solid Geometry

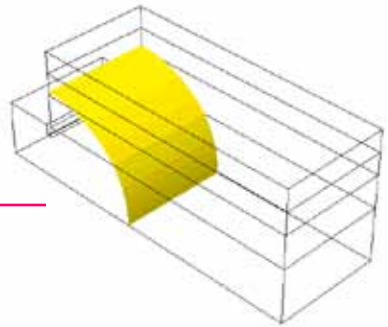


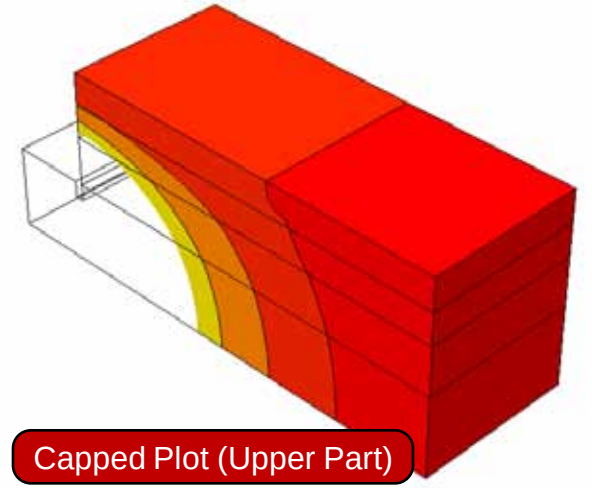
Capped Plot (Lower Part)



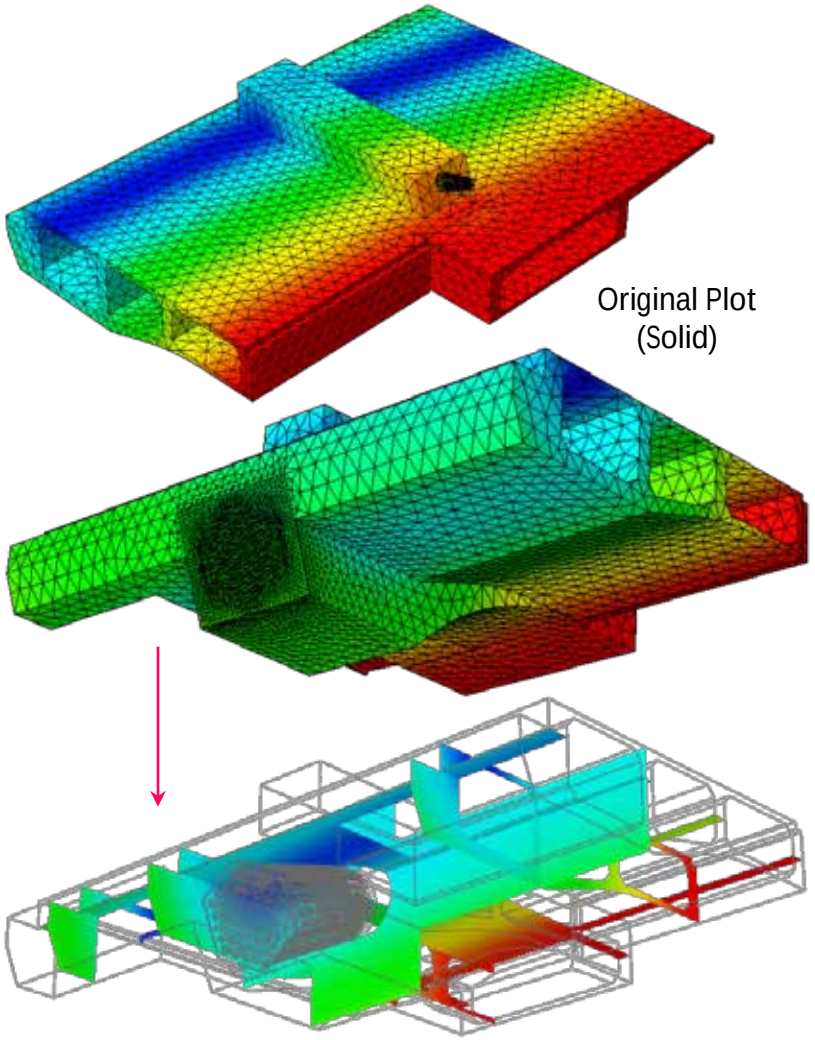
Multiple Iso-surfaces

Base Iso-surface



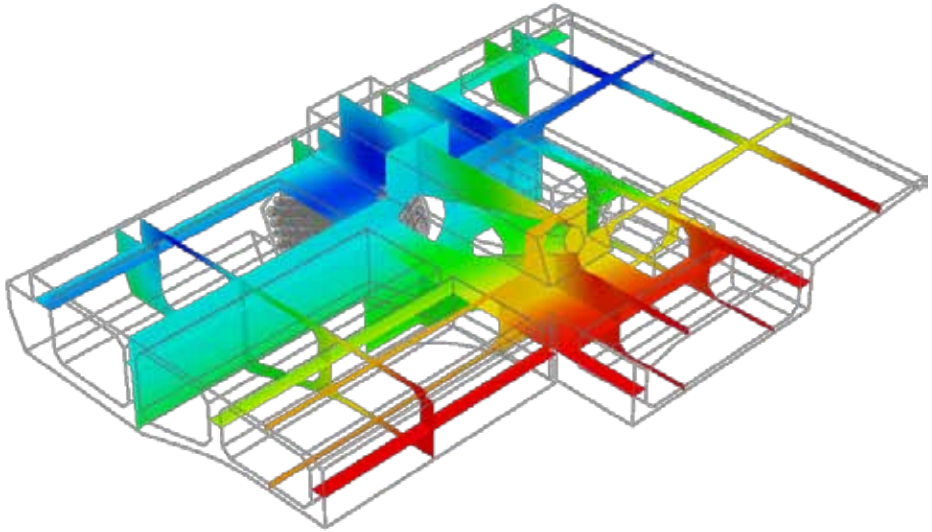


Capped Plot (Upper Part)

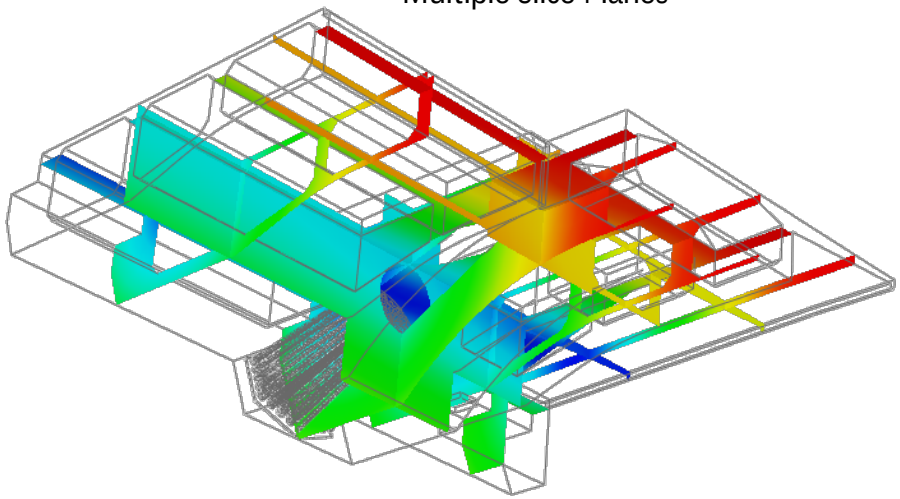


Original Plot
(Solid)

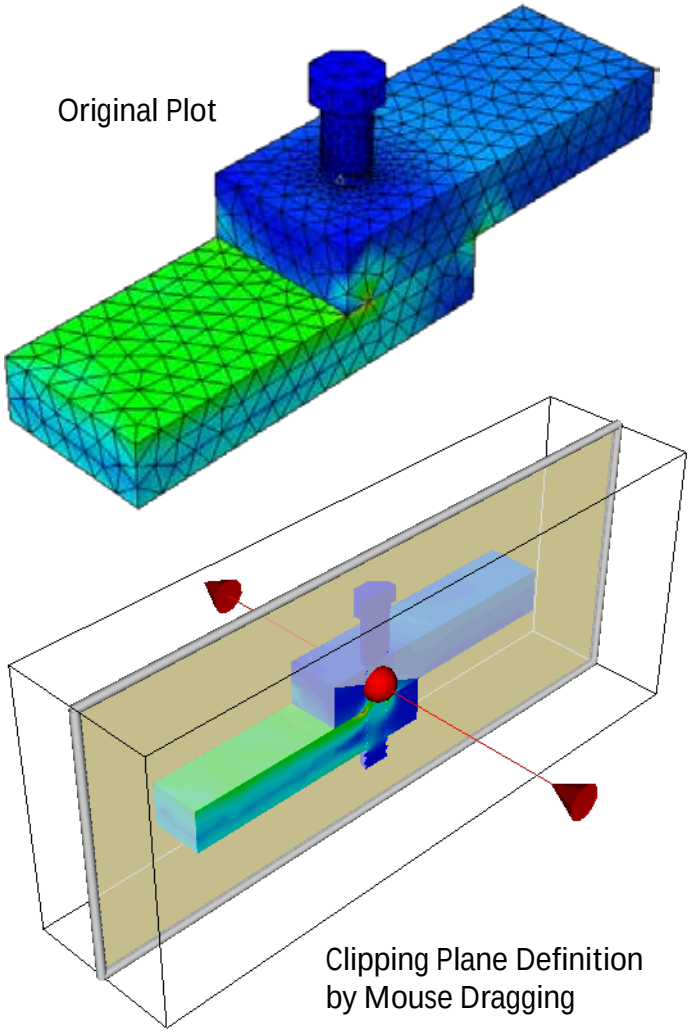
Slice Plot at Arbitrary Plane



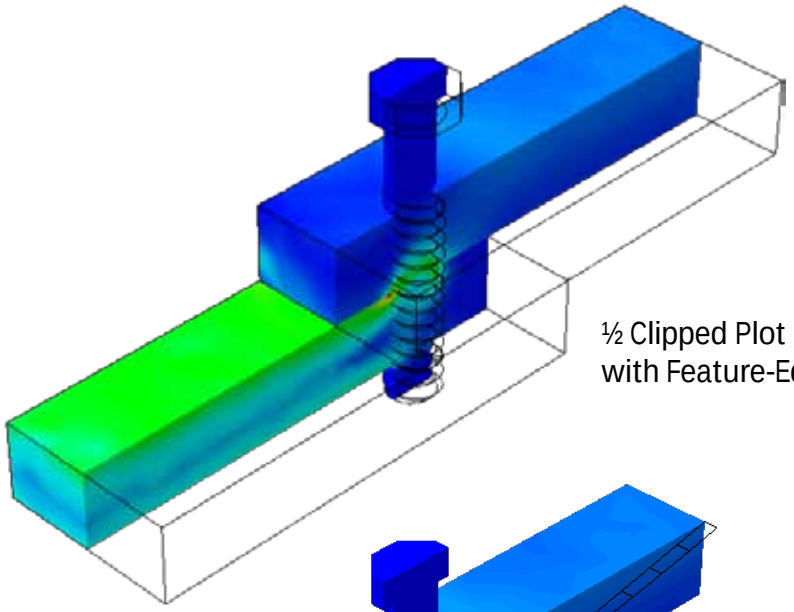
Multiple Slice Planes



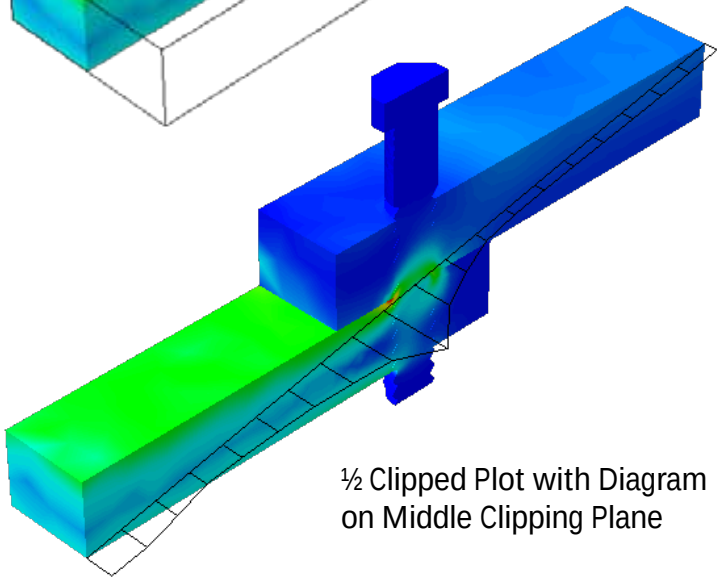
Original Plot



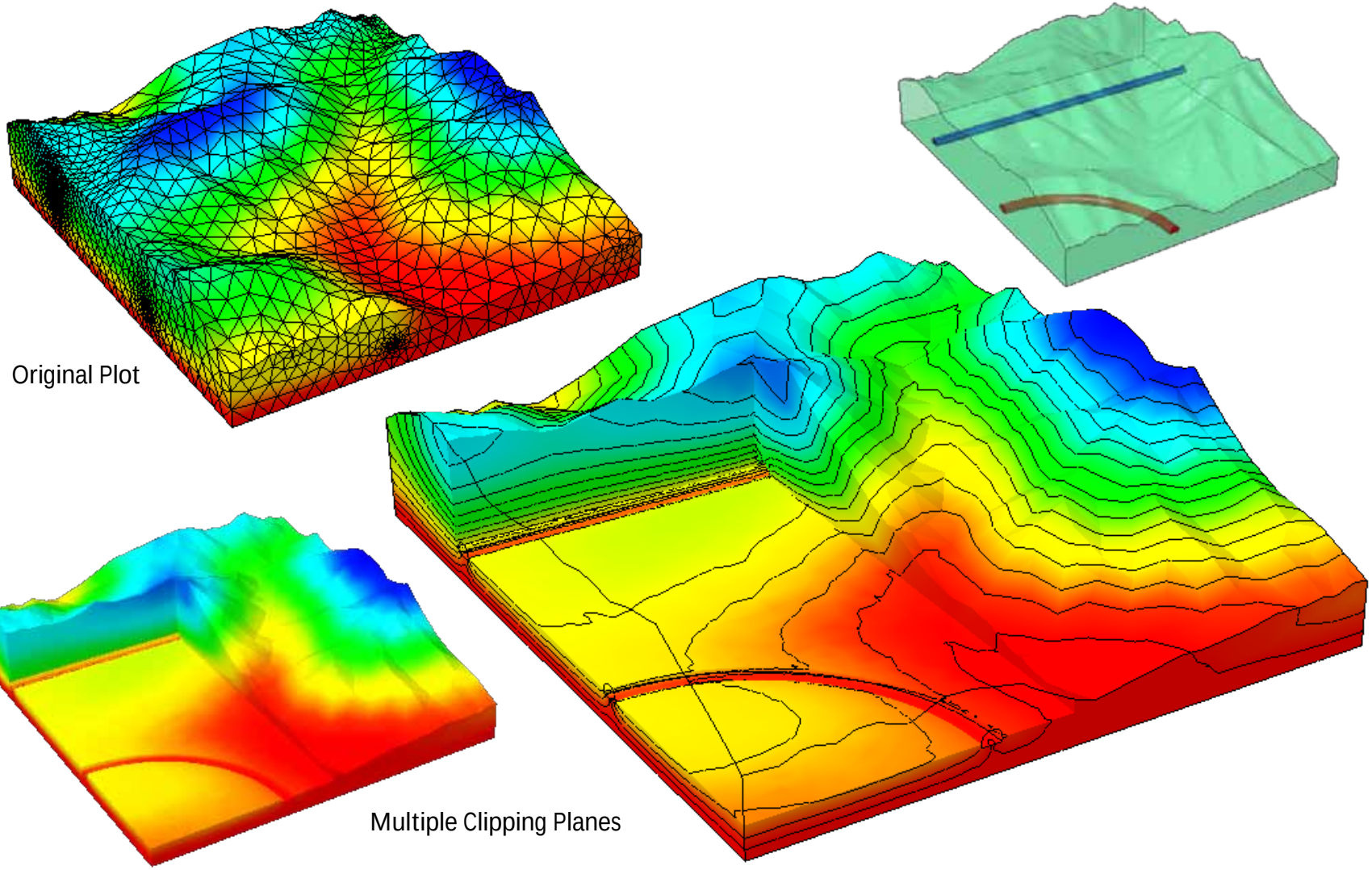
Clipping Plane Definition
by Mouse Dragging

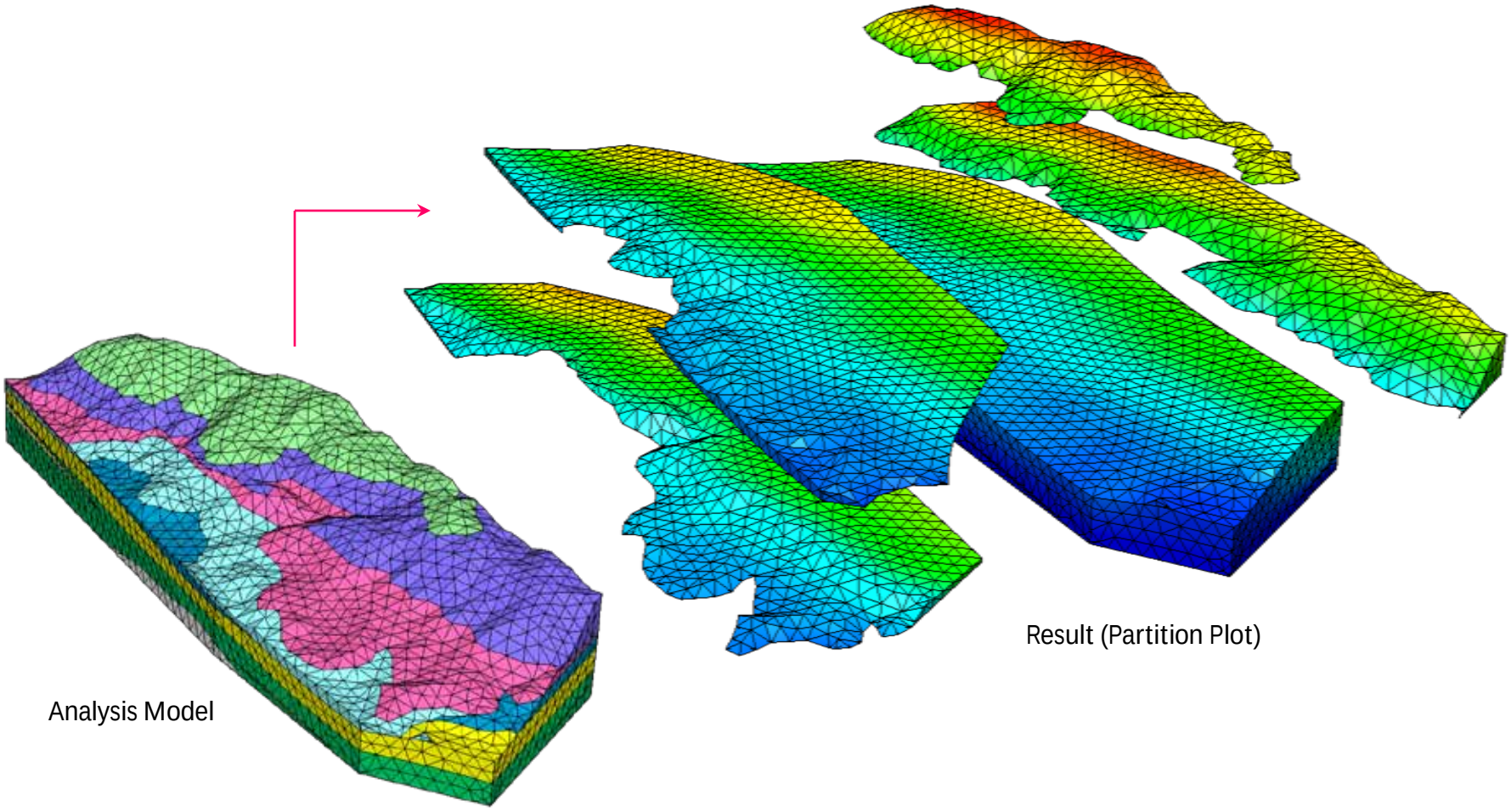


½ Clipped Plot
with Feature-Edge

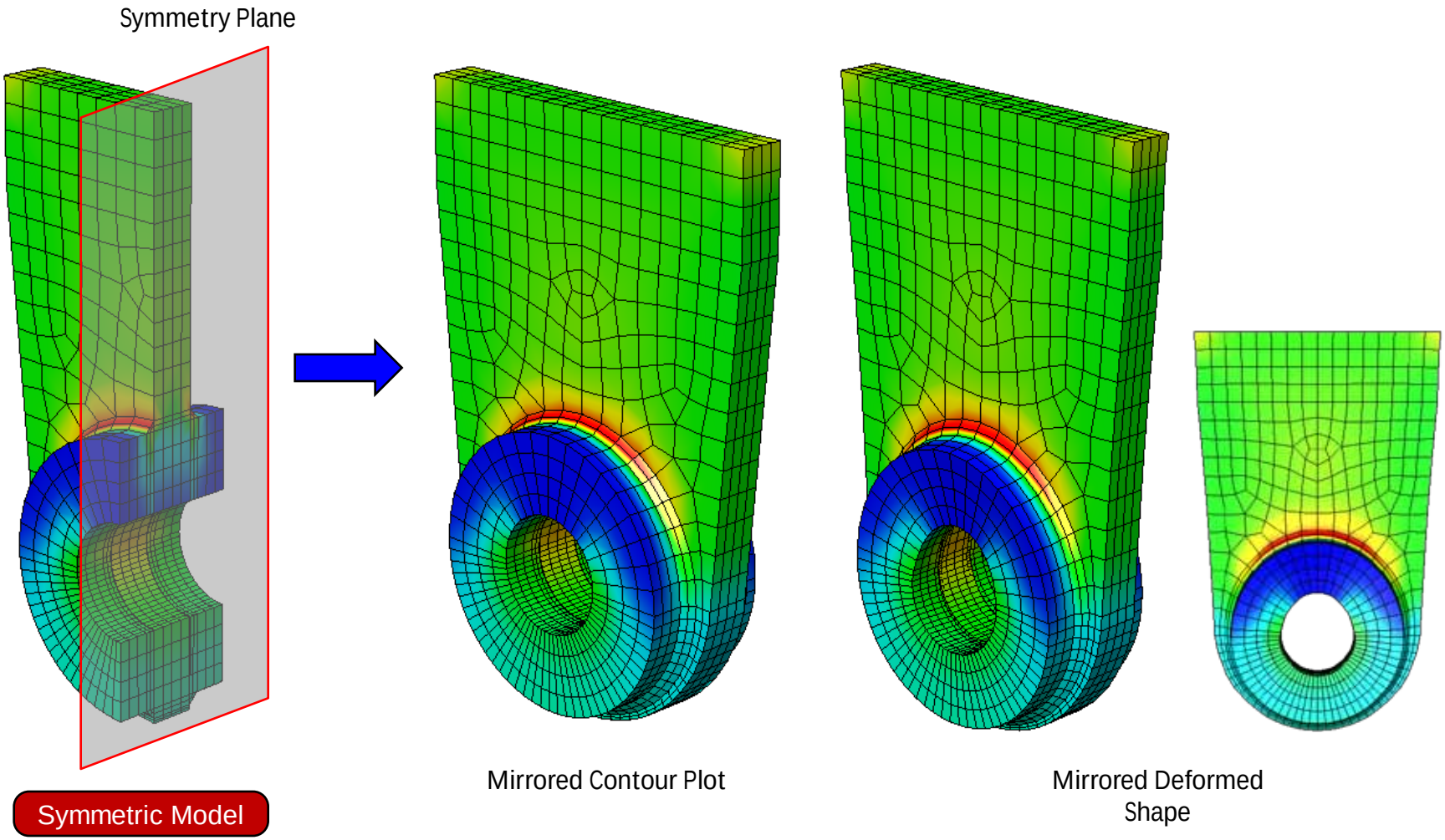


½ Clipped Plot with Diagram
on Middle Clipping Plane

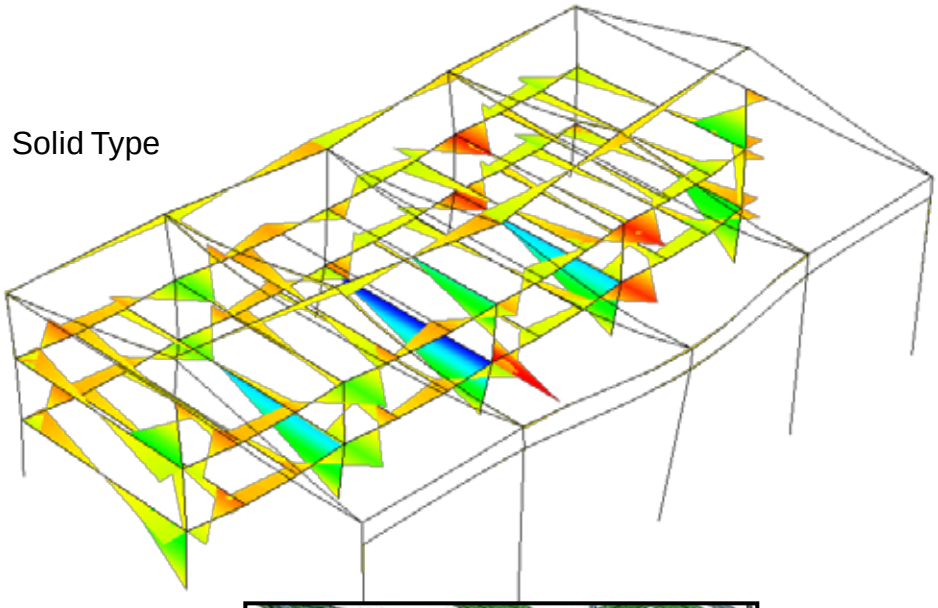

Original Plot
Multiple Clipping Planes

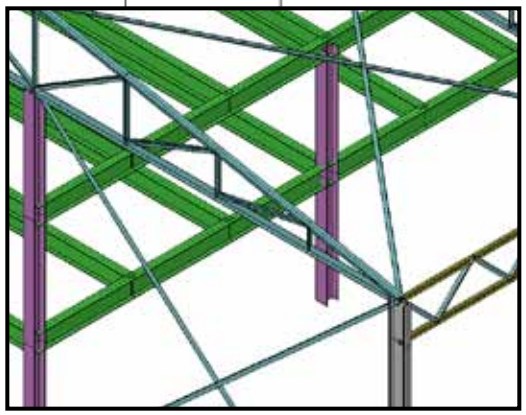


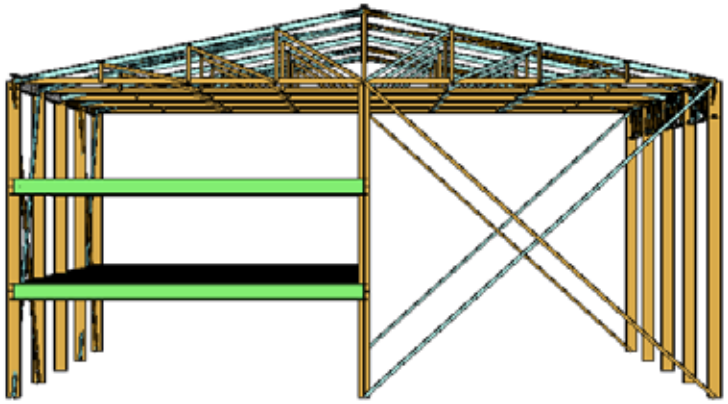

Geotechnical Model with Multiple Strata Configuration


Symmetry Plane
Symmetric Model
Mirrored Contour Plot
Mirrored Deformed Shape

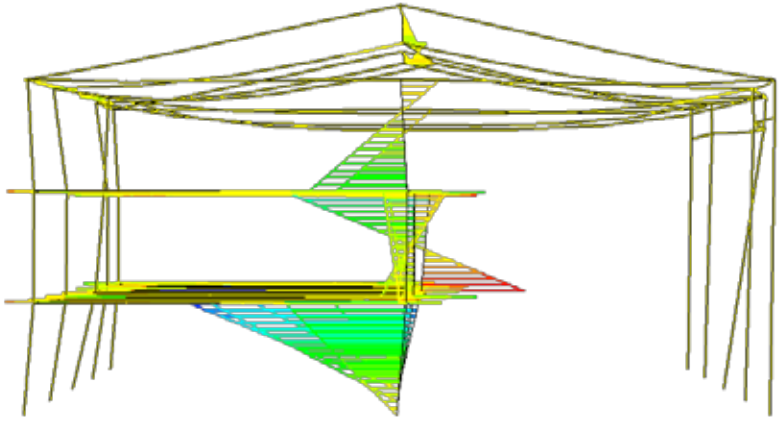
Solid Type







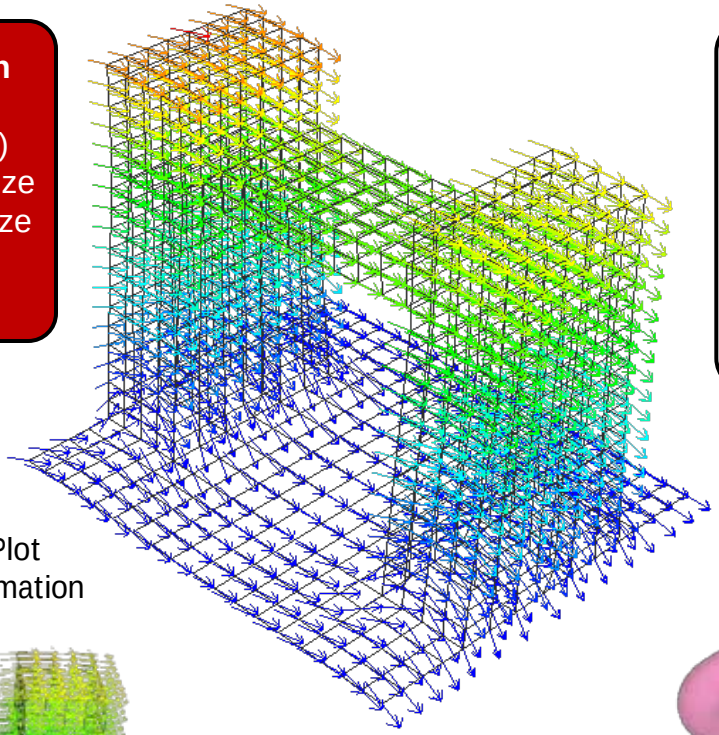
Section Plot of Frames



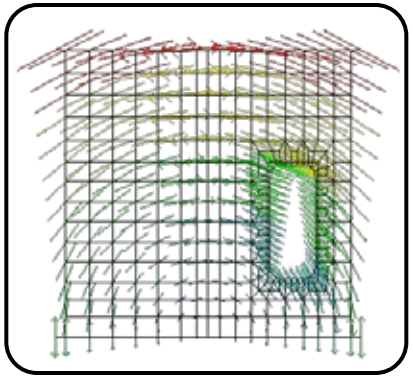
Line Type

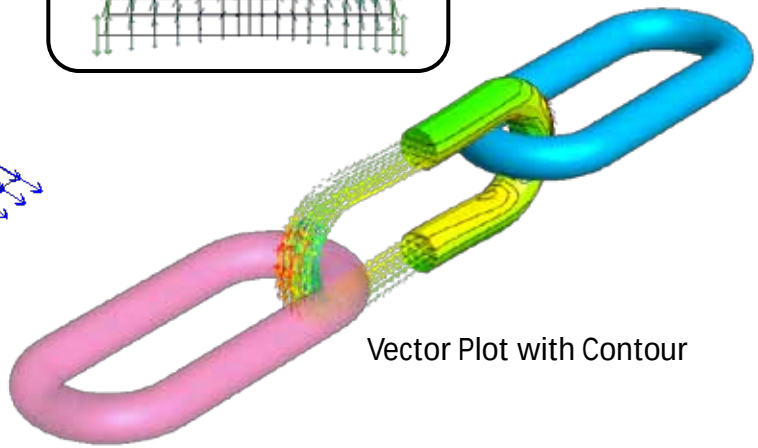
Diagram Plot with Deformed Shape

**Vector Plot Option**
- Head Type (Both, One, None)
- Constant Head Size
- Constant Body Size
- Color (Contour, Mono)

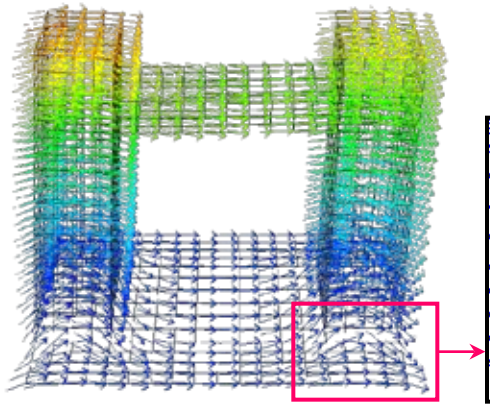


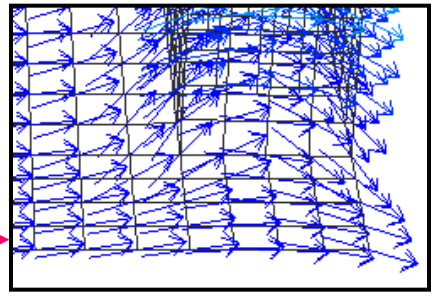
Vector Plot with Deformation

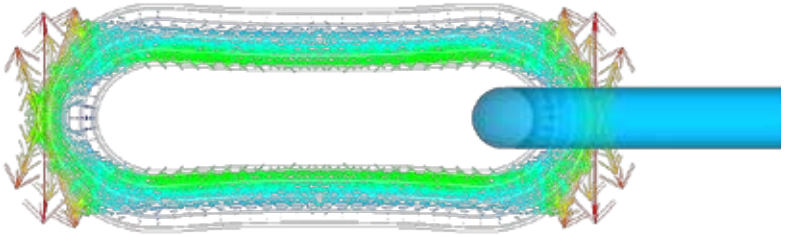




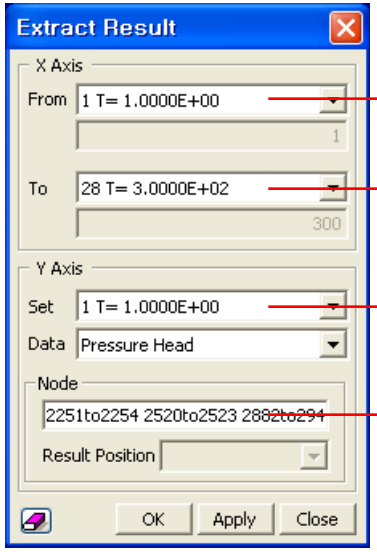
Vector Plot with Contour







Vector Plot with Transparent Geometry

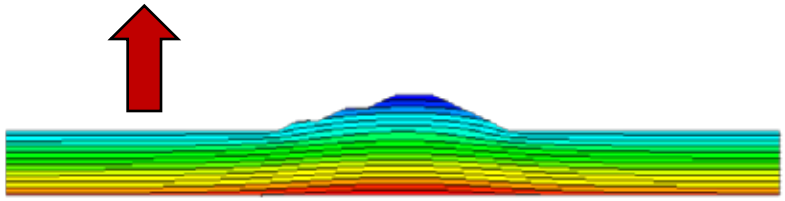



Start Step / Time

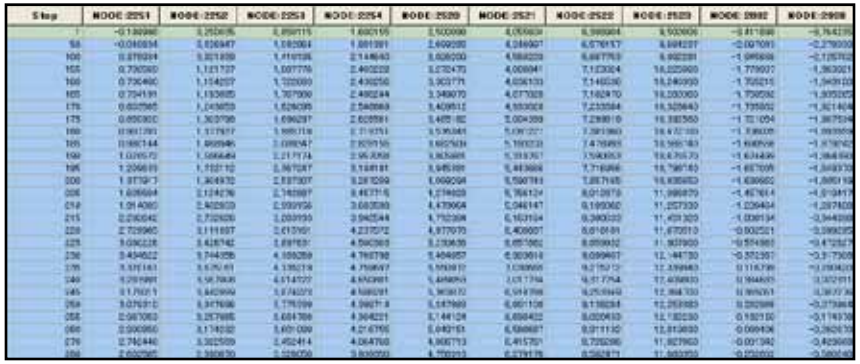
End Step / Time

Step / Output Set
Result Type

Node / Element IDs

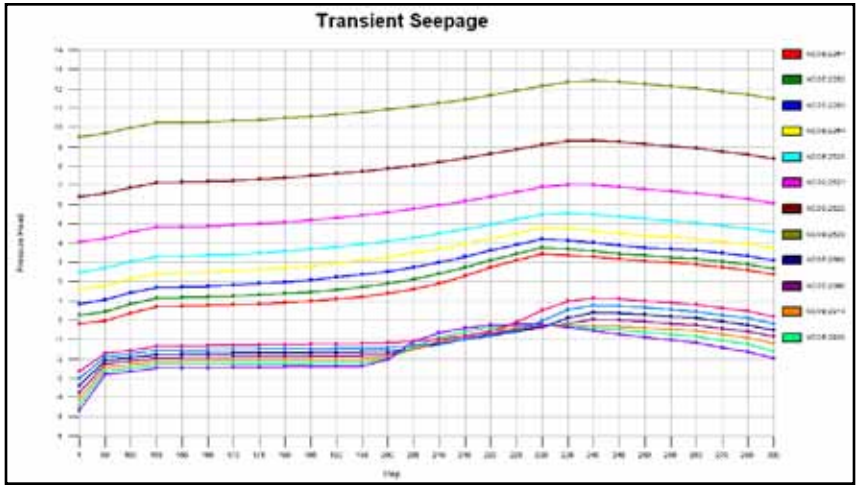


Transient Analysis

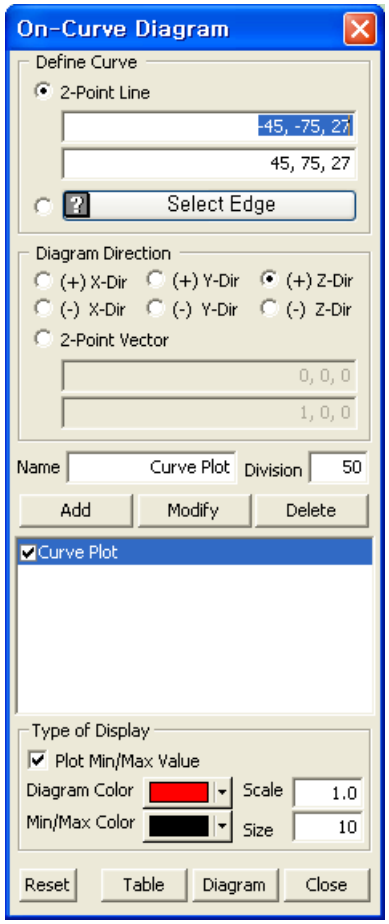


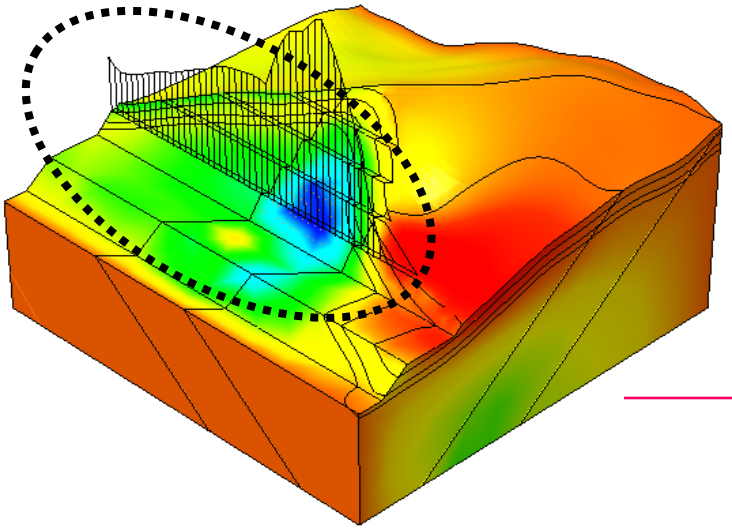
MS-Excel compatible Table
(Time & Result Value)

Graph (Time .vs. Result Value)




- Results can be extracted based on:
  - Time (Transient Analysis)
  - Step (Nonlinear / Construction Stage Analysis)
  - Coordinate (User-defined Coordinate Sys.)

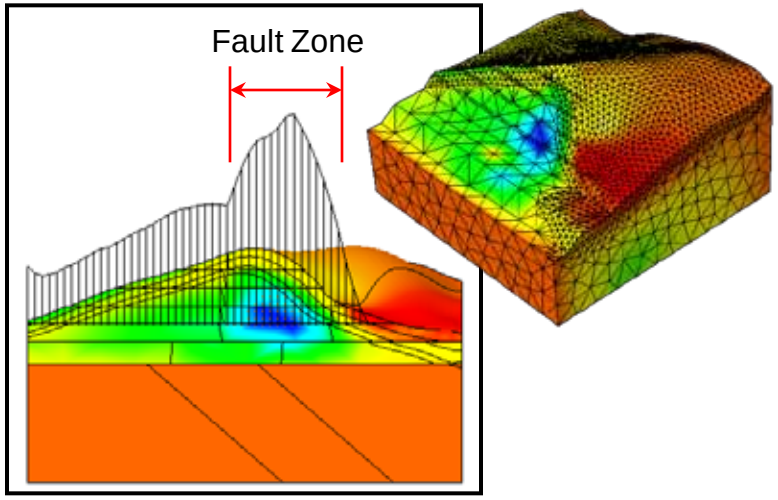


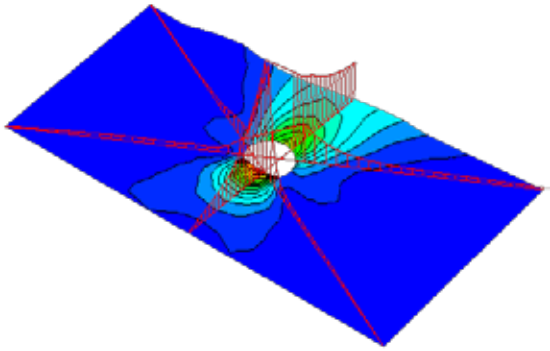
3D On-Curve Graphs on Contour Plot

| ID | X (m) | Y (m) | Z (m) | Value |
|---|---|---|---|---|
| 1 | 102,13 | 34,75 | 182,00 | 0,0001 |
| 2 | 100,09 | 34,75 | 182,00 | 0,0001 |
| 3 | 98,05 | 34,75 | 182,00 | 0,0001 |
| 4 | 96,01 | 34,75 | 182,00 | 0,0000 |
| 5 | 93,96 | 34,75 | 182,00 | -0,0001 |
| 6 | 91,92 | 34,75 | 182,00 | -0,0003 |
| 7 | 89,88 | 34,75 | 182,00 | -0,0005 |
| 8 | 87,84 | 34,75 | 182,00 | -0,0008 |
| 9 | 85,79 | 34,75 | 182,00 | -0,0011 |
| 10 | 83,75 | 34,75 | 182,00 | -0,0014 |
| 11 | 81,71 | 34,75 | 182,00 | -0,0017 |
| 12 | 79,66 | 34,75 | 182,00 | -0,0019 |
| 13 | 77,62 | 34,75 | 182,00 | -0,0021 |
| 14 | 75,58 | 34,75 | 182,00 | -0,0022 |
| 15 | 73,54 | 34,75 | 182,00 | -0,0024 |
| 16 | 71,49 | 34,75 | 182,00 | -0,0024 |

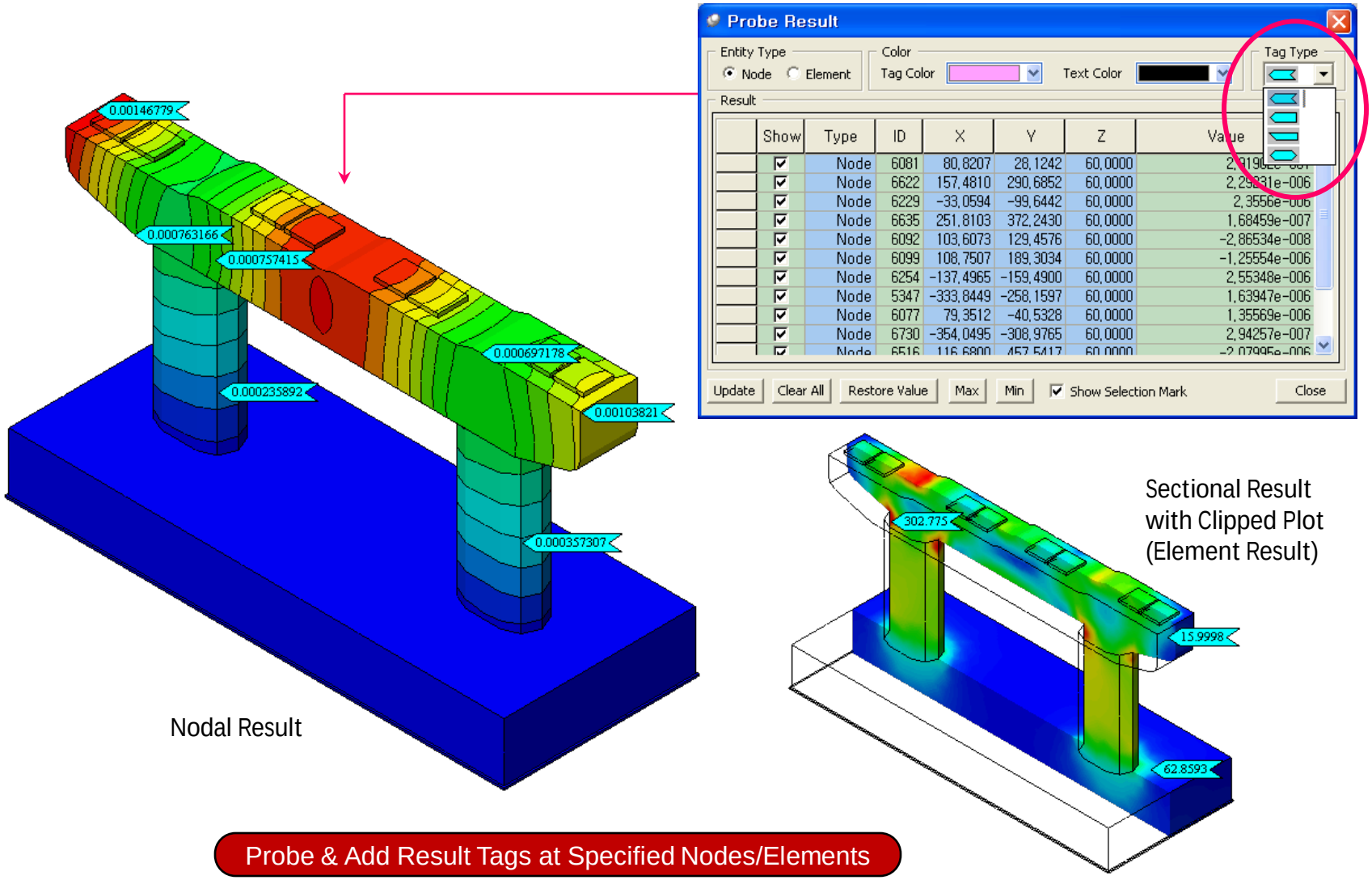
Result Data at User-Specified Sampling Points




Front View

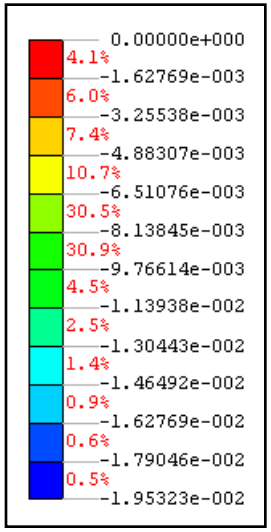


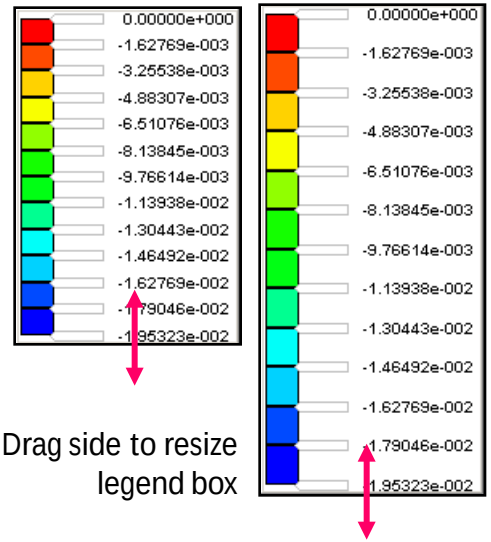
2D On-Curve Graphs on Contour Plot



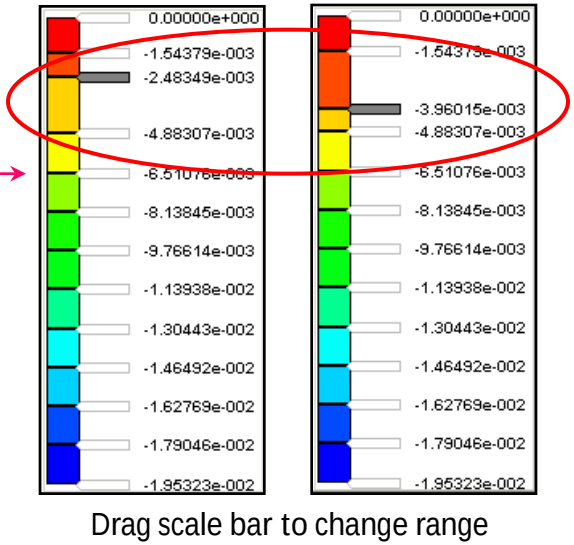

Probe & Add Result Tags at Specified Nodes/Elements

**In FEA, legend can be controlled for its position, size, format and range (including min/max value) by mouse dragging.**

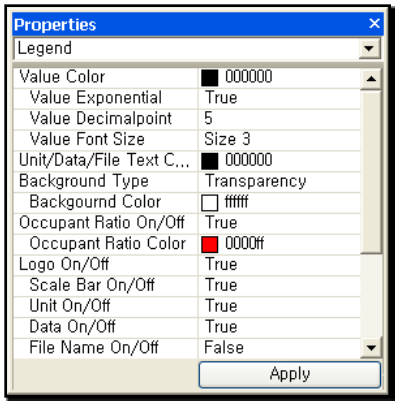



Drag side to resize legend box



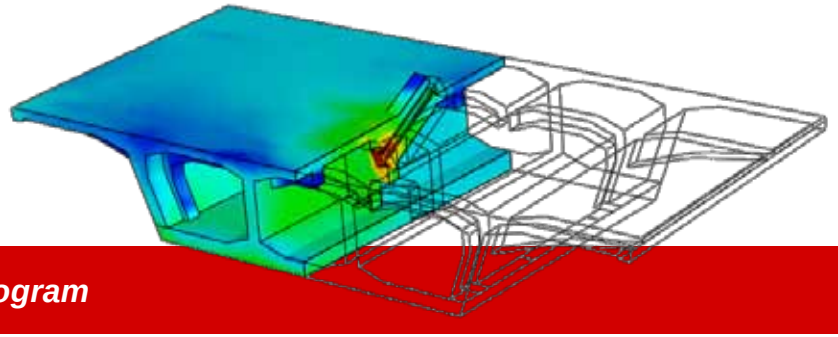

Drag scale bar to change range




Property Window (Legend Option)

- Legend Option:
  - Color (Value, Ratio, Description)
  - Logo
  - Range (including Min/Max/Zero)
  - Format (Fixed/Scientific, Width)

# Thank You!



*Advanced Nonlinear and Detail Analysis Program*

midas **FEA**