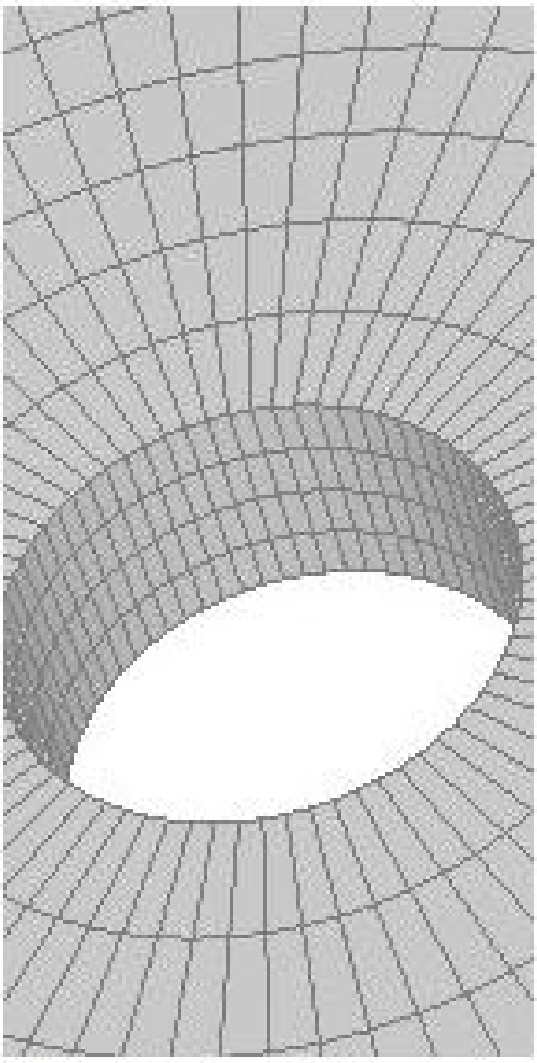
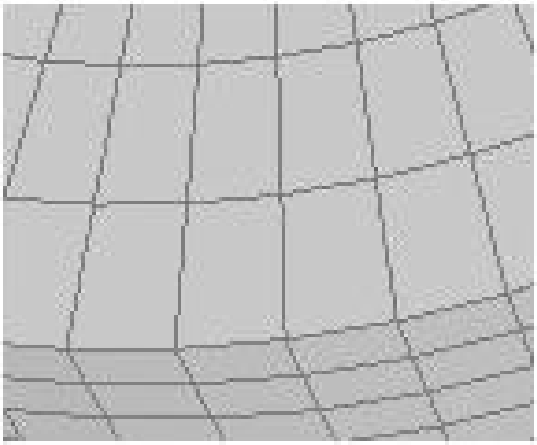


VOLUME B

ELEMENT LIBRARY



Contents

Introduction

SolidMAT contains an extensive element library. These elements provide coverage of truss, plane stress and plane strain structures, plate, beam and arbitrary shell structures, and full three-dimensional solid structures. A short description of each element and a summary of the data necessary for the use of elements are included in this section. The general outline of element descriptions is as follows,

- Element Characteristics
- Element Assignments
- Element Output

Note that many elements serve the same purpose. You should be aware that though the accuracy of the solution increases with the interpolation degree of elements, the bandwidth of the resulting system stiffness matrix also increases. The optimization of demanded accuracy level, element mesh characteristics and interpolation degrees, and storage-solution time requirements requires you to exercise your analytical skills and judgement. In return, you are rewarded, for instance, by a more accurate stress and displacement picture.

In general, the lower order quadrilateral elements give significantly better results than triangular elements in two dimensions, and similar conclusion applies in three dimensions for hexahedral and tetrahedral elements. For a number of elements in SolidMAT, a selective integration scheme is used to determine the stiffness matrix of the element. This is especially realized for elements using shear-deformable theories, in order to overcome a possible shear locking effect in which case the element stiffness matrix becomes stiff. In such a scheme, the integration of related terms (i.e. transverse shear and/or membrane-bending coupling) is not exact; the contribution of the highest order terms in the deformation field is neglected. Selective integration elements have specific advantages and disadvantages. The most obvious advantage is the reduced cost for element assembly, and as mentioned, more realistic element behavior when the element is very thin. But the same feature also forms the disadvantage of the element. Each of the selective integration elements has some specific higher-order deformation mode(s) which do not give any contribution to the strain energy in the element. So, these elements must be used cautiously.

■ Element Classifications

General Classification			
Type	**Geometry**	**Mechanics**	**Interpolation**
0	Line	Truss	Linear
1	Line	Truss	Quadratic
2	Line	Truss	Cubic
3	Quadrilateral	Plane Stress	Linear
4	Quadrilateral	Plane Stress	Quadratic
5	Triangular	Plane Stress	Linear
6	Triangular	Plane Stress	Quadratic
7	Quadrilateral	Plane Stress	Cubic
8	Quadrilateral	Plane Strain	Linear
9	Quadrilateral	Plane Strain	Quadratic
10	Quadrilateral	Plane Strain	Cubic
11	Triangular	Plane Strain	Linear
12	Triangular	Plane Strain	Quadratic
13	Line	Beam	Linear
14	Line	Beam	Quadratic
15	Line	Beam	Cubic
16	Quadrilateral	Shell	Linear
17	Quadrilateral	Shell	Quadratic
18	Triangular	Shell	Quadratic
19	Quadrilateral	Doubly Curved Shell	Linear
20	Quadrilateral	Doubly Curved Shell	Quadratic
21	Triangular	Doubly Curved Shell	Quadratic
22	Hexahedral	Solid	Linear
23	Hexahedral	Solid	Quadratic
24	Quadrilateral	Plate	Linear
25	Quadrilateral	Plate	Quadratic
26	Triangular	Plate	Quadratic
27	Line	Curved Beam	Linear
28	Line	Curved Beam	Quadratic
29	Line	Curved Beam	Cubic
30	Tetrahedral	Solid	Linear
31	Tetrahedral	Solid	Quadratic

Mechanical Classification	
Mechanics	**Type**
Truss	0, 1, 2
Beam	13, 14, 15
Curved Beam	27, 28, 29
Plane Stress	3, 4, 5, 6, 7
Plane Strain	8, 9, 10, 11, 12
Plate	24, 25, 26
Shell	16, 17, 18
Doubly Curved Shell	19, 20, 21
Solid	22, 23, 30, 31

Geometrical Classification	
Geometry	**Type**
Line	0, 1, 2, 13, 14, 15, 27, 28, 29
Quadrilateral	3, 4, 7, 8, 9, 10, 16, 17, 19, 20, 24, 25
Triangular	5, 6, 11, 12, 18, 21, 26
Hexahedral	22, 23
Tetrahedral	30, 31

Interpolation Classification	
Interpolation	**Type**
Linear	0, 3, 5, 8, 11, 13, 16, 19, 22, 24, 27, 30
Quadratic	1, 4, 6, 9, 12, 14, 17, 18, 20, 21, 23, 25, 26, 28, 31
Cubic	2, 7, 10, 15, 29

Element 0 - Two-node Truss Element

Element Characteristics

Mechanics

This is a three dimensional, constant cross section, straight truss element. Isotropic or Orthotropic linear material models can be used with this element. Element stiffness, mass and stability matrices are evaluated analytically.

Geometry and Nodes

Element has two nodes. Three coordinates per node in global x, y and z direction, and a constant cross section are given as input. Axial rotation can be assigned as user-defined local axes.

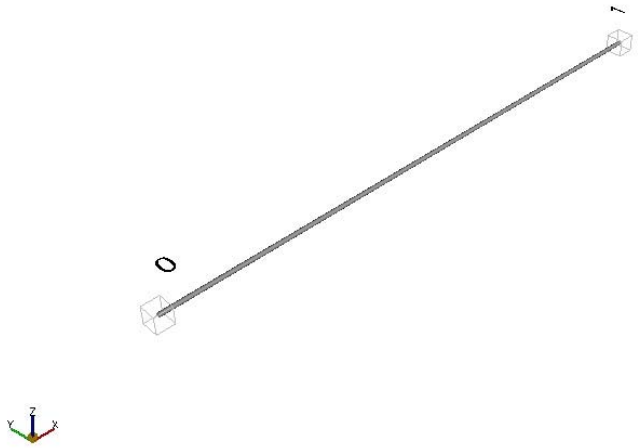


Figure – Element 0

Interpolation

Element has linear-Lagrange interpolation functions.

Degrees of Freedom

Global dofs (per node) are:

- u_x displacement
- u_y displacement
- u_z displacement

Local dofs (per node) are:

- u_1 displacement

Element Assignments

Mechanical Loading

Distributed global loads can be applied as follows:

- f_x force per unit length (uniform or linear)
- f_y force per unit length (uniform or linear)
- f_z force per unit length (uniform or linear)
- Gravity loading in global x, y or z direction

Distributed local loads can be applied as follows:

- f_1 force per unit length (uniform or linear)
- Gravity loading in local 1 direction

Temperature Loading

Element can be loaded with constant temperature.

Additional Mass

Global additional element masses can be applied as follows:

- mu_x translational mass per unit length
- mu_y translational mass per unit length
- mu_z translational mass per unit length

Local additional element masses can be applied as follows:

- mu_1 translational mass per unit length

Additional Stiffness

Global additional element stiffness can be applied as follows:

- su_x translational stiffness per unit length
- su_y translational stiffness per unit length

- su_z translational stiffness per unit length

Local additional element stiffness can be applied as follows:

- su_1 translational stiffness per unit length

Element Output

Displacements

Element output displacements are:

- u_1 displacement

Strains

Element output strains are:

- ε_{11} normal strain
- ε_{22} normal strain
- ε_{33} normal strain

Stresses

Element output stresses are:

- σ_{11} normal stress

Forces

Element output internal forces are:

- N_1 normal force

Element 1 - Three-node Truss Element

Element Characteristics

Mechanics

This is a three dimensional, constant cross section, straight truss element. Isotropic or Orthotropic linear material models can be used with this element. By default, element internal nodes have same local axes with element local axes. Element stiffness, mass and stability matrices are evaluated analytically.

Geometry and Nodes

Element has three nodes with the order starting from end nodes. Three coordinates for end nodes in global x, y and z direction, and a constant cross section are given as input. Axial rotation can be assigned as user-defined local axes.

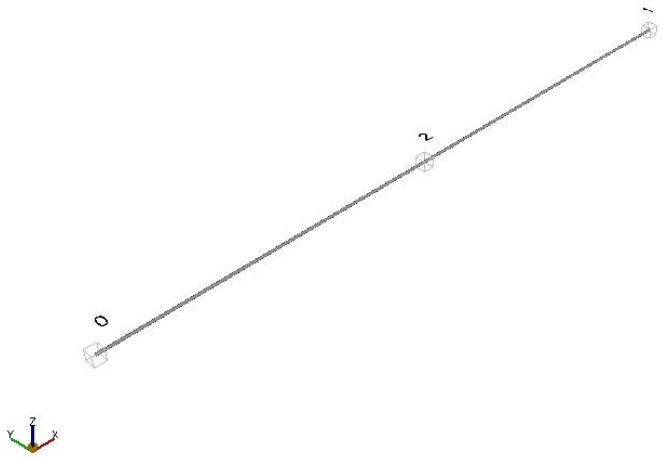


Figure – Element 1

Interpolation

Element has quadratic-Lagrange interpolation functions.

Degrees of Freedom

Global dofs (per node) are:

- u_x displacement
- u_y displacement

- u_z displacement

Local dofs (per node) are:

- u_1 displacement

Element Assignments

Mechanical Loading

Distributed global loads can be applied as follows:

- f_x force per unit length (uniform or linear)
- f_y force per unit length (uniform or linear)
- f_z force per unit length (uniform or linear)
- Gravity loading in global x, y or z direction

Distributed local loads can be applied as follows:

- f_1 force per unit length (uniform or linear)
- Gravity loading in local 1 direction

Temperature Loading

Element can be loaded with constant temperature.

Additional Mass

Global additional element masses can be applied as follows:

- mu_x translational mass per unit length
- mu_y translational mass per unit length
- mu_z translational mass per unit length

Local additional element masses can be applied as follows:

- mu_1 translational mass per unit length

Additional Stiffness

Global additional element stiffness can be applied as follows:

- su_x translational stiffness per unit length

- su_y translational stiffness per unit length
- su_z translational stiffness per unit length

Local additional element stiffness can be applied as follows:

- su_1 translational stiffness per unit length

Element Output

Displacements

Element output displacements are:

- u_1 displacement

Strains

Element output strains are:

- ε_{11} normal strain
- ε_{22} normal strain
- ε_{33} normal strain

Stresses

Element output stresses are:

- σ_{11} normal stress

Forces

Element output internal forces are:

- N_1 normal force

Element 2 - Four-node Truss Element

Element Characteristics

Mechanics

This is a three dimensional, constant cross section, straight truss element. Isotropic or Orthotropic linear material models can be used with this element. By default, element internal nodes have same local axes with element local axes. Element stiffness, mass and stability matrices are evaluated analytically.

Geometry and Nodes

Element has four nodes with the order starting from end nodes. Three coordinates for end nodes in global x, y and z direction, and a constant cross section are given as input. Axial rotation can be assigned as user-defined local axes.

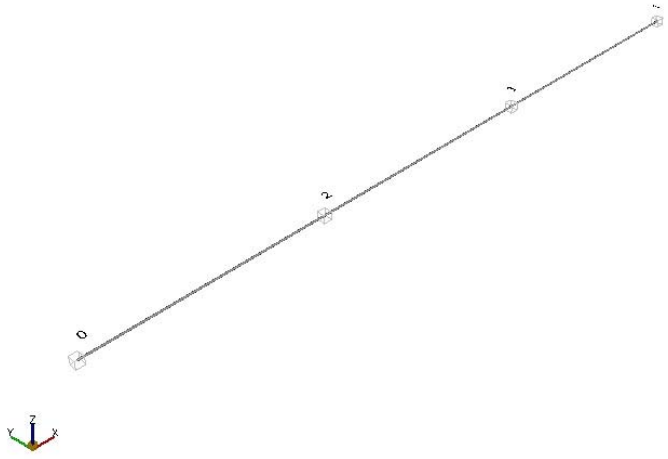


Figure – Element 2

Interpolation

Element has quadratic-Lagrange interpolation functions.

Degrees of Freedom

Global dofs (per node) are:

- u_x displacement
- u_y displacement

- u_z displacement

Local dofs (per node) are:

- u_1 displacement

Element Assignments

Mechanical Loading

Distributed global loads can be applied as follows:

- f_x force per unit length (uniform or linear)
- f_y force per unit length (uniform or linear)
- f_z force per unit length (uniform or linear)
- Gravity loading in global x, y or z direction

Distributed local loads can be applied as follows:

- f_1 force per unit length (uniform or linear)
- Gravity loading in local 1 direction

Temperature Loading

Element can be loaded with constant temperature.

Additional Mass

Global additional element masses can be applied as follows:

- mu_x translational mass per unit length
- mu_y translational mass per unit length
- mu_z translational mass per unit length

Local additional element masses can be applied as follows:

- mu_1 translational mass per unit length

Additional Stiffness

Global additional element stiffness can be applied as follows:

- su_x translational stiffness per unit length

- su_y translational stiffness per unit length
- su_z translational stiffness per unit length

Local additional element stiffness can be applied as follows:

- su_1 translational stiffness per unit length

Element Output

Displacements

Element output displacements are:

- u_1 displacement

Strains

Element output strains are:

- ε_{11} normal strain
- ε_{22} normal strain
- ε_{33} normal strain

Stresses

Element output stresses are:

- σ_{11} normal stress

Forces

Element output internal forces are:

- N_1 normal force

Element 3 - Four-node Plane Stress Element

Element Characteristics

Mechanics

This is a three dimensional, constant thickness, quadrilateral plane stress element. Isotropic or Orthotropic linear material models can be used with this element. Element stiffness, mass and stability matrices are evaluated by two-point Gaussian integration in each local direction.

Geometry and Nodes

Element has quadrilateral geometry and four nodes with counterclockwise order. Three coordinates per node in global x, y and z direction, and a constant thickness are given as input.

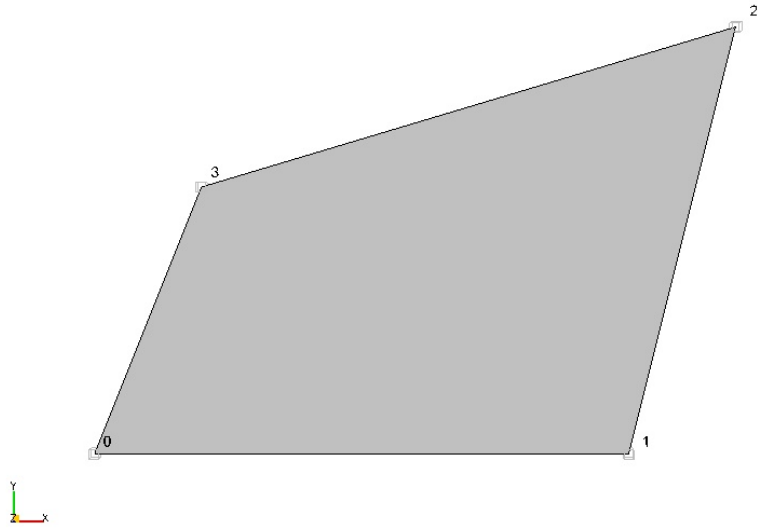


Figure – Element 3

Interpolation

Element has bilinear-Lagrange interpolation functions.

Degrees of Freedom

Global dofs (per node) are:

- u_x displacement
- u_y displacement

- u_z displacement

Local dofs (per node) are:

- u_1 displacement
- u_2 displacement

Element Assignments

Mechanical Loading

Distributed global loads can be applied as follows:

- f_x force per unit area (uniform or bilinear)
- f_y force per unit area (uniform or bilinear)
- f_z force per unit area (uniform or bilinear)
- Gravity loading in global x, y or z direction

Distributed local loads can be applied as follows:

- f_1 force per unit area (uniform or bilinear)
- f_2 force per unit area (uniform or bilinear)
- Gravity loading in local 1 or 2 direction

Temperature Loading

Element can be loaded with constant temperature.

Additional Mass

Global additional element masses can be applied as follows:

- mu_x translational mass per unit area
- mu_y translational mass per unit area
- mu_z translational mass per unit area

Local additional element masses can be applied as follows:

- mu_1 translational mass per unit area
- mu_2 translational mass per unit area

Additional Stiffness

Global additional element stiffness can be applied as follows:

- su_x translational stiffness per unit area
- su_y translational stiffness per unit area
- su_z translational stiffness per unit area

Local additional element stiffness can be applied as follows:

- su_1 translational stiffness per unit area
- su_2 translational stiffness per unit area

Element Output

Displacements

Element output displacements are:

- u_1 displacement
- u_2 displacement

Strains

Element output strains are:

- ε_{11} normal strain
- ε_{22} normal strain
- ε_{33} normal strain
- ε_{12} shear strain

Stresses

Element output stresses are:

- σ_{11} normal stress
- σ_{22} normal stress
- σ_{12} shear stress

Forces

Element output internal forces are:

- P_{11} membrane force
- N_{22} membrane force
- Q_{12} membrane shearing force

Element 4 - Eight-node Plane Stress Element

Element Characteristics

Mechanics

This is a three dimensional, constant thickness, quadrilateral plane stress element. Isotropic or Orthotropic linear material models can be used with this element. By default, element internal nodes have same local axes with element local axes. Element stiffness, mass and stability matrices are evaluated by four-point Gaussian integration in each local direction.

Geometry and Nodes

Element has quadrilateral geometry and eight nodes with counterclockwise order starting from corner nodes. Three coordinates for each corner node in global x, y and z direction, and a constant thickness are given as input.

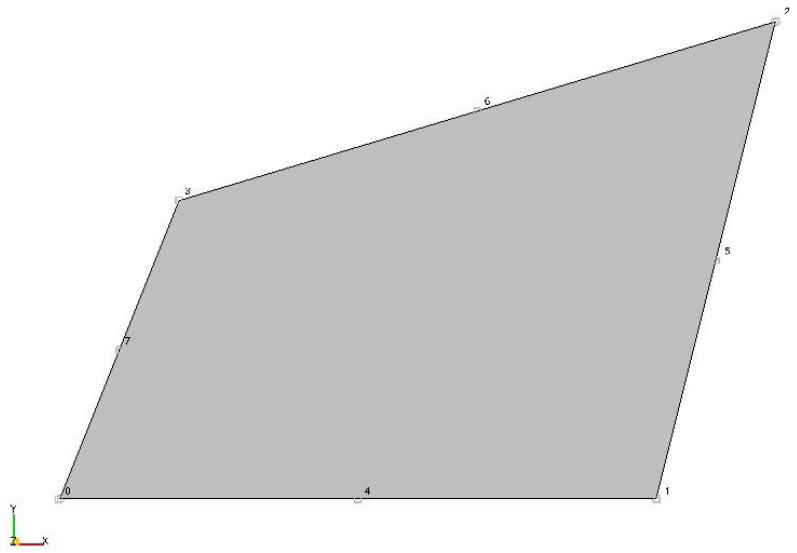


Figure – Element 4

Interpolation

Element has biquadratic-Serendipity interpolation functions.

Degrees of Freedom

Global dofs (per node) are:

- u_x displacement
- u_y displacement
- u_z displacement

Local dofs (per node) are:

- u_1 displacement
- u_2 displacement

Element Assignments

Mechanical Loading

Distributed global loads can be applied as follows:

- f_x force per unit area (uniform or bilinear)
- f_y force per unit area (uniform or bilinear)
- f_z force per unit area (uniform or bilinear)
- Gravity loading in global x, y or z direction

Distributed local loads can be applied as follows:

- f_1 force per unit area (uniform or bilinear)
- f_2 force per unit area (uniform or bilinear)
- Gravity loading in local 1 or 2 direction

Temperature Loading

Element can be loaded with constant temperature.

Additional Mass

Global additional element masses can be applied as follows:

- mu_x translational mass per unit area
- mu_y translational mass per unit area
- mu_z translational mass per unit area

Local additional element masses can be applied as follows:

- mu_1 translational mass per unit area
- mu_2 translational mass per unit area

Additional Stiffness

Global additional element stiffness can be applied as follows:

- su_x translational stiffness per unit area
- su_y translational stiffness per unit area
- su_z translational stiffness per unit area

Local additional element stiffness can be applied as follows:

- su_1 translational stiffness per unit area
- su_2 translational stiffness per unit area

Element Output

Displacements

Element output displacements are:

- u_1 displacement
- u_2 displacement

Strains

Element output strains are:

- ε_{11} normal strain
- ε_{22} normal strain
- ε_{33} normal strain
- ε_{12} shear strain

Stresses

Element output stresses are:

- σ_{11} normal stress
- σ_{22} normal stress

- σ_{12} shear stress

Forces

Element output internal forces are:

- P_{11} membrane force
- N_{22} membrane force
- Q_{12} membrane shearing force

Element 5 - Three-node Plane Stress Element

Element Characteristics

Mechanics

This is a three dimensional, constant thickness, triangular plane stress element. Isotropic or Orthotropic linear material models can be used with this element. Element stiffness matrix is evaluated by one-point, element mass and stability matrices are evaluated by three-point Gaussian integration in each local direction, respectively.

Geometry and Nodes

Element has triangular geometry and three nodes with counterclockwise order. Three coordinates per node in global x, y and z direction, and a constant thickness are given as input.

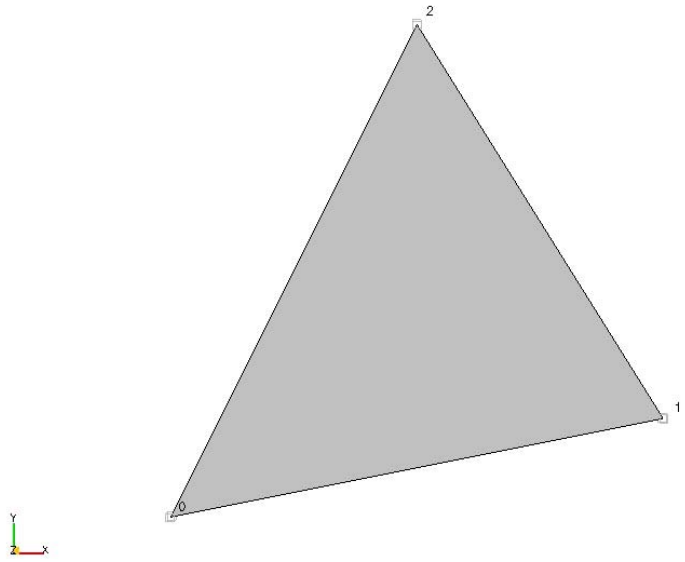


Figure – Element 5

Interpolation

Element has linear-Lagrange interpolation functions.

Degrees of Freedom

Global dofs (per node) are:

- u_x displacement
- u_y displacement
- u_z displacement

Local dofs (per node) are:

- u_1 displacement
- u_2 displacement

Element Assignments

Mechanical Loading

Distributed global loads can be applied as follows:

- f_x force per unit area (uniform or bilinear)
- f_y force per unit area (uniform or bilinear)
- f_z force per unit area (uniform or bilinear)
- Gravity loading in global x, y or z direction

Distributed local loads can be applied as follows:

- f_1 force per unit area (uniform or bilinear)
- f_2 force per unit area (uniform or bilinear)
- Gravity loading in local 1 or 2 direction

Temperature Loading

Element can be loaded with constant temperature.

Additional Mass

Global additional element masses can be applied as follows:

- mu_x translational mass per unit area
- mu_y translational mass per unit area
- mu_z translational mass per unit area

Local additional element masses can be applied as follows:

- mu_1 translational mass per unit area
- mu_2 translational mass per unit area

Additional Stiffness

Global additional element stiffness can be applied as follows:

- su_x translational stiffness per unit area
- su_y translational stiffness per unit area
- su_z translational stiffness per unit area

Local additional element stiffness can be applied as follows:

- su_1 translational stiffness per unit area
- su_2 translational stiffness per unit area

Element Output

Displacements

Element output displacements are:

- u_1 displacement
- u_2 displacement

Strains

Element output strains are:

- ε_{11} normal strain
- ε_{22} normal strain
- ε_{33} normal strain
- ε_{12} shear strain

Stresses

Element output stresses are:

- σ_{11} normal stress
- σ_{22} normal stress

- σ_{12} shear stress

Forces

Element output internal forces are:

- P_{11} membrane force
- N_{22} membrane force
- Q_{12} membrane shearing force

Element 6 - Six-node Plane Stress Element

Element Characteristics

Mechanics

This is a three dimensional, constant thickness, triangular plane stress element. Isotropic or Orthotropic linear material models can be used with this element. By default, element internal nodes have same local axes with element local axes. Element stiffness, mass and stability matrices are evaluated by three-point Gaussian integration in each local direction.

Geometry and Nodes

Element has triangular geometry and six nodes with counterclockwise order starting from corner nodes. Three coordinates for each corner node in global x, y and z direction, and a constant thickness are given as input.

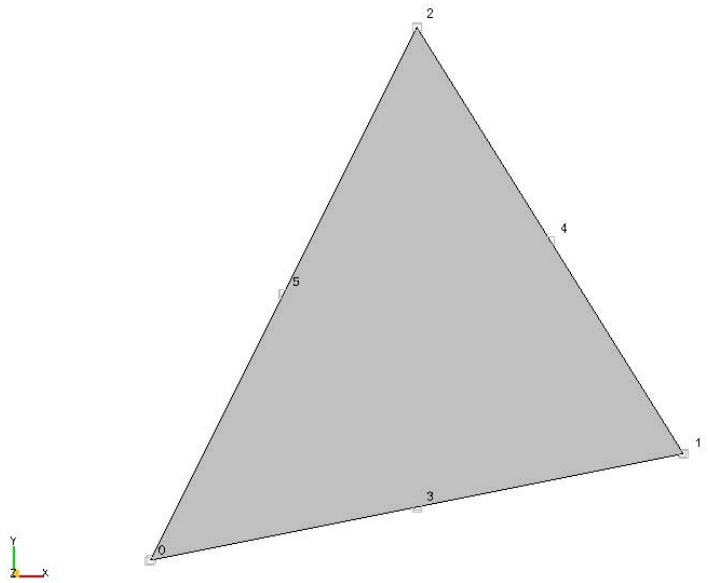


Figure – Element 6

Interpolation

Element has quadratic-Lagrange interpolation functions.

Degrees of Freedom

Global dofs (per node) are:

- u_x displacement
- u_y displacement
- u_z displacement

Local dofs (per node) are:

- u_1 displacement
- u_2 displacement

Element Assignments

Mechanical Loading

Distributed global loads can be applied as follows:

- f_x force per unit area (uniform or bilinear)
- f_y force per unit area (uniform or bilinear)
- f_z force per unit area (uniform or bilinear)
- Gravity loading in global x, y or z direction

Distributed local loads can be applied as follows:

- f_1 force per unit area (uniform or bilinear)
- f_2 force per unit area (uniform or bilinear)
- Gravity loading in local 1 or 2 direction

Temperature Loading

Element can be loaded with constant temperature.

Additional Mass

Global additional element masses can be applied as follows:

- mu_x translational mass per unit area
- mu_y translational mass per unit area
- mu_z translational mass per unit area

Local additional element masses can be applied as follows:

- mu_1 translational mass per unit area
- mu_2 translational mass per unit area

Additional Stiffness

Global additional element stiffness can be applied as follows:

- su_x translational stiffness per unit area
- su_y translational stiffness per unit area
- su_z translational stiffness per unit area

Local additional element stiffness can be applied as follows:

- su_1 translational stiffness per unit area
- su_2 translational stiffness per unit area

Element Output

Displacements

Element output displacements are:

- u_1 displacement
- u_2 displacement

Strains

Element output strains are:

- ε_{11} normal strain
- ε_{22} normal strain
- ε_{33} normal strain
- ε_{12} shear strain

Stresses

Element output stresses are:

- σ_{11} normal stress
- σ_{22} normal stress

- σ_{12} shear stress

Forces

Element output internal forces are:

- P_{11} membrane force
- N_{22} membrane force
- Q_{12} membrane shearing force

Element 7 - Twelve-node Plane Stress Element

Element Characteristics

Mechanics

This is a three dimensional, constant thickness, quadrilateral plane stress element. Isotropic or Orthotropic linear material models can be used with this element. By default, element internal nodes have same local axes with element local axes. Element stiffness and stability matrices are evaluated by eight-point and element mass matrix is evaluated by six-point Gaussian integration in each local direction, respectively.

Geometry and Nodes

Element has quadrilateral geometry and twelve nodes with counterclockwise order starting from corner nodes. Three coordinates for each corner node in global x, y and z direction, and a constant thickness are given as input.

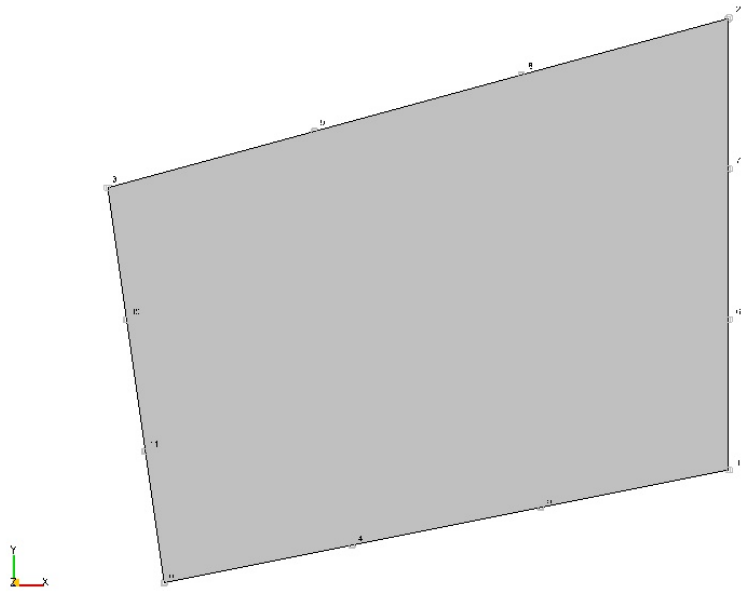


Figure – Element 7

Interpolation

Element has bicubic-Serendipity interpolation functions.

Degrees of Freedom

Global dofs (per node) are:

- u_x displacement
- u_y displacement
- u_z displacement

Local dofs (per node) are:

- u_1 displacement
- u_2 displacement

Element Assignments

Mechanical Loading

Distributed global loads can be applied as follows:

- f_x force per unit area (uniform or bilinear)
- f_y force per unit area (uniform or bilinear)
- f_z force per unit area (uniform or bilinear)
- Gravity loading in global x, y or z direction

Distributed local loads can be applied as follows:

- f_1 force per unit area (uniform or bilinear)
- f_2 force per unit area (uniform or bilinear)
- Gravity loading in local 1 or 2 direction

Temperature Loading

Element can be loaded with constant temperature.

Additional Mass

Global additional element masses can be applied as follows:

- mu_x translational mass per unit area
- mu_y translational mass per unit area
- mu_z translational mass per unit area

Local additional element masses can be applied as follows:

- mu_1 translational mass per unit area
- mu_2 translational mass per unit area

Additional Stiffness

Global additional element stiffness can be applied as follows:

- su_x translational stiffness per unit area
- su_y translational stiffness per unit area
- su_z translational stiffness per unit area

Local additional element stiffness can be applied as follows:

- su_1 translational stiffness per unit area
- su_2 translational stiffness per unit area

Element Output

Displacements

Element output displacements are:

- u_1 displacement
- u_2 displacement

Strains

Element output strains are:

- ε_{11} normal strain
- ε_{22} normal strain
- ε_{33} normal strain
- ε_{12} shear strain

Stresses

Element output stresses are:

- σ_{11} normal stress
- σ_{22} normal stress

- σ_{12} shear stress

Forces

Element output internal forces are:

- P_{11} membrane force
- N_{22} membrane force
- Q_{12} membrane shearing force

Element 8 - Four-node Plane Strain Element

Element Characteristics

Mechanics

This is a three dimensional, constant thickness, quadrilateral plane strain element. Isotropic or Orthotropic linear material models can be used with this element. Element stiffness, mass and stability matrices are evaluated by two-point Gaussian integration in each local direction.

Geometry and Nodes

Element has quadrilateral geometry and four nodes with counterclockwise order. Three coordinates per node in global x, y and z direction, and a constant thickness are given as input.

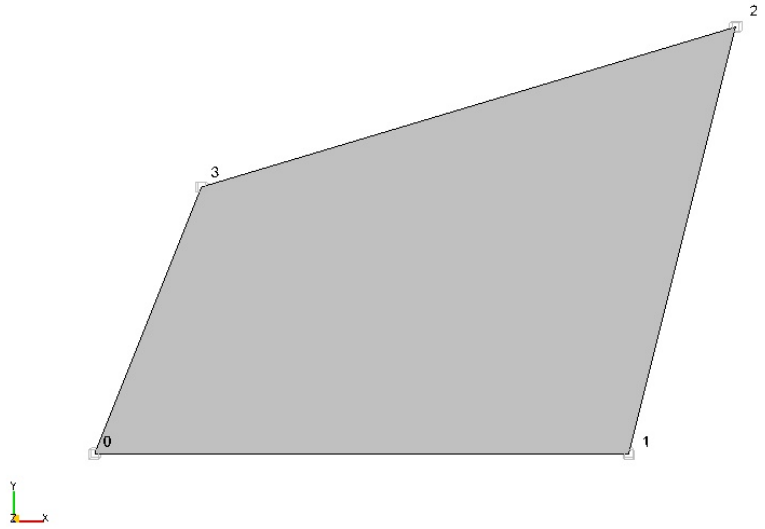


Figure – Element 8

Interpolation

Element has bilinear-Lagrange interpolation functions.

Degrees of Freedom

Global dofs (per node) are:

- u_x displacement
- u_y displacement

- u_z displacement

Local dofs (per node) are:

- u_1 displacement
- u_2 displacement

Element Assignments

Mechanical Loading

Distributed global loads can be applied as follows:

- f_x force per unit area (uniform or bilinear)
- f_y force per unit area (uniform or bilinear)
- f_z force per unit area (uniform or bilinear)
- Gravity loading in global x, y or z direction

Distributed local loads can be applied as follows:

- f_1 force per unit area (uniform or bilinear)
- f_2 force per unit area (uniform or bilinear)
- Gravity loading in local 1 or 2 direction

Temperature Loading

Element can be loaded with constant temperature.

Additional Mass

Global additional element masses can be applied as follows:

- mu_x translational mass per unit area
- mu_y translational mass per unit area
- mu_z translational mass per unit area

Local additional element masses can be applied as follows:

- mu_1 translational mass per unit area
- mu_2 translational mass per unit area

Additional Stiffness

Global additional element stiffness can be applied as follows:

- su_x translational stiffness per unit area
- su_y translational stiffness per unit area
- su_z translational stiffness per unit area

Local additional element stiffness can be applied as follows:

- su_1 translational stiffness per unit area
- su_2 translational stiffness per unit area

Element Output

Displacements

Element output displacements are:

- u_1 displacement
- u_2 displacement

Strains

Element output strains are:

- ε_{11} normal strain
- ε_{22} normal strain
- ε_{33} normal strain
- ε_{12} shear strain

Stresses

Element output stresses are:

- σ_{11} normal stress
- σ_{22} normal stress
- σ_{12} shear stress

Forces

Element output internal forces are:

- P_{11} membrane force
- N_{22} membrane force
- Q_{12} membrane shearing force

Element 9 - Eight-node Plane Strain Element

Element Characteristics

Mechanics

This is a three dimensional, constant thickness, quadrilateral plane strain element. Isotropic or Orthotropic linear material models can be used with this element. By default, element internal nodes have same local axes with element local axes. Element stiffness, mass and stability matrices are evaluated by four-point Gaussian integration in each local direction.

Geometry and Nodes

Element has quadrilateral geometry and eight nodes with counterclockwise order starting from corner nodes. Three coordinates for each corner node in global x, y and z direction, and a constant thickness are given as input.

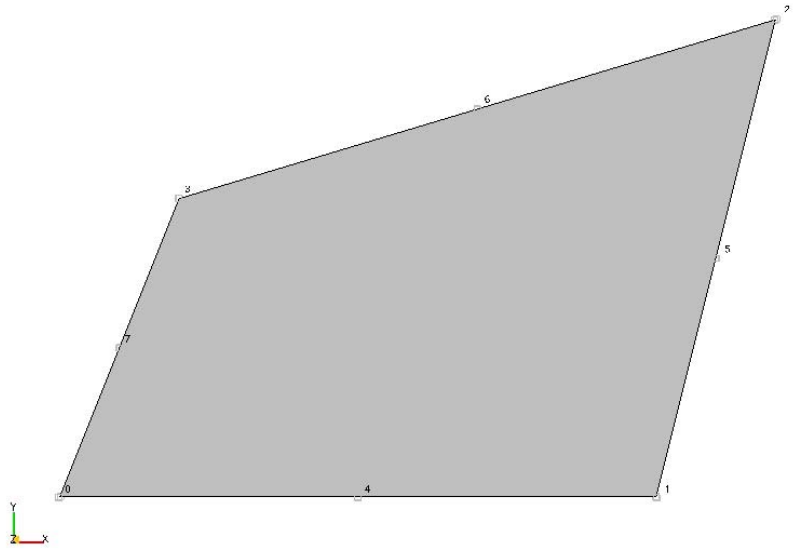


Figure – Element 9

Interpolation

Element has biquadratic-Serendipity interpolation functions.

Degrees of Freedom

Global dofs (per node) are:

- u_x displacement
- u_y displacement
- u_z displacement

Local dofs (per node) are:

- u_1 displacement
- u_2 displacement

Element Assignments

Mechanical Loading

Distributed global loads can be applied as follows:

- f_x force per unit area (uniform or bilinear)
- f_y force per unit area (uniform or bilinear)
- f_z force per unit area (uniform or bilinear)
- Gravity loading in global x, y or z direction

Distributed local loads can be applied as follows:

- f_1 force per unit area (uniform or bilinear)
- f_2 force per unit area (uniform or bilinear)
- Gravity loading in local 1 or 2 direction

Temperature Loading

Element can be loaded with constant temperature.

Additional Mass

Global additional element masses can be applied as follows:

- mu_x translational mass per unit area
- mu_y translational mass per unit area
- mu_z translational mass per unit area

Local additional element masses can be applied as follows:

- mu_1 translational mass per unit area
- mu_2 translational mass per unit area

Additional Stiffness

Global additional element stiffness can be applied as follows:

- su_x translational stiffness per unit area
- su_y translational stiffness per unit area
- su_z translational stiffness per unit area

Local additional element stiffness can be applied as follows:

- su_1 translational stiffness per unit area
- su_2 translational stiffness per unit area

Element Output

Displacements

Element output displacements are:

- u_1 displacement
- u_2 displacement

Strains

Element output strains are:

- ε_{11} normal strain
- ε_{22} normal strain
- ε_{33} normal strain
- ε_{12} shear strain

Stresses

Element output stresses are:

- σ_{11} normal stress
- σ_{22} normal stress

- σ_{12} shear stress

Forces

Element output internal forces are:

- P_{11} membrane force
- N_{22} membrane force
- Q_{12} membrane shearing force

Element 10 - Twelve-node Plane Strain Element

Element Characteristics

Mechanics

This is a three dimensional, constant thickness, quadrilateral plane strain element. Isotropic or Orthotropic linear material models can be used with this element. By default, element internal nodes have same local axes with element local axes. Element stiffness and stability matrices are evaluated by eight-point and element mass matrix is evaluated by six-point Gaussian integration in each local direction, respectively.

Geometry and Nodes

Element has quadrilateral geometry and twelve nodes with counterclockwise order starting from corner nodes. Three coordinates for each corner node in global x, y and z direction, and a constant thickness are given as input.

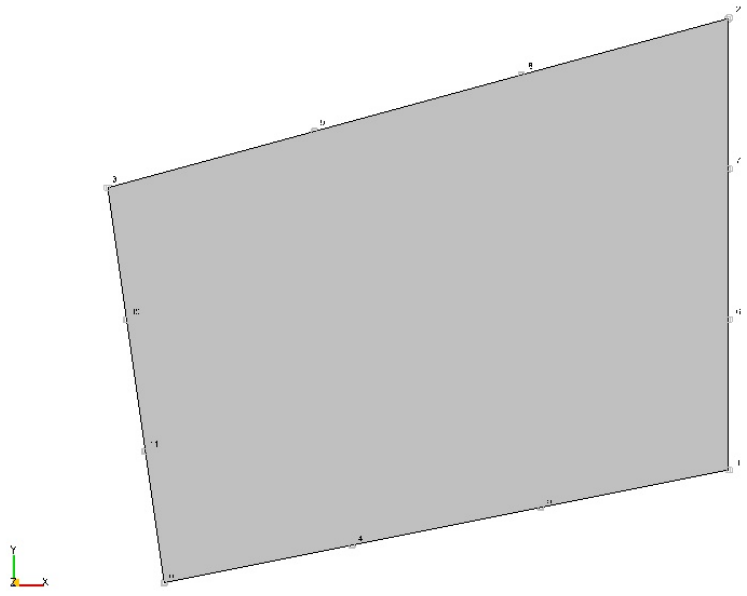


Figure – Element 10

Interpolation

Element has bicubic-Serendipity interpolation functions.

Degrees of Freedom

Global dofs (per node) are:

- u_x displacement
- u_y displacement
- u_z displacement

Local dofs (per node) are:

- u_1 displacement
- u_2 displacement

Element Assignments

Mechanical Loading

Distributed global loads can be applied as follows:

- f_x force per unit area (uniform or bilinear)
- f_y force per unit area (uniform or bilinear)
- f_z force per unit area (uniform or bilinear)
- Gravity loading in global x, y or z direction

Distributed local loads can be applied as follows:

- f_1 force per unit area (uniform or bilinear)
- f_2 force per unit area (uniform or bilinear)
- Gravity loading in local 1 or 2 direction

Temperature Loading

Element can be loaded with constant temperature.

Additional Mass

Global additional element masses can be applied as follows:

- mu_x translational mass per unit area
- mu_y translational mass per unit area
- mu_z translational mass per unit area

Local additional element masses can be applied as follows:

- mu_1 translational mass per unit area
- mu_2 translational mass per unit area

Additional Stiffness

Global additional element stiffness can be applied as follows:

- su_x translational stiffness per unit area
- su_y translational stiffness per unit area
- su_z translational stiffness per unit area

Local additional element stiffness can be applied as follows:

- su_1 translational stiffness per unit area
- su_2 translational stiffness per unit area

Element Output

Displacements

Element output displacements are:

- u_1 displacement
- u_2 displacement

Strains

Element output strains are:

- ε_{11} normal strain
- ε_{22} normal strain
- ε_{33} normal strain
- ε_{12} shear strain

Stresses

Element output stresses are:

- σ_{11} normal stress
- σ_{22} normal stress

- σ_{12} shear stress

Forces

Element output internal forces are:

- P_{11} membrane force
- N_{22} membrane force
- Q_{12} membrane shearing force

Element 11 - Three-node Plane Strain Element

Element Characteristics

Mechanics

This is a three dimensional, constant thickness, triangular plane strain element. Isotropic or Orthotropic linear material models can be used with this element. Element stiffness matrix is evaluated by one-point, element mass and stability matrices are evaluated by three-point Gaussian integration in each local direction, respectively.

Geometry and Nodes

Element has triangular geometry and three nodes with counterclockwise order. Three coordinates per node in global x, y and z direction, and a constant thickness are given as input.

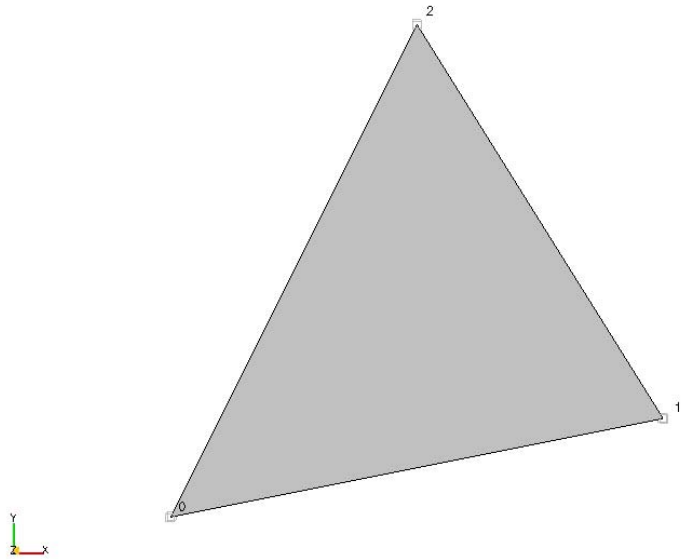


Figure – Element 11

Interpolation

Element has linear-Lagrange interpolation functions.

Degrees of Freedom

Global dofs (per node) are:

- u_x displacement
- u_y displacement
- u_z displacement

Local dofs (per node) are:

- u_1 displacement
- u_2 displacement

Element Assignments

Mechanical Loading

Distributed global loads can be applied as follows:

- f_x force per unit area (uniform or bilinear)
- f_y force per unit area (uniform or bilinear)
- f_z force per unit area (uniform or bilinear)
- Gravity loading in global x, y or z direction

Distributed local loads can be applied as follows:

- f_1 force per unit area (uniform or bilinear)
- f_2 force per unit area (uniform or bilinear)
- Gravity loading in local 1 or 2 direction

Temperature Loading

Element can be loaded with constant temperature.

Additional Mass

Global additional element masses can be applied as follows:

- mu_x translational mass per unit area
- mu_y translational mass per unit area
- mu_z translational mass per unit area

Local additional element masses can be applied as follows:

- mu_1 translational mass per unit area
- mu_2 translational mass per unit area

Additional Stiffness

Global additional element stiffness can be applied as follows:

- su_x translational stiffness per unit area
- su_y translational stiffness per unit area
- su_z translational stiffness per unit area

Local additional element stiffness can be applied as follows:

- su_1 translational stiffness per unit area
- su_2 translational stiffness per unit area

Element Output

Displacements

Element output displacements are:

- u_1 displacement
- u_2 displacement

Strains

Element output strains are:

- ε_{11} normal strain
- ε_{22} normal strain
- ε_{33} normal strain
- ε_{12} shear strain

Stresses

Element output stresses are:

- σ_{11} normal stress
- σ_{22} normal stress

- σ_{12} shear stress

Forces

Element output internal forces are:

- P_{11} membrane force
- N_{22} membrane force
- Q_{12} membrane shearing force

Element 12 - Six-node Plane Strain Element

Element Characteristics

Mechanics

This is a three dimensional, constant thickness, triangular plane strain element. Isotropic or Orthotropic linear material models can be used with this element. By default, element internal nodes have same local axes with element local axes. Element stiffness, mass and stability matrices are evaluated by three-point Gaussian integration in each local direction.

Geometry and Nodes

Element has triangular geometry and six nodes with counterclockwise order starting from corner nodes. Three coordinates for each corner node in global x, y and z direction, and a constant thickness are given as input.

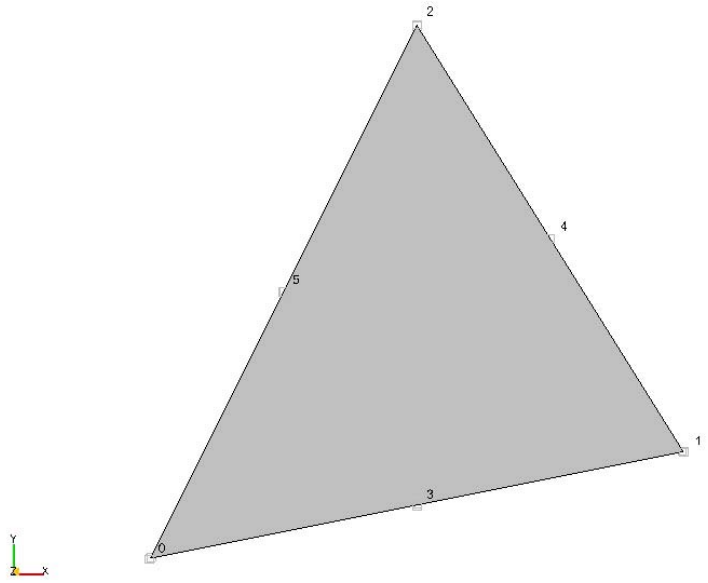


Figure – Element 12

Interpolation

Element has quadratic-Lagrange interpolation functions.

Degrees of Freedom

Global dofs (per node) are:

- u_x displacement
- u_y displacement
- u_z displacement

Local dofs (per node) are:

- u_1 displacement
- u_2 displacement

Element Assignments

Mechanical Loading

Distributed global loads can be applied as follows:

- f_x force per unit area (uniform or bilinear)
- f_y force per unit area (uniform or bilinear)
- f_z force per unit area (uniform or bilinear)
- Gravity loading in global x, y or z direction

Distributed local loads can be applied as follows:

- f_1 force per unit area (uniform or bilinear)
- f_2 force per unit area (uniform or bilinear)
- Gravity loading in local 1 or 2 direction

Temperature Loading

Element can be loaded with constant temperature.

Additional Mass

Global additional element masses can be applied as follows:

- mu_x translational mass per unit area
- mu_y translational mass per unit area
- mu_z translational mass per unit area

Local additional element masses can be applied as follows:

- mu_1 translational mass per unit area
- mu_2 translational mass per unit area

Additional Stiffness

Global additional element stiffness can be applied as follows:

- su_x translational stiffness per unit area
- su_y translational stiffness per unit area
- su_z translational stiffness per unit area

Local additional element stiffness can be applied as follows:

- su_1 translational stiffness per unit area
- su_2 translational stiffness per unit area

Element Output

Displacements

Element output displacements are:

- u_1 displacement
- u_2 displacement

Strains

Element output strains are:

- ε_{11} normal strain
- ε_{22} normal strain
- ε_{33} normal strain
- ε_{12} shear strain

Stresses

Element output stresses are:

- σ_{11} normal stress
- σ_{22} normal stress

- σ_{12} shear stress

Forces

Element output internal forces are:

- P_{11} membrane force
- N_{22} membrane force
- Q_{12} membrane shearing force

Element 13 - Two-node Thick Beam Element

Element Characteristics

Mechanics

This is a three dimensional, constant cross section, straight, shear deformable (Timoshenko) beam element. Isotropic or Orthotropic linear material models can be used with this element. Element stiffness, mass matrices are evaluated analytically except for the transverse shear terms which are under-integrated against shear locking. Element stability matrix is evaluated by one-point Gaussian integration.

Geometry and Nodes

Element has two nodes. Three coordinates per node in global x, y and z direction, and a constant cross section are given as input. Axial rotation can be assigned as user-defined local axes.

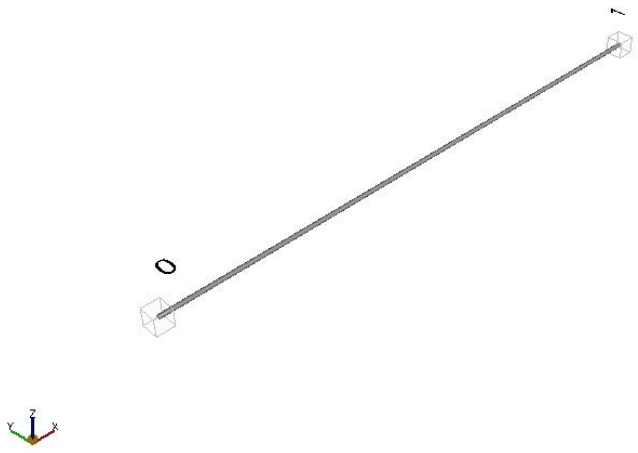


Figure – Element 13

Interpolation

Element has linear-Lagrange interpolation functions.

Degrees of Freedom

Global dofs (per node) are:

- u_x displacement

- u_y displacement
- u_z displacement
- r_x rotation
- r_y rotation
- r_z rotation

Local dofs (per node) are:

- u_1 displacement
- u_2 displacement
- u_3 displacement
- r_1 rotation
- r_2 rotation
- r_3 rotation

Element Assignments

Mechanical Loading

Distributed global loads can be applied as follows:

- f_x force per unit length (uniform or linear)
- f_y force per unit length (uniform or linear)
- f_z force per unit length (uniform or linear)
- m_x moment per unit length (uniform or linear)
- m_y moment per unit length (uniform or linear)
- m_z moment per unit length (uniform or linear)
- Gravity loading in global x, y or z direction

Distributed local loads can be applied as follows:

- f_1 force per unit length (uniform or linear)
- f_2 force per unit length (uniform or linear)

- f_3 force per unit length (uniform or linear)
- m_1 moment per unit length (uniform or linear)
- m_2 moment per unit length (uniform or linear)
- m_3 moment per unit length (uniform or linear)
- Gravity loading in local 1, 2 or 3 direction

Temperature Loading

Element can be loaded with constant temperature.

Additional Mass

Global additional element masses can be applied as follows:

- mu_x translational mass per unit area
- mu_y translational mass per unit area
- mu_z translational mass per unit area
- mr_x rotational mass per unit area
- mr_y rotational mass per unit area
- mr_z rotational mass per unit area

Local additional element masses can be applied as follows:

- mu_1 translational mass per unit area
- mu_2 translational mass per unit area
- mu_3 translational mass per unit area
- mr_1 rotational mass per unit area
- mr_2 rotational mass per unit area
- mr_3 rotational mass per unit area

Additional Stiffness

Global additional element stiffness can be applied as follows:

- su_x translational stiffness per unit area

- su_y translational stiffness per unit area
- su_z translational stiffness per unit area
- sr_x rotational stiffness per unit area
- sr_y rotational stiffness per unit area
- sr_z rotational stiffness per unit area

Local additional element stiffness can be applied as follows:

- su_1 translational stiffness per unit area
- su_2 translational stiffness per unit area
- su_3 translational stiffness per unit area
- sr_1 rotational stiffness per unit area
- sr_2 rotational stiffness per unit area
- sr_3 rotational stiffness per unit area

Element Output

Displacements

Element output displacements are:

- u_1 displacement
- u_2 displacement
- u_3 displacement
- r_1 rotation
- r_2 rotation
- r_3 rotation

Strains

Element output strains are:

- ε_{11} normal strain
- ε_{12} shear strain

- ε_{13} shear strain

Stresses

Element output stresses are:

- σ_{11} normal stress
- σ_{12} shear stress
- σ_{13} shear stress

Forces

Element output internal forces are:

- N_1 normal force
- V_2 shear force
- V_3 shear force
- T_1 twisting moment
- M_2 bending moment
- M_3 bending moment

Element 14 - Three-node Thick Beam Element

Element Characteristics

Mechanics

This is a three dimensional, constant cross section, straight, shear deformable (Timoshenko) beam element. Isotropic or Orthotropic linear material models can be used with this element. Element stiffness and mass matrices are evaluated analytically except for the transverse shear terms which are under-integrated against shear locking. Element stability matrix is evaluated by two-point Gaussian integration.

Geometry and Nodes

Element has three nodes with the order starting from end nodes. Three coordinates for each end node in global x, y and z direction, and a constant cross section are given as input. Axial rotation can be assigned as user-defined local axes.

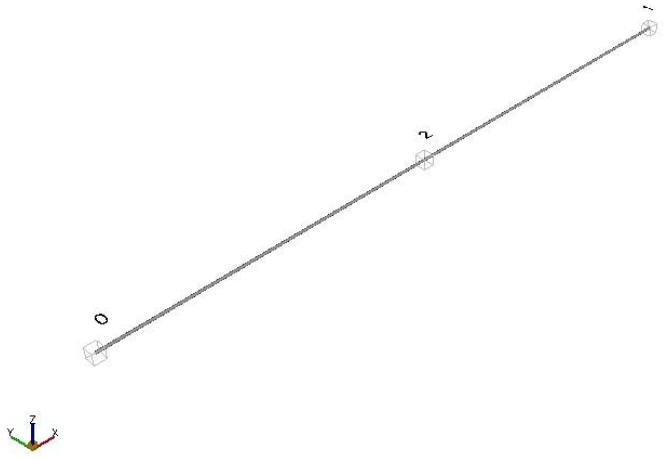


Figure – Element 14

Interpolation

Element has quadratic-Lagrange interpolation functions.

Degrees of Freedom

Global dofs (per node) are:

- u_x displacement

- u_y displacement
- u_z displacement
- r_x rotation
- r_y rotation
- r_z rotation

Local dofs (per node) are:

- u_1 displacement
- u_2 displacement
- u_3 displacement
- r_1 rotation
- r_2 rotation
- r_3 rotation

Element Assignments

Mechanical Loading

Distributed global loads can be applied as follows:

- f_x force per unit length (uniform or linear)
- f_y force per unit length (uniform or linear)
- f_z force per unit length (uniform or linear)
- m_x moment per unit length (uniform or linear)
- m_y moment per unit length (uniform or linear)
- m_z moment per unit length (uniform or linear)
- Gravity loading in global x, y or z direction

Distributed local loads can be applied as follows:

- f_1 force per unit length (uniform or linear)
- f_2 force per unit length (uniform or linear)

- f_3 force per unit length (uniform or linear)
- m_1 moment per unit length (uniform or linear)
- m_2 moment per unit length (uniform or linear)
- m_3 moment per unit length (uniform or linear)
- Gravity loading in local 1, 2 or 3 direction

Temperature Loading

Element can be loaded with constant temperature.

Additional Mass

Global additional element masses can be applied as follows:

- mu_x translational mass per unit area
- mu_y translational mass per unit area
- mu_z translational mass per unit area
- mr_x rotational mass per unit area
- mr_y rotational mass per unit area
- mr_z rotational mass per unit area

Local additional element masses can be applied as follows:

- mu_1 translational mass per unit area
- mu_2 translational mass per unit area
- mu_3 translational mass per unit area
- mr_1 rotational mass per unit area
- mr_2 rotational mass per unit area
- mr_3 rotational mass per unit area

Additional Stiffness

Global additional element stiffness can be applied as follows:

- su_x translational stiffness per unit area

- su_y translational stiffness per unit area
- su_z translational stiffness per unit area
- sr_x rotational stiffness per unit area
- sr_y rotational stiffness per unit area
- sr_z rotational stiffness per unit area

Local additional element stiffness can be applied as follows:

- su_1 translational stiffness per unit area
- su_2 translational stiffness per unit area
- su_3 translational stiffness per unit area
- sr_1 rotational stiffness per unit area
- sr_2 rotational stiffness per unit area
- sr_3 rotational stiffness per unit area

Element Output

Displacements

Element output displacements are:

- u_1 displacement
- u_2 displacement
- u_3 displacement
- r_1 rotation
- r_2 rotation
- r_3 rotation

Strains

Element output strains are:

- ε_{11} normal strain
- ε_{12} shear strain

- ε_{13} shear strain

Stresses

Element output stresses are:

- σ_{11} normal stress
- σ_{12} shear stress
- σ_{13} shear stress

Forces

Element output internal forces are:

- N_1 normal force
- V_2 shear force
- V_3 shear force
- T_1 twisting moment
- M_2 bending moment
- M_3 bending moment

Element 15 - Four-node Thick Beam Element

Element Characteristics

Mechanics

This is a three dimensional, constant cross section, straight, shear deformable (Timoshenko) beam element. Isotropic or Orthotropic linear material models can be used with this element. Element stiffness and mass matrices are evaluated analytically. Element stability matrix is evaluated by three-point Gaussian integration.

Geometry and Nodes

Element has four nodes with the order starting from end nodes. Three coordinates for each end node in global x, y and z direction, and a constant cross section are given as input. Axial rotation can be assigned as user-defined local axes.

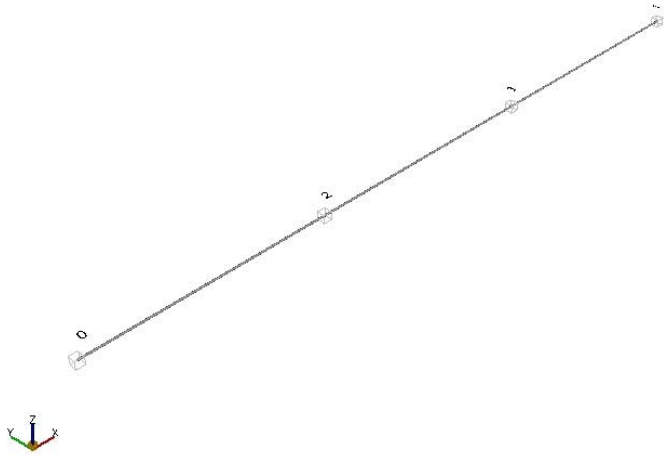


Figure – Element 15

Interpolation

Element has cubic-Lagrange interpolation functions.

Degrees of Freedom

Global dofs (per node) are:

- u_x displacement
- u_y displacement

- u_z displacement
- r_x rotation
- r_y rotation
- r_z rotation

Local dofs (per node) are:

- u_1 displacement
- u_2 displacement
- u_3 displacement
- r_1 rotation
- r_2 rotation
- r_3 rotation

Element Assignments

Mechanical Loading

Distributed global loads can be applied as follows:

- f_x force per unit length (uniform or linear)
- f_y force per unit length (uniform or linear)
- f_z force per unit length (uniform or linear)
- m_x moment per unit length (uniform or linear)
- m_y moment per unit length (uniform or linear)
- m_z moment per unit length (uniform or linear)
- Gravity loading in global x, y or z direction

Distributed local loads can be applied as follows:

- f_1 force per unit length (uniform or linear)
- f_2 force per unit length (uniform or linear)
- f_3 force per unit length (uniform or linear)

- m_1 moment per unit length (uniform or linear)
- m_2 moment per unit length (uniform or linear)
- m_3 moment per unit length (uniform or linear)
- Gravity loading in local 1, 2 or 3 direction

Temperature Loading

Element can be loaded with constant temperature.

Additional Mass

Global additional element masses can be applied as follows:

- mu_x translational mass per unit area
- mu_y translational mass per unit area
- mu_z translational mass per unit area
- mr_x rotational mass per unit area
- mr_y rotational mass per unit area
- mr_z rotational mass per unit area

Local additional element masses can be applied as follows:

- mu_1 translational mass per unit area
- mu_2 translational mass per unit area
- mu_3 translational mass per unit area
- mr_1 rotational mass per unit area
- mr_2 rotational mass per unit area
- mr_3 rotational mass per unit area

Additional Stiffness

Global additional element stiffness can be applied as follows:

- su_x translational stiffness per unit area
- su_y translational stiffness per unit area

- su_z translational stiffness per unit area
- sr_x rotational stiffness per unit area
- sr_y rotational stiffness per unit area
- sr_z rotational stiffness per unit area

Local additional element stiffness can be applied as follows:

- su_1 translational stiffness per unit area
- su_2 translational stiffness per unit area
- su_3 translational stiffness per unit area
- sr_1 rotational stiffness per unit area
- sr_2 rotational stiffness per unit area
- sr_3 rotational stiffness per unit area

Element Output

Displacements

Element output displacements are:

- u_1 displacement
- u_2 displacement
- u_3 displacement
- r_1 rotation
- r_2 rotation
- r_3 rotation

Strains

Element output strains are:

- ε_{11} normal strain
- ε_{12} shear strain
- ε_{13} shear strain

Stresses

Element output stresses are:

- σ_{11} normal stress
- σ_{12} shear stress
- σ_{13} shear stress

Forces

Element output internal forces are:

- N_1 normal force
- V_2 shear force
- V_3 shear force
- T_1 twisting moment
- M_2 bending moment
- M_3 bending moment

Element 16 - Four-node Thick Shell Element

Element Characteristics

Mechanics

This is a three dimensional, constant thickness, quadrilateral, flat, shear deformable (Mindlin-Reissner) shell element. Isotropic or Orthotropic linear material models can be used with this element. Element stiffness, mass and stability matrices are evaluated by two-point Gaussian integration in each local direction while the transverse shear terms are under-integrated against shear locking.

Geometry and Nodes

Element has quadrilateral geometry and four nodes with counterclockwise order. Three coordinates per node in global x, y and z direction, and a constant thickness are given as input.

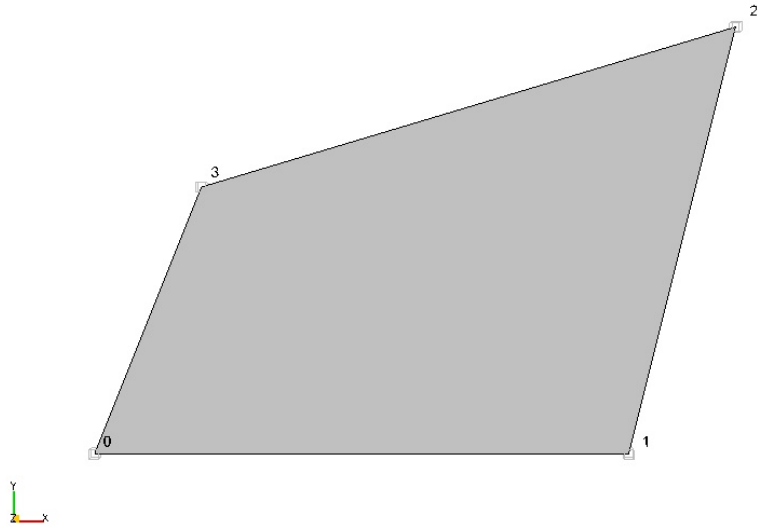


Figure – Element 16

Interpolation

Element has bilinear-Lagrange interpolation functions.

Degrees of Freedom

Global dofs (per node) are:

- u_x displacement
- u_y displacement
- u_z displacement
- r_x rotation
- r_y rotation
- r_z rotation

Local dofs (per node) are:

- u_1 displacement
- u_2 displacement
- u_3 displacement
- r_1 rotation
- r_2 rotation

Element Assignments

Mechanical Loading

Distributed global loads can be applied as follows:

- f_x force per unit area (uniform or bilinear)
- f_y force per unit area (uniform or bilinear)
- f_z force per unit area (uniform or bilinear)
- m_x moment per unit area (uniform or bilinear)
- m_y moment per unit area (uniform or bilinear)
- m_z moment per unit area (uniform or bilinear)
- Gravity loading in global x, y or z direction

Distributed local loads can be applied as follows:

- f_1 force per unit area (uniform or bilinear)
- f_2 force per unit area (uniform or bilinear)

- f_3 force per unit area (uniform or bilinear)
- m_1 moment per unit area (uniform or bilinear)
- m_2 moment per unit area (uniform or bilinear)
- Gravity loading in local 1, 2 or 3 direction

Temperature Loading

Element can be loaded with constant temperature.

Additional Mass

Global additional element masses can be applied as follows:

- mu_x translational mass per unit area
- mu_y translational mass per unit area
- mu_z translational mass per unit area
- mr_x rotational mass per unit area
- mr_y rotational mass per unit area
- mr_z rotational mass per unit area

Local additional element masses can be applied as follows:

- mu_1 translational mass per unit area
- mu_2 translational mass per unit area
- mu_3 translational mass per unit area
- mr_1 rotational mass per unit area
- mr_2 rotational mass per unit area

Additional Stiffness

Global additional element stiffness can be applied as follows:

- su_x translational stiffness per unit area
- su_y translational stiffness per unit area
- su_z translational stiffness per unit area

- sr_x rotational stiffness per unit area
- sr_y rotational stiffness per unit area
- sr_z rotational stiffness per unit area

Local additional element stiffness can be applied as follows:

- su_1 translational stiffness per unit area
- su_2 translational stiffness per unit area
- su_3 translational stiffness per unit area
- sr_1 rotational stiffness per unit area
- sr_2 rotational stiffness per unit area

Element Output

Displacements

Element output displacements are:

- u_1 displacement
- u_2 displacement
- u_3 displacement
- r_1 rotation
- r_2 rotation

Strains

Element output strains are:

- ε_{11} normal strain
- ε_{22} normal strain
- ε_{12} shear strain
- ε_{13} shear strain
- ε_{23} shear strain

Stresses

Element output stresses are:

- σ_{11} normal stress
- σ_{22} normal stress
- σ_{33} normal stress
- σ_{12} shear stress
- σ_{13} shear stress
- σ_{23} shear stress

Forces

Element output internal forces are:

- P_{11} membrane force
- N_{22} membrane force
- Q_{12} membrane shearing force
- F_{13} shear force
- H_{23} shear force
- K_{22} bending moment
- M_{11} bending moment
- T_{12} twisting moment

Element 17 - Eight-node Thick Shell Element

Element Characteristics

Mechanics

This is a three dimensional, constant thickness, quadrilateral, flat, shear deformable (Mindlin-Reissner) shell element. Isotropic or Orthotropic linear material models can be used with this element. Element stiffness, mass and stability matrices are evaluated by three-point Gaussian integration in each local direction while the transverse shear terms are under-integrated against shear locking.

Geometry and Nodes

Element has quadrilateral geometry and eight nodes with counterclockwise order starting from the corner nodes. Three coordinates for each corner node in global x, y and z direction, and a constant thickness are given as input.

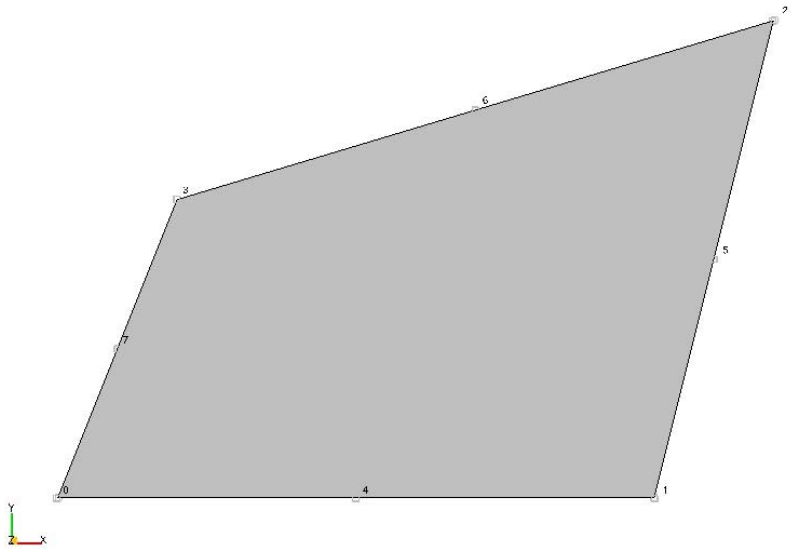


Figure – Element 17

Interpolation

Element has biquadratic-Serendipity interpolation functions.

Degrees of Freedom

Global dofs (per node) are:

- u_x displacement
- u_y displacement
- u_z displacement
- r_x rotation
- r_y rotation
- r_z rotation

Local dofs (per node) are:

- u_1 displacement
- u_2 displacement
- u_3 displacement
- r_1 rotation
- r_2 rotation

Element Assignments

Mechanical Loading

Distributed global loads can be applied as follows:

- f_x force per unit area (uniform or bilinear)
- f_y force per unit area (uniform or bilinear)
- f_z force per unit area (uniform or bilinear)
- m_x moment per unit area (uniform or bilinear)
- m_y moment per unit area (uniform or bilinear)
- m_z moment per unit area (uniform or bilinear)
- Gravity loading in global x, y or z direction

Distributed local loads can be applied as follows:

- f_1 force per unit area (uniform or bilinear)
- f_2 force per unit area (uniform or bilinear)

- f_3 force per unit area (uniform or bilinear)
- m_1 moment per unit area (uniform or bilinear)
- m_2 moment per unit area (uniform or bilinear)
- Gravity loading in local 1, 2 or 3 direction

Temperature Loading

Element can be loaded with constant temperature.

Additional Mass

Global additional element masses can be applied as follows:

- mu_x translational mass per unit area
- mu_y translational mass per unit area
- mu_z translational mass per unit area
- mr_x rotational mass per unit area
- mr_y rotational mass per unit area
- mr_z rotational mass per unit area

Local additional element masses can be applied as follows:

- mu_1 translational mass per unit area
- mu_2 translational mass per unit area
- mu_3 translational mass per unit area
- mr_1 rotational mass per unit area
- mr_2 rotational mass per unit area

Additional Stiffness

Global additional element stiffness can be applied as follows:

- su_x translational stiffness per unit area
- su_y translational stiffness per unit area
- su_z translational stiffness per unit area

- sr_x rotational stiffness per unit area
- sr_y rotational stiffness per unit area
- sr_z rotational stiffness per unit area

Local additional element stiffness can be applied as follows:

- su_1 translational stiffness per unit area
- su_2 translational stiffness per unit area
- su_3 translational stiffness per unit area
- sr_1 rotational stiffness per unit area
- sr_2 rotational stiffness per unit area

Element Output

Displacements

Element output displacements are:

- u_1 displacement
- u_2 displacement
- u_3 displacement
- r_1 rotation
- r_2 rotation

Strains

Element output strains are:

- ε_{11} normal strain
- ε_{22} normal strain
- ε_{12} shear strain
- ε_{13} shear strain
- ε_{23} shear strain

Stresses

Element output stresses are:

- σ_{11} normal stress
- σ_{22} normal stress
- σ_{33} normal stress
- σ_{12} shear stress
- σ_{13} shear stress
- σ_{23} shear stress

Forces

Element output internal forces are:

- P_{11} membrane force
- N_{22} membrane force
- Q_{12} membrane shearing force
- F_{13} shear force
- H_{23} shear force
- K_{22} bending moment
- M_{11} bending moment
- T_{12} twisting moment

Element 18 - Six-node Thick Shell Element

Element Characteristics

Mechanics

This is a three dimensional, constant thickness, triangular, flat, shear deformable (Mindlin-Reissner) shell element. Isotropic or Orthotropic linear material models can be used with this element. Element stiffness, mass and stability matrices are evaluated by seven-point Gaussian integration while the transverse shear terms are under-integrated against shear locking.

Geometry and Nodes

Element has triangular geometry and six nodes with counterclockwise order starting from the corner nodes. Three coordinates for each corner node in global x, y and z direction, and a constant thickness are given as input.

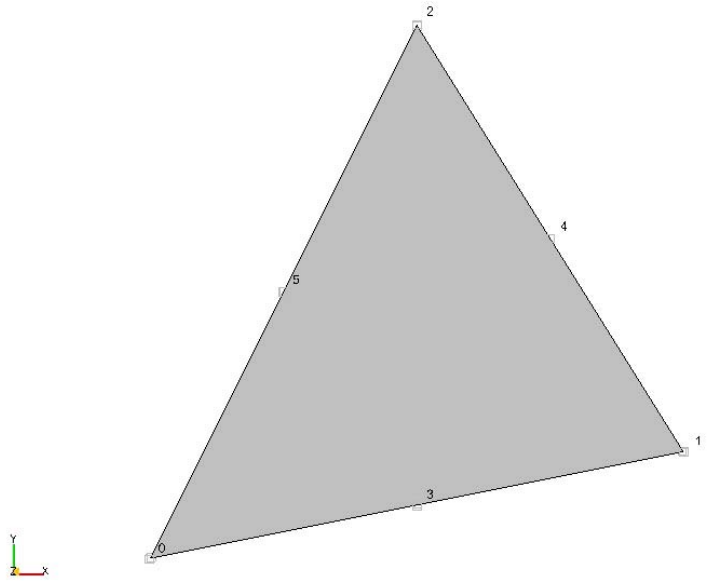


Figure – Element 18

Interpolation

Element has linear-Lagrange interpolation functions.

Degrees of Freedom

Global dofs (per node) are:

- u_x displacement
- u_y displacement
- u_z displacement
- r_x rotation
- r_y rotation
- r_z rotation

Local dofs (per node) are:

- u_1 displacement
- u_2 displacement
- u_3 displacement
- r_1 rotation
- r_2 rotation

Element Assignments

Mechanical Loading

Distributed global loads can be applied as follows:

- f_x force per unit area (uniform or bilinear)
- f_y force per unit area (uniform or bilinear)
- f_z force per unit area (uniform or bilinear)
- m_x moment per unit area (uniform or bilinear)
- m_y moment per unit area (uniform or bilinear)
- m_z moment per unit area (uniform or bilinear)
- Gravity loading in global x, y or z direction

Distributed local loads can be applied as follows:

- f_1 force per unit area (uniform or bilinear)
- f_2 force per unit area (uniform or bilinear)

- f_3 force per unit area (uniform or bilinear)
- m_1 moment per unit area (uniform or bilinear)
- m_2 moment per unit area (uniform or bilinear)
- Gravity loading in local 1, 2 or 3 direction

Temperature Loading

Element can be loaded with constant temperature.

Additional Mass

Global additional element masses can be applied as follows:

- mu_x translational mass per unit area
- mu_y translational mass per unit area
- mu_z translational mass per unit area
- mr_x rotational mass per unit area
- mr_y rotational mass per unit area
- mr_z rotational mass per unit area

Local additional element masses can be applied as follows:

- mu_1 translational mass per unit area
- mu_2 translational mass per unit area
- mu_3 translational mass per unit area
- mr_1 rotational mass per unit area
- mr_2 rotational mass per unit area

Additional Stiffness

Global additional element stiffness can be applied as follows:

- su_x translational stiffness per unit area
- su_y translational stiffness per unit area
- su_z translational stiffness per unit area

- sr_x rotational stiffness per unit area
- sr_y rotational stiffness per unit area
- sr_z rotational stiffness per unit area

Local additional element stiffness can be applied as follows:

- su_1 translational stiffness per unit area
- su_2 translational stiffness per unit area
- su_3 translational stiffness per unit area
- sr_1 rotational stiffness per unit area
- sr_2 rotational stiffness per unit area

Element Output

Displacements

Element output displacements are:

- u_1 displacement
- u_2 displacement
- u_3 displacement
- r_1 rotation
- r_2 rotation

Strains

Element output strains are:

- ε_{11} normal strain
- ε_{22} normal strain
- ε_{12} shear strain
- ε_{13} shear strain
- ε_{23} shear strain

Stresses

Element output stresses are:

- σ_{11} normal stress
- σ_{22} normal stress
- σ_{33} normal stress
- σ_{12} shear stress
- σ_{13} shear stress
- σ_{23} shear stress

Forces

Element output internal forces are:

- P_{11} membrane force
- N_{22} membrane force
- Q_{12} membrane shearing force
- F_{13} shear force
- H_{23} shear force
- K_{22} bending moment
- M_{11} bending moment
- T_{12} twisting moment

Element 19 - Four-node Doubly Curved Thick Shell Element

Element Characteristics

Mechanics

This is a three dimensional, constant thickness, quadrilateral, doubly curved, shear deformable (Sander) shell element. Isotropic or Orthotropic linear material models can be used with this element. Element stiffness, mass and stability matrices are evaluated by two-point Gaussian integration in each local direction while the transverse shear and membrane-bending coupling terms are under-integrated against shear and membrane locking.

Geometry and Nodes

Element has quadrilateral geometry and four nodes with counterclockwise order. Three coordinates per node in global x, y and z direction, radii of curvatures in each local direction and a constant thickness are given as input.

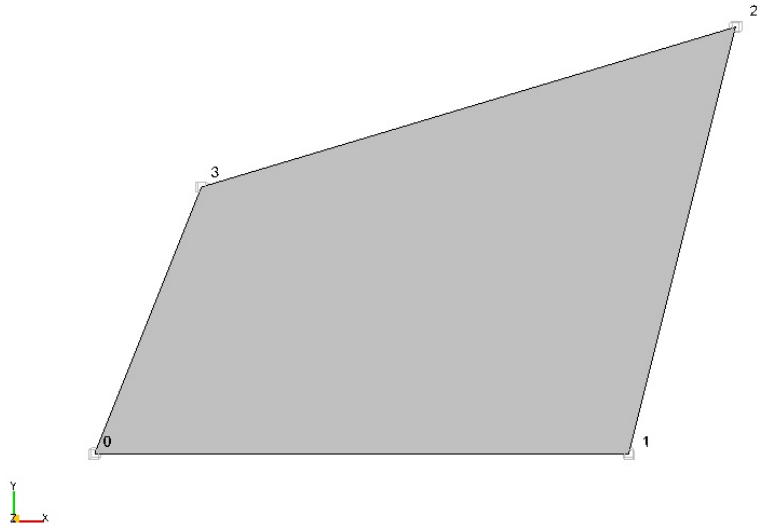


Figure – Element 19

Interpolation

Element has bilinear-Lagrange interpolation functions.

Degrees of Freedom

Global dofs (per node) are:

- u_x displacement
- u_y displacement
- u_z displacement
- r_x rotation
- r_y rotation
- r_z rotation

Local dofs (per node) are:

- u_1 displacement
- u_2 displacement
- u_3 displacement
- r_1 rotation
- r_2 rotation

Element Assignments

Mechanical Loading

Distributed global loads can be applied as follows:

- f_x force per unit area (uniform or bilinear)
- f_y force per unit area (uniform or bilinear)
- f_z force per unit area (uniform or bilinear)
- m_x moment per unit area (uniform or bilinear)
- m_y moment per unit area (uniform or bilinear)
- m_z moment per unit area (uniform or bilinear)
- Gravity loading in global x, y or z direction

Distributed local loads can be applied as follows:

- f_1 force per unit area (uniform or bilinear)
- f_2 force per unit area (uniform or bilinear)

- f_3 force per unit area (uniform or bilinear)
- m_1 moment per unit area (uniform or bilinear)
- m_2 moment per unit area (uniform or bilinear)
- Gravity loading in local 1, 2 or 3 direction

Temperature Loading

Element can be loaded with constant temperature.

Additional Mass

Global additional element masses can be applied as follows:

- mu_x translational mass per unit area
- mu_y translational mass per unit area
- mu_z translational mass per unit area
- mr_x rotational mass per unit area
- mr_y rotational mass per unit area
- mr_z rotational mass per unit area

Local additional element masses can be applied as follows:

- mu_1 translational mass per unit area
- mu_2 translational mass per unit area
- mu_3 translational mass per unit area
- mr_1 rotational mass per unit area
- mr_2 rotational mass per unit area

Additional Stiffness

Global additional element stiffness can be applied as follows:

- su_x translational stiffness per unit area
- su_y translational stiffness per unit area
- su_z translational stiffness per unit area

- sr_x rotational stiffness per unit area
- sr_y rotational stiffness per unit area
- sr_z rotational stiffness per unit area

Local additional element stiffness can be applied as follows:

- su_1 translational stiffness per unit area
- su_2 translational stiffness per unit area
- su_3 translational stiffness per unit area
- sr_1 rotational stiffness per unit area
- sr_2 rotational stiffness per unit area

Element Output

Displacements

Element output displacements are:

- u_1 displacement
- u_2 displacement
- u_3 displacement
- r_1 rotation
- r_2 rotation

Strains

Element output strains are:

- ε_{11} normal strain
- ε_{22} normal strain
- ε_{12} shear strain
- ε_{13} shear strain
- ε_{23} shear strain

Stresses

Element output stresses are:

- σ_{11} normal stress
- σ_{22} normal stress
- σ_{33} normal stress
- σ_{12} shear stress
- σ_{13} shear stress
- σ_{23} shear stress

Forces

Element output internal forces are:

- P_{11} membrane force
- N_{22} membrane force
- Q_{12} membrane shearing force
- F_{13} shear force
- H_{23} shear force
- K_{22} bending moment
- M_{11} bending moment
- T_{12} twisting moment

Element 20 - Eight-node Doubly Curved Thick Shell Element

Element Characteristics

Mechanics

This is a three dimensional, constant thickness, quadrilateral, doubly curved, shear deformable (Sander) shell element. Isotropic or Orthotropic linear material models can be used with this element. Element stiffness, mass and stability matrices are evaluated by three-point Gaussian integration in each local direction while the transverse shear and membrane-bending coupling terms are under-integrated against shear and membrane locking.

Geometry and Nodes

Element has quadrilateral geometry and eight nodes with counterclockwise order starting from the corner nodes. Three coordinates for each corner node in global x, y and z direction, radii of curvatures in each local direction and a constant thickness are given as input.

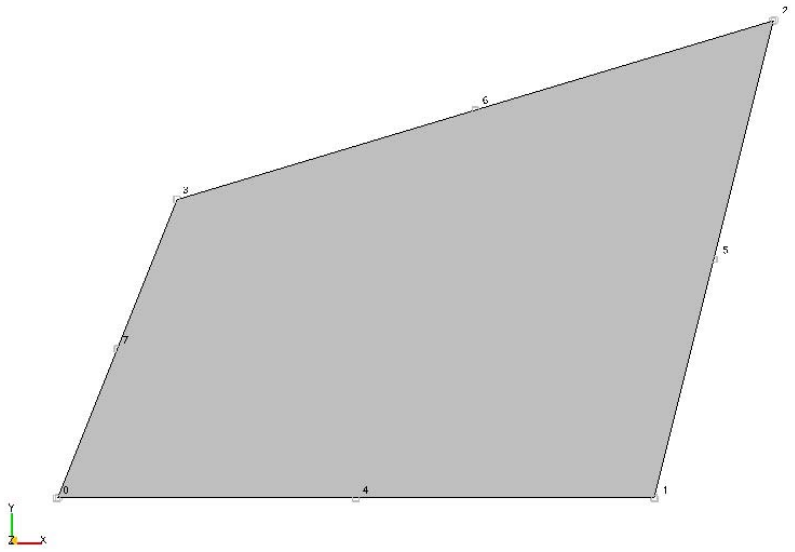


Figure – Element 20

Interpolation

Element has biquadratic-Serendipity interpolation functions.

Degrees of Freedom

Global dofs (per node) are:

- u_x displacement
- u_y displacement
- u_z displacement
- r_x rotation
- r_y rotation
- r_z rotation

Local dofs (per node) are:

- u_1 displacement
- u_2 displacement
- u_3 displacement
- r_1 rotation
- r_2 rotation

Element Assignments

Mechanical Loading

Distributed global loads can be applied as follows:

- f_x force per unit area (uniform or bilinear)
- f_y force per unit area (uniform or bilinear)
- f_z force per unit area (uniform or bilinear)
- m_x moment per unit area (uniform or bilinear)
- m_y moment per unit area (uniform or bilinear)
- m_z moment per unit area (uniform or bilinear)
- Gravity loading in global x, y or z direction

Distributed local loads can be applied as follows:

- f_1 force per unit area (uniform or bilinear)
- f_2 force per unit area (uniform or bilinear)

- f_3 force per unit area (uniform or bilinear)
- m_1 moment per unit area (uniform or bilinear)
- m_2 moment per unit area (uniform or bilinear)
- Gravity loading in local 1, 2 or 3 direction

Temperature Loading

Element can be loaded with constant temperature.

Additional Mass

Global additional element masses can be applied as follows:

- mu_x translational mass per unit area
- mu_y translational mass per unit area
- mu_z translational mass per unit area
- mr_x rotational mass per unit area
- mr_y rotational mass per unit area
- mr_z rotational mass per unit area

Local additional element masses can be applied as follows:

- mu_1 translational mass per unit area
- mu_2 translational mass per unit area
- mu_3 translational mass per unit area
- mr_1 rotational mass per unit area
- mr_2 rotational mass per unit area

Additional Stiffness

Global additional element stiffness can be applied as follows:

- su_x translational stiffness per unit area
- su_y translational stiffness per unit area
- su_z translational stiffness per unit area

- sr_x rotational stiffness per unit area
- sr_y rotational stiffness per unit area
- sr_z rotational stiffness per unit area

Local additional element stiffness can be applied as follows:

- su_1 translational stiffness per unit area
- su_2 translational stiffness per unit area
- su_3 translational stiffness per unit area
- sr_1 rotational stiffness per unit area
- sr_2 rotational stiffness per unit area

Element Output

Displacements

Element output displacements are:

- u_1 displacement
- u_2 displacement
- u_3 displacement
- r_1 rotation
- r_2 rotation

Strains

Element output strains are:

- ε_{11} normal strain
- ε_{22} normal strain
- ε_{12} shear strain
- ε_{13} shear strain
- ε_{23} shear strain

Stresses

Element output stresses are:

- σ_{11} normal stress
- σ_{22} normal stress
- σ_{33} normal stress
- σ_{12} shear stress
- σ_{13} shear stress
- σ_{23} shear stress

Forces

Element output internal forces are:

- P_{11} membrane force
- N_{22} membrane force
- Q_{12} membrane shearing force
- F_{13} shear force
- H_{23} shear force
- K_{22} bending moment
- M_{11} bending moment
- T_{12} twisting moment

Element 21 - Six-node Doubly Curved Thick Shell Element

Element Characteristics

Mechanics

This is a three dimensional, constant thickness, triangular, doubly curved, shear deformable (Sander) shell element. Isotropic or Orthotropic linear material models can be used with this element. Element stiffness, mass and stability matrices are evaluated by seven-point Gaussian integration while the transverse shear and membrane-bending coupling terms are under-integrated against shear and membrane locking.

Geometry and Nodes

Element has triangular geometry and six nodes with counterclockwise order starting from the corner nodes. Three coordinates for each corner node in global x, y and z direction, radii of curvatures in each local direction and a constant thickness are given as input.

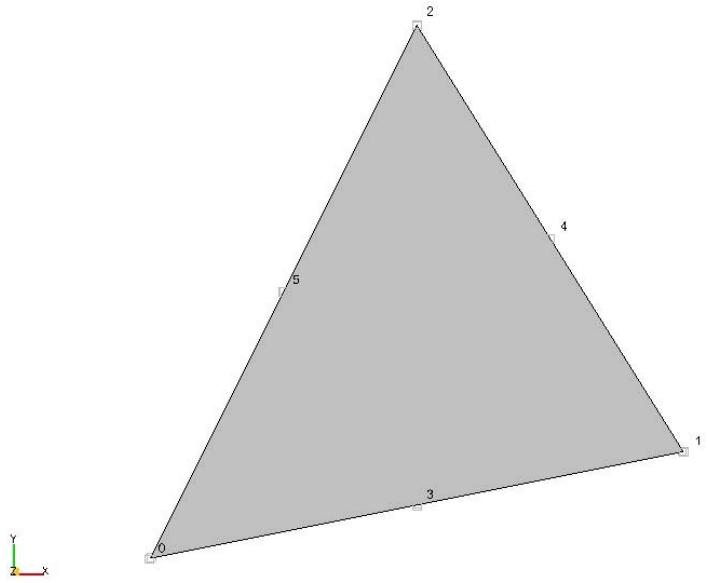


Figure – Element 21

Interpolation

Element has linear-Lagrange interpolation functions.

Degrees of Freedom

Global dofs (per node) are:

- u_x displacement
- u_y displacement
- u_z displacement
- r_x rotation
- r_y rotation
- r_z rotation

Local dofs (per node) are:

- u_1 displacement
- u_2 displacement
- u_3 displacement
- r_1 rotation
- r_2 rotation

Element Assignments

Mechanical Loading

Distributed global loads can be applied as follows:

- f_x force per unit area (uniform or bilinear)
- f_y force per unit area (uniform or bilinear)
- f_z force per unit area (uniform or bilinear)
- m_x moment per unit area (uniform or bilinear)
- m_y moment per unit area (uniform or bilinear)
- m_z moment per unit area (uniform or bilinear)
- Gravity loading in global x, y or z direction

Distributed local loads can be applied as follows:

- f_1 force per unit area (uniform or bilinear)
- f_2 force per unit area (uniform or bilinear)

- f_3 force per unit area (uniform or bilinear)
- m_1 moment per unit area (uniform or bilinear)
- m_2 moment per unit area (uniform or bilinear)
- Gravity loading in local 1, 2 or 3 direction

Temperature Loading

Element can be loaded with constant temperature.

Additional Mass

Global additional element masses can be applied as follows:

- mu_x translational mass per unit area
- mu_y translational mass per unit area
- mu_z translational mass per unit area
- mr_x rotational mass per unit area
- mr_y rotational mass per unit area
- mr_z rotational mass per unit area

Local additional element masses can be applied as follows:

- mu_1 translational mass per unit area
- mu_2 translational mass per unit area
- mu_3 translational mass per unit area
- mr_1 rotational mass per unit area
- mr_2 rotational mass per unit area

Additional Stiffness

Global additional element stiffness can be applied as follows:

- su_x translational stiffness per unit area
- su_y translational stiffness per unit area
- su_z translational stiffness per unit area

- sr_x rotational stiffness per unit area
- sr_y rotational stiffness per unit area
- sr_z rotational stiffness per unit area

Local additional element stiffness can be applied as follows:

- su_1 translational stiffness per unit area
- su_2 translational stiffness per unit area
- su_3 translational stiffness per unit area
- sr_1 rotational stiffness per unit area
- sr_2 rotational stiffness per unit area

Element Output

Displacements

Element output displacements are:

- u_1 displacement
- u_2 displacement
- u_3 displacement
- r_1 rotation
- r_2 rotation

Strains

Element output strains are:

- ε_{11} normal strain
- ε_{22} normal strain
- ε_{12} shear strain
- ε_{13} shear strain
- ε_{23} shear strain

Stresses

Element output stresses are:

- σ_{11} normal stress
- σ_{22} normal stress
- σ_{33} normal stress
- σ_{12} shear stress
- σ_{13} shear stress
- σ_{23} shear stress

Forces

Element output internal forces are:

- P_{11} membrane force
- N_{22} membrane force
- Q_{12} membrane shearing force
- F_{13} shear force
- H_{23} shear force
- K_{22} bending moment
- M_{11} bending moment
- T_{12} twisting moment

Element 22 - Eight-node Solid Element

Element Characteristics

Mechanics

This is a three dimensional, hexahedral, solid element. Isotropic or Orthotropic linear material models can be used with this element. Element stiffness, mass and stability matrices are evaluated by two-point Gaussian integration in each local direction.

Geometry and Nodes

Element has hexahedral geometry and eight nodes with counterclockwise order starting from the top side. Three coordinates per node in global x, y and z direction are given as input.

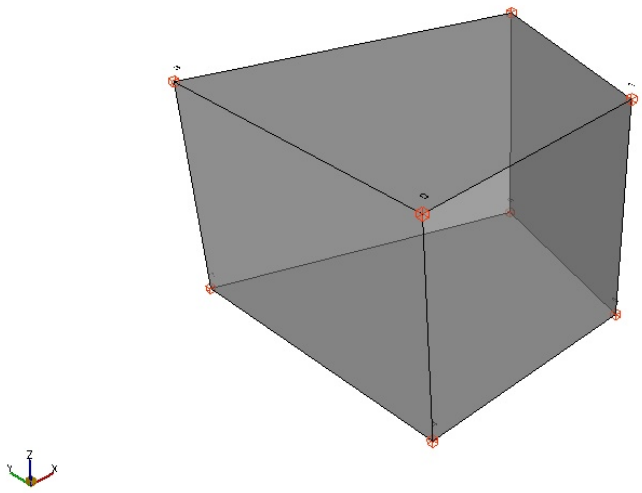


Figure – Element 22

Interpolation

Element has trilinear-Lagrange interpolation functions.

Degrees of Freedom

Global dofs (per node) are:

- u_x displacement
- u_y displacement
- u_z displacement

Local dofs (per node) are:

- u_1 displacement
- u_2 displacement
- u_3 displacement

Element Assignments

Mechanical Loading

Distributed global loads can be applied as follows:

- f_x force per unit volume (uniform)
- f_y force per unit volume (uniform)
- f_z force per unit volume (uniform)
- Gravity loading in global x, y or z direction

Distributed local loads can be applied as follows:

- f_1 force per unit volume (uniform)
- f_2 force per unit volume (uniform)
- f_3 force per unit volume (uniform)
- Gravity loading in local 1, 2 or 3 direction

Temperature Loading

Element can be loaded with constant temperature.

Additional Mass

Global additional element masses can be applied as follows:

- mu_x translational mass per unit volume
- mu_y translational mass per unit volume
- mu_z translational mass per unit volume

Local additional element masses can be applied as follows:

- mu_1 translational mass per unit volume
- mu_2 translational mass per unit volume

- mu_3 translational mass per unit volume

Additional Stiffness

Global additional element stiffness can be applied as follows:

- su_x translational stiffness per unit volume
- su_y translational stiffness per unit volume
- su_z translational stiffness per unit volume

Local additional element stiffness can be applied as follows:

- su_1 translational stiffness per unit volume
- su_2 translational stiffness per unit volume
- su_3 translational stiffness per unit volume

Element Output

Displacements

Element output displacements are:

- u_1 displacement
- u_2 displacement
- u_3 displacement

Strains

Element output strains are:

- ε_{11} normal strain
- ε_{22} normal strain
- ε_{33} normal strain
- ε_{12} shear strain
- ε_{13} shear strain
- ε_{23} shear strain

Stresses

Element output stresses are:

- σ_{11} normal stress
- σ_{22} normal stress
- σ_{33} normal stress
- σ_{12} shear stress
- σ_{13} shear stress
- σ_{23} shear stress

Forces

No internal element forces are available for this element.

Element 23 - Twenty-node Solid Element

Element Characteristics

Mechanics

This is a three dimensional, hexahedral, solid element. Isotropic or Orthotropic linear material models can be used with this element. Element stiffness, mass and stability matrices are evaluated by three-point Gaussian integration in each local direction.

Geometry and Nodes

Element has hexahedral geometry and twenty nodes with counterclockwise order starting from the top side and vertex nodes. Three coordinates for each vertex node in global x, y and z direction are given as input.

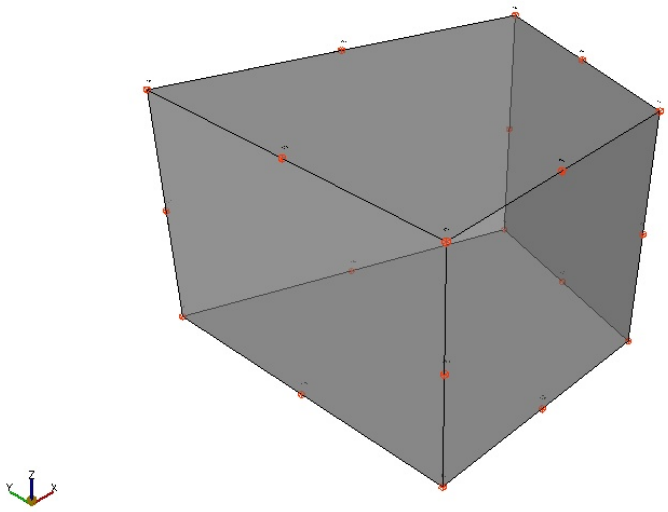


Figure – Element 23

Interpolation

Element has triquadratic-Serendipity interpolation functions.

Degrees of Freedom

Global dofs (per node) are:

- u_x displacement
- u_y displacement
- u_z displacement

Local dofs (per node) are:

- u_1 displacement
- u_2 displacement
- u_3 displacement

Element Assignments

Mechanical Loading

Distributed global loads can be applied as follows:

- f_x force per unit volume (uniform)
- f_y force per unit volume (uniform)
- f_z force per unit volume (uniform)
- Gravity loading in global x, y or z direction

Distributed local loads can be applied as follows:

- f_1 force per unit volume (uniform)
- f_2 force per unit volume (uniform)
- f_3 force per unit volume (uniform)
- Gravity loading in local 1, 2 or 3 direction

Temperature Loading

Element can be loaded with constant temperature.

Additional Mass

Global additional element masses can be applied as follows:

- mu_x translational mass per unit volume
- mu_y translational mass per unit volume
- mu_z translational mass per unit volume

Local additional element masses can be applied as follows:

- mu_1 translational mass per unit volume

- mu_2 translational mass per unit volume
- mu_3 translational mass per unit volume

Additional Stiffness

Global additional element stiffness can be applied as follows:

- su_x translational stiffness per unit volume
- su_y translational stiffness per unit volume
- su_z translational stiffness per unit volume

Local additional element stiffness can be applied as follows:

- su_1 translational stiffness per unit volume
- su_2 translational stiffness per unit volume
- su_3 translational stiffness per unit volume

Element Output

Displacements

Element output displacements are:

- u_1 displacement
- u_2 displacement
- u_3 displacement

Strains

Element output strains are:

- ε_{11} normal strain
- ε_{22} normal strain
- ε_{33} normal strain
- ε_{12} shear strain
- ε_{13} shear strain
- ε_{23} shear strain

Stresses

Element output stresses are:

- σ_{11} normal stress
- σ_{22} normal stress
- σ_{33} normal stress
- σ_{12} shear stress
- σ_{13} shear stress
- σ_{23} shear stress

Forces

No internal element forces are available for this element.

Element 24 - Four-node Thick Plate Element

Element Characteristics

Mechanics

This is a three dimensional, constant thickness, quadrilateral, shear deformable (Mindlin-Reissner) plate element. Isotropic or Orthotropic linear material models can be used with this element. Element stiffness, mass and stability matrices are evaluated by two-point Gaussian integration in each local direction while the transverse shear terms are under-integrated against shear locking.

Geometry and Nodes

Element has quadrilateral geometry and four nodes with counterclockwise order. Three coordinates per node in global x, y and z direction, and a constant thickness are given as input.

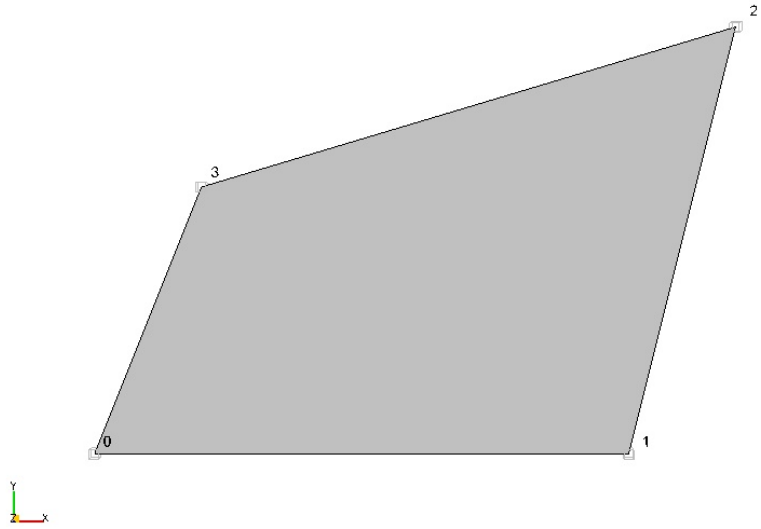


Figure – Element 24

Interpolation

Element has bilinear-Lagrange interpolation functions.

Degrees of Freedom

Global dofs (per node) are:

- u_x displacement
- u_y displacement
- u_z displacement
- r_x rotation
- r_y rotation
- r_z rotation

Local dofs (per node) are:

- u_3 displacement
- r_1 rotation
- r_2 rotation

Element Assignments

Mechanical Loading

Distributed global loads can be applied as follows:

- f_x force per unit area (uniform or bilinear)
- f_y force per unit area (uniform or bilinear)
- f_z force per unit area (uniform or bilinear)
- m_x moment per unit area (uniform or bilinear)
- m_y moment per unit area (uniform or bilinear)
- m_z moment per unit area (uniform or bilinear)
- Gravity loading in global x, y or z direction

Distributed local loads can be applied as follows:

- f_3 force per unit area (uniform or bilinear)
- m_1 moment per unit area (uniform or bilinear)
- m_2 moment per unit area (uniform or bilinear)
- Gravity loading in local 3 direction

Temperature Loading

No temperature loading is available for this element.

Additional Mass

Global additional element masses can be applied as follows:

- mu_x translational mass per unit area
- mu_y translational mass per unit area
- mu_z translational mass per unit area
- mr_x rotational mass per unit area
- mr_y rotational mass per unit area
- mr_z rotational mass per unit area

Local additional element masses can be applied as follows:

- mu_3 translational mass per unit area
- mr_1 rotational mass per unit area
- mr_2 rotational mass per unit area

Additional Stiffness

Global additional element stiffness can be applied as follows:

- su_x translational stiffness per unit area
- su_y translational stiffness per unit area
- su_z translational stiffness per unit area
- sr_x rotational stiffness per unit area
- sr_y rotational stiffness per unit area
- sr_z rotational stiffness per unit area

Local additional element stiffness can be applied as follows:

- su_3 translational stiffness per unit area
- sr_1 rotational stiffness per unit area

- sr_2 rotational stiffness per unit area

Element Output

Displacements

Element output displacements are:

- u_3 displacement
- r_1 rotation
- r_2 rotation

Strains

Element output strains are:

- ε_{11} normal strain
- ε_{22} normal strain
- ε_{12} shear strain
- ε_{13} shear strain
- ε_{23} shear strain

Stresses

Element output stresses are:

- σ_{11} normal stress
- σ_{22} normal stress
- σ_{33} normal stress
- σ_{12} shear stress
- σ_{13} shear stress
- σ_{23} shear stress

Forces

Element output internal forces are:

- F_{13} shear force

- H_{23} shear force
- K_{22} bending moment
- M_{11} bending moment
- T_{12} twisting moment

Element 25 - Eight-node Thick Plate Element

Element Characteristics

Mechanics

This is a three dimensional, constant thickness, quadrilateral, shear deformable (Mindlin-Reissner) plate element. Isotropic or Orthotropic linear material models can be used with this element. Element stiffness, mass and stability matrices are evaluated by three-point Gaussian integration in each local direction while the transverse shear terms are under-integrated against shear locking.

Geometry and Nodes

Element has quadrilateral geometry and eight nodes with counterclockwise order starting from the corner nodes. Three coordinates for each corner node in global x, y and z direction, and a constant thickness are given as input.

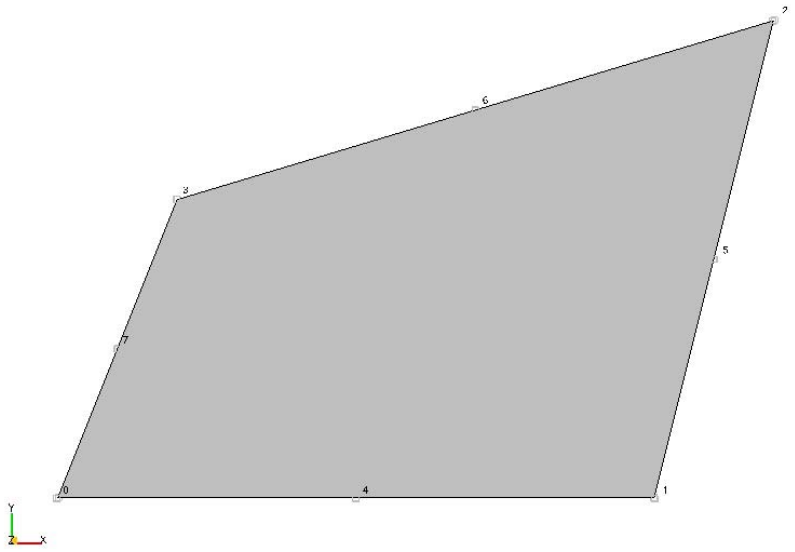


Figure – Element 25

Interpolation

Element has biquadratic-Serendipity interpolation functions.

Degrees of Freedom

Global dofs (per node) are:

- u_x displacement
- u_y displacement
- u_z displacement
- r_x rotation
- r_y rotation
- r_z rotation

Local dofs (per node) are:

- u_3 displacement
- r_1 rotation
- r_2 rotation

Element Assignments

Mechanical Loading

Distributed global loads can be applied as follows:

- f_x force per unit area (uniform or bilinear)
- f_y force per unit area (uniform or bilinear)
- f_z force per unit area (uniform or bilinear)
- m_x moment per unit area (uniform or bilinear)
- m_y moment per unit area (uniform or bilinear)
- m_z moment per unit area (uniform or bilinear)
- Gravity loading in global x, y or z direction

Distributed local loads can be applied as follows:

- f_3 force per unit area (uniform or bilinear)
- m_1 moment per unit area (uniform or bilinear)
- m_2 moment per unit area (uniform or bilinear)
- Gravity loading in local 3 direction

Temperature Loading

No temperature loading is available for this element.

Additional Mass

Global additional element masses can be applied as follows:

- mu_x translational mass per unit area
- mu_y translational mass per unit area
- mu_z translational mass per unit area
- mr_x rotational mass per unit area
- mr_y rotational mass per unit area
- mr_z rotational mass per unit area

Local additional element masses can be applied as follows:

- mu_3 translational mass per unit area
- mr_1 rotational mass per unit area
- mr_2 rotational mass per unit area

Additional Stiffness

Global additional element stiffness can be applied as follows:

- su_x translational stiffness per unit area
- su_y translational stiffness per unit area
- su_z translational stiffness per unit area
- sr_x rotational stiffness per unit area
- sr_y rotational stiffness per unit area
- sr_z rotational stiffness per unit area

Local additional element stiffness can be applied as follows:

- su_3 translational stiffness per unit area
- sr_1 rotational stiffness per unit area

- sr_2 rotational stiffness per unit area

Element Output

Displacements

Element output displacements are:

- u_3 displacement
- r_1 rotation
- r_2 rotation

Strains

Element output strains are:

- ε_{11} normal strain
- ε_{22} normal strain
- ε_{12} shear strain
- ε_{13} shear strain
- ε_{23} shear strain

Stresses

Element output stresses are:

- σ_{11} normal stress
- σ_{22} normal stress
- σ_{33} normal stress
- σ_{12} shear stress
- σ_{13} shear stress
- σ_{23} shear stress

Forces

Element output internal forces are:

- F_{13} shear force

- H_{23} shear force
- K_{22} bending moment
- M_{11} bending moment
- T_{12} twisting moment

Element 26 - Six-node Thick Plate Element

Element Characteristics

Mechanics

This is a three dimensional, constant thickness, triangular, shear deformable (Mindlin-Reissner) plate element. Isotropic or Orthotropic linear material models can be used with this element. Element stiffness, mass and stability matrices are evaluated by seven-point Gaussian integration while the transverse shear terms are under-integrated against shear locking.

Geometry and Nodes

Element has triangular geometry and six nodes with counterclockwise order starting from the corner nodes. Three coordinates for each corner node in global x, y and z direction, and a constant thickness are given as input.

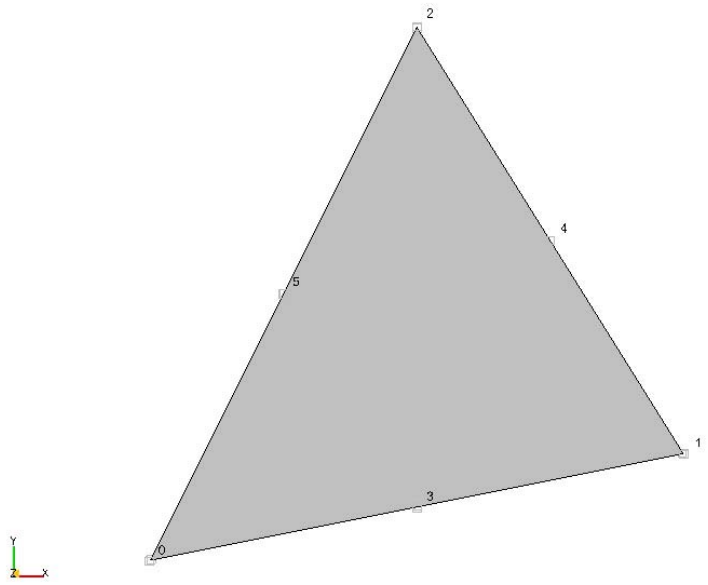


Figure – Element 26

Interpolation

Element has quadratic-Lagrange interpolation functions.

Degrees of Freedom

Global dofs (per node) are:

- u_x displacement
- u_y displacement
- u_z displacement
- r_x rotation
- r_y rotation
- r_z rotation

Local dofs (per node) are:

- u_3 displacement
- r_1 rotation
- r_2 rotation

Element Assignments

Mechanical Loading

Distributed global loads can be applied as follows:

- f_x force per unit area (uniform or bilinear)
- f_y force per unit area (uniform or bilinear)
- f_z force per unit area (uniform or bilinear)
- m_x moment per unit area (uniform or bilinear)
- m_y moment per unit area (uniform or bilinear)
- m_z moment per unit area (uniform or bilinear)
- Gravity loading in global x, y or z direction

Distributed local loads can be applied as follows:

- f_3 force per unit area (uniform or bilinear)
- m_1 moment per unit area (uniform or bilinear)
- m_2 moment per unit area (uniform or bilinear)
- Gravity loading in local 3 direction

Temperature Loading

No temperature loading is available for this element.

Additional Mass

Global additional element masses can be applied as follows:

- mu_x translational mass per unit area
- mu_y translational mass per unit area
- mu_z translational mass per unit area
- mr_x rotational mass per unit area
- mr_y rotational mass per unit area
- mr_z rotational mass per unit area

Local additional element masses can be applied as follows:

- mu_3 translational mass per unit area
- mr_1 rotational mass per unit area
- mr_2 rotational mass per unit area

Additional Stiffness

Global additional element stiffness can be applied as follows:

- su_x translational stiffness per unit area
- su_y translational stiffness per unit area
- su_z translational stiffness per unit area
- sr_x rotational stiffness per unit area
- sr_y rotational stiffness per unit area
- sr_z rotational stiffness per unit area

Local additional element stiffness can be applied as follows:

- su_3 translational stiffness per unit area
- sr_1 rotational stiffness per unit area

- sr_2 rotational stiffness per unit area

Element Output

Displacements

Element output displacements are:

- u_3 displacement
- r_1 rotation
- r_2 rotation

Strains

Element output strains are:

- ε_{11} normal strain
- ε_{22} normal strain
- ε_{12} shear strain
- ε_{13} shear strain
- ε_{23} shear strain

Stresses

Element output stresses are:

- σ_{11} normal stress
- σ_{22} normal stress
- σ_{33} normal stress
- σ_{12} shear stress
- σ_{13} shear stress
- σ_{23} shear stress

Forces

Element output internal forces are:

- F_{13} shear force

- H_{23} shear force
- K_{22} bending moment
- M_{11} bending moment
- T_{12} twisting moment

Element 27 - Two-node Curved Thick Beam Element

Element Characteristics

Mechanics

This is a three dimensional, constant cross section, curved, shear deformable (Timoshenko) beam element. Isotropic or Orthotropic linear material models can be used with this element. Element stiffness and mass matrices are evaluated analytically except for the transverse shear terms which are under-integrated against shear locking. Element stability matrix is evaluated by one-point Gaussian integration.

Geometry and Nodes

Element has two nodes. Three coordinates per node in global x, y and z direction, radius of curvature and a constant cross section are given as input. Axial rotation can be assigned as user-defined local axes.

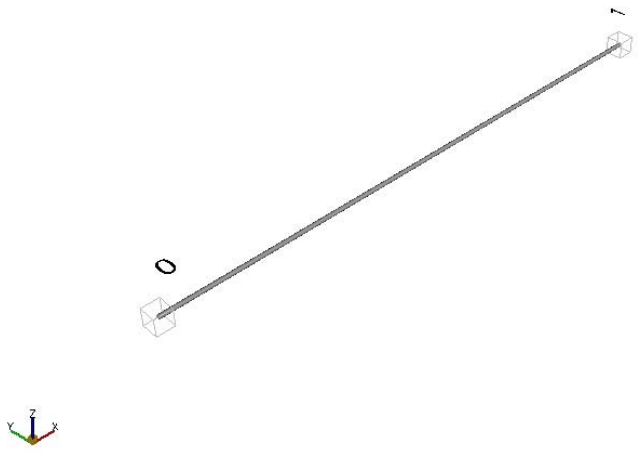


Figure – Element 27

Interpolation

Element has linear-Lagrange interpolation functions.

Degrees of Freedom

Global dofs (per node) are:

- u_x displacement

- u_y displacement
- u_z displacement
- r_x rotation
- r_y rotation
- r_z rotation

Local dofs (per node) are:

- u_1 displacement
- u_2 displacement
- u_3 displacement
- r_1 rotation
- r_2 rotation
- r_3 rotation

Element Assignments

Mechanical Loading

Distributed global loads can be applied as follows:

- f_x force per unit length (uniform or linear)
- f_y force per unit length (uniform or linear)
- f_z force per unit length (uniform or linear)
- m_x moment per unit length (uniform or linear)
- m_y moment per unit length (uniform or linear)
- m_z moment per unit length (uniform or linear)
- Gravity loading in global x, y or z direction

Distributed local loads can be applied as follows:

- f_1 force per unit length (uniform or linear)
- f_2 force per unit length (uniform or linear)

- f_3 force per unit length (uniform or linear)
- m_1 moment per unit length (uniform or linear)
- m_2 moment per unit length (uniform or linear)
- m_3 moment per unit length (uniform or linear)
- Gravity loading in local 1, 2 or 3 direction

Temperature Loading

Element can be loaded with constant temperature.

Additional Mass

Global additional element masses can be applied as follows:

- mu_x translational mass per unit area
- mu_y translational mass per unit area
- mu_z translational mass per unit area
- mr_x rotational mass per unit area
- mr_y rotational mass per unit area
- mr_z rotational mass per unit area

Local additional element masses can be applied as follows:

- mu_1 translational mass per unit area
- mu_2 translational mass per unit area
- mu_3 translational mass per unit area
- mr_1 rotational mass per unit area
- mr_2 rotational mass per unit area
- mr_3 rotational mass per unit area

Additional Stiffness

Global additional element stiffness can be applied as follows:

- su_x translational stiffness per unit area

- su_y translational stiffness per unit area
- su_z translational stiffness per unit area
- sr_x rotational stiffness per unit area
- sr_y rotational stiffness per unit area
- sr_z rotational stiffness per unit area

Local additional element stiffness can be applied as follows:

- su_1 translational stiffness per unit area
- su_2 translational stiffness per unit area
- su_3 translational stiffness per unit area
- sr_1 rotational stiffness per unit area
- sr_2 rotational stiffness per unit area
- sr_3 rotational stiffness per unit area

Element Output

Displacements

Element output displacements are:

- u_1 displacement
- u_2 displacement
- u_3 displacement
- r_1 rotation
- r_2 rotation
- r_3 rotation

Strains

Element output strains are:

- ε_{11} normal strain
- ε_{12} shear strain

- ε_{13} shear strain

Stresses

Element output stresses are:

- σ_{11} normal stress
- σ_{12} shear stress
- σ_{13} shear stress

Forces

Element output internal forces are:

- N_1 normal force
- V_2 shear force
- V_3 shear force
- T_1 twisting moment
- M_2 bending moment
- M_3 bending moment

Element 28 - Three-node Curved Thick Beam Element

Element Characteristics

Mechanics

This is a three dimensional, constant cross section, curved, shear deformable (Timoshenko) beam element. Isotropic or Orthotropic linear material models can be used with this element. Element stiffness and mass matrices are evaluated analytically except for the transverse shear terms which are under-integrated against shear locking. Element stability matrix is evaluated by two-point Gaussian integration.

Geometry and Nodes

Element has three nodes with the order starting from end nodes. Three coordinates for each end node in global x, y and z direction, radius of curvature and a constant cross section are given as input. Axial rotation can be assigned as user-defined local axes.

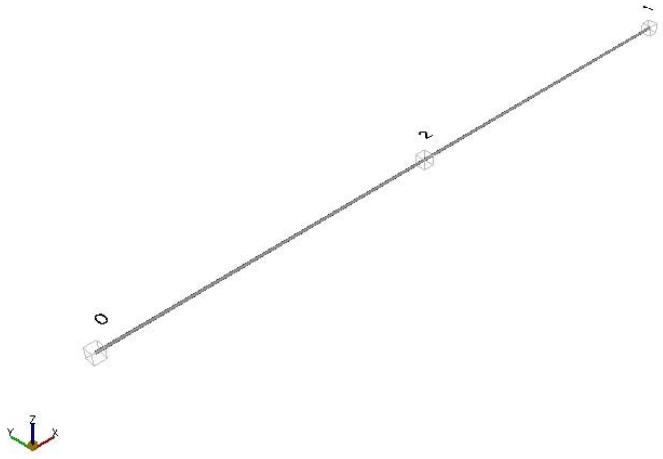


Figure – Element 28

Interpolation

Element has quadratic-Lagrange interpolation functions.

Degrees of Freedom

Global dofs (per node) are:

- u_x displacement

- u_y displacement
- u_z displacement
- r_x rotation
- r_y rotation
- r_z rotation

Local dofs (per node) are:

- u_1 displacement
- u_2 displacement
- u_3 displacement
- r_1 rotation
- r_2 rotation
- r_3 rotation

Element Assignments

Mechanical Loading

Distributed global loads can be applied as follows:

- f_x force per unit length (uniform or linear)
- f_y force per unit length (uniform or linear)
- f_z force per unit length (uniform or linear)
- m_x moment per unit length (uniform or linear)
- m_y moment per unit length (uniform or linear)
- m_z moment per unit length (uniform or linear)
- Gravity loading in global x, y or z direction

Distributed local loads can be applied as follows:

- f_1 force per unit length (uniform or linear)
- f_2 force per unit length (uniform or linear)

- f_3 force per unit length (uniform or linear)
- m_1 moment per unit length (uniform or linear)
- m_2 moment per unit length (uniform or linear)
- m_3 moment per unit length (uniform or linear)
- Gravity loading in local 1, 2 or 3 direction

Temperature Loading

Element can be loaded with constant temperature.

Additional Mass

Global additional element masses can be applied as follows:

- mu_x translational mass per unit area
- mu_y translational mass per unit area
- mu_z translational mass per unit area
- mr_x rotational mass per unit area
- mr_y rotational mass per unit area
- mr_z rotational mass per unit area

Local additional element masses can be applied as follows:

- mu_1 translational mass per unit area
- mu_2 translational mass per unit area
- mu_3 translational mass per unit area
- mr_1 rotational mass per unit area
- mr_2 rotational mass per unit area
- mr_3 rotational mass per unit area

Additional Stiffness

Global additional element stiffness can be applied as follows:

- su_x translational stiffness per unit area

- su_y translational stiffness per unit area
- su_z translational stiffness per unit area
- sr_x rotational stiffness per unit area
- sr_y rotational stiffness per unit area
- sr_z rotational stiffness per unit area

Local additional element stiffness can be applied as follows:

- su_1 translational stiffness per unit area
- su_2 translational stiffness per unit area
- su_3 translational stiffness per unit area
- sr_1 rotational stiffness per unit area
- sr_2 rotational stiffness per unit area
- sr_3 rotational stiffness per unit area

Element Output

Displacements

Element output displacements are:

- u_1 displacement
- u_2 displacement
- u_3 displacement
- r_1 rotation
- r_2 rotation
- r_3 rotation

Strains

Element output strains are:

- ε_{11} normal strain
- ε_{12} shear strain

- ε_{13} shear strain

Stresses

Element output stresses are:

- σ_{11} normal stress
- σ_{12} shear stress
- σ_{13} shear stress

Forces

Element output internal forces are:

- N_1 normal force
- V_2 shear force
- V_3 shear force
- T_1 twisting moment
- M_2 bending moment
- M_3 bending moment

Element 29 - Four-node Curved Thick Beam Element

Element Characteristics

Mechanics

This is a three dimensional, constant cross section, curved, shear deformable (Timoshenko) beam element. Isotropic or Orthotropic linear material models can be used with this element. Element stiffness and mass matrices are evaluated analytically. Element stability matrix is evaluated by three-point Gaussian integration.

Geometry and Nodes

Element has four nodes with the order starting from end nodes. Three coordinates for each end node in global x, y and z direction, radius of curvature and a constant cross section are given as input. Axial rotation can be assigned as user-defined local axes.

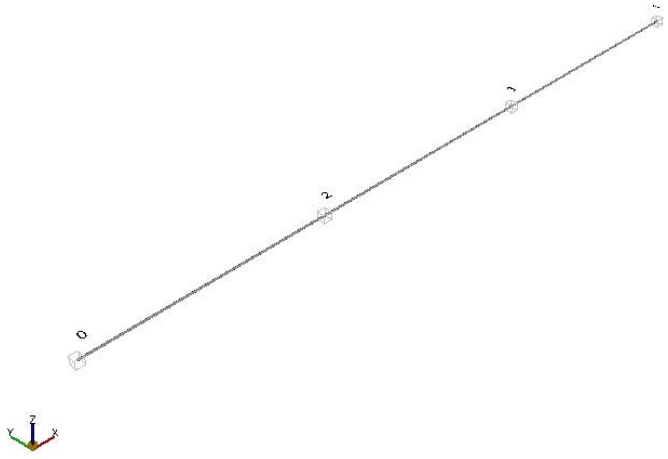


Figure – Element 29

Interpolation

Element has cubic-Lagrange interpolation functions.

Degrees of Freedom

Global dofs (per node) are:

- u_x displacement
- u_y displacement

- u_z displacement
- r_x rotation
- r_y rotation
- r_z rotation

Local dofs (per node) are:

- u_1 displacement
- u_2 displacement
- u_3 displacement
- r_1 rotation
- r_2 rotation
- r_3 rotation

Element Assignments

Mechanical Loading

Distributed global loads can be applied as follows:

- f_x force per unit length (uniform or linear)
- f_y force per unit length (uniform or linear)
- f_z force per unit length (uniform or linear)
- m_x moment per unit length (uniform or linear)
- m_y moment per unit length (uniform or linear)
- m_z moment per unit length (uniform or linear)
- Gravity loading in global x, y or z direction

Distributed local loads can be applied as follows:

- f_1 force per unit length (uniform or linear)
- f_2 force per unit length (uniform or linear)
- f_3 force per unit length (uniform or linear)

- m_1 moment per unit length (uniform or linear)
- m_2 moment per unit length (uniform or linear)
- m_3 moment per unit length (uniform or linear)
- Gravity loading in local 1, 2 or 3 direction

Temperature Loading

Element can be loaded with constant temperature.

Additional Mass

Global additional element masses can be applied as follows:

- mu_x translational mass per unit area
- mu_y translational mass per unit area
- mu_z translational mass per unit area
- mr_x rotational mass per unit area
- mr_y rotational mass per unit area
- mr_z rotational mass per unit area

Local additional element masses can be applied as follows:

- mu_1 translational mass per unit area
- mu_2 translational mass per unit area
- mu_3 translational mass per unit area
- mr_1 rotational mass per unit area
- mr_2 rotational mass per unit area
- mr_3 rotational mass per unit area

Additional Stiffness

Global additional element stiffness can be applied as follows:

- su_x translational stiffness per unit area
- su_y translational stiffness per unit area

- su_z translational stiffness per unit area
- sr_x rotational stiffness per unit area
- sr_y rotational stiffness per unit area
- sr_z rotational stiffness per unit area

Local additional element stiffness can be applied as follows:

- su_1 translational stiffness per unit area
- su_2 translational stiffness per unit area
- su_3 translational stiffness per unit area
- sr_1 rotational stiffness per unit area
- sr_2 rotational stiffness per unit area
- sr_3 rotational stiffness per unit area

Element Output

Displacements

Element output displacements are:

- u_1 displacement
- u_2 displacement
- u_3 displacement
- r_1 rotation
- r_2 rotation
- r_3 rotation

Strains

Element output strains are:

- ε_{11} normal strain
- ε_{12} shear strain
- ε_{13} shear strain

Stresses

Element output stresses are:

- σ_{11} normal stress
- σ_{12} shear stress
- σ_{13} shear stress

Forces

Element output internal forces are:

- N_1 normal force
- V_2 shear force
- V_3 shear force
- T_1 twisting moment
- M_2 bending moment
- M_3 bending moment

Element 30 - Four-node Solid Element

Element Characteristics

Mechanics

This is a three dimensional, tetrahedral, solid element. Isotropic or Orthotropic linear material models can be used with this element. Element stiffness, mass and stability matrices are evaluated by two-point Gaussian integration in each local direction.

Geometry and Nodes

Element has tetrahedral geometry and four nodes with counterclockwise order. Three coordinates per node in global x, y and z direction are given as input.

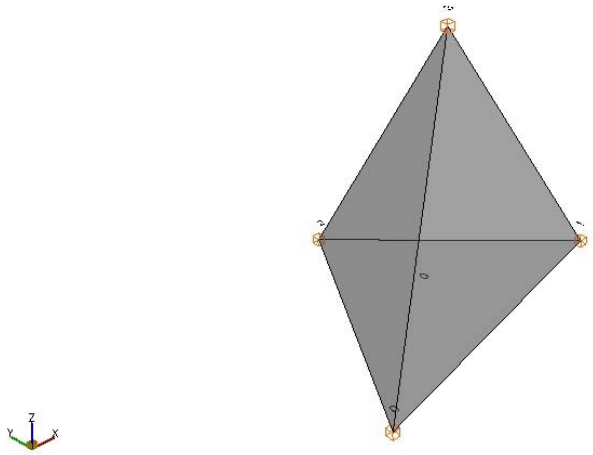


Figure – Element 30

Interpolation

Element has trilinear-Lagrange interpolation functions.

Degrees of Freedom

Global dofs (per node) are:

- u_x displacement
- u_y displacement
- u_z displacement

Local dofs (per node) are:

- u_1 displacement
- u_2 displacement
- u_3 displacement

Element Assignments

Mechanical Loading

Distributed global loads can be applied as follows:

- f_x force per unit volume (uniform)
- f_y force per unit volume (uniform)
- f_z force per unit volume (uniform)
- Gravity loading in global x, y or z direction

Distributed local loads can be applied as follows:

- f_1 force per unit volume (uniform)
- f_2 force per unit volume (uniform)
- f_3 force per unit volume (uniform)
- Gravity loading in local 1, 2 or 3 direction

Temperature Loading

Element can be loaded with constant temperature.

Additional Mass

Global additional element masses can be applied as follows:

- mu_x translational mass per unit volume
- mu_y translational mass per unit volume
- mu_z translational mass per unit volume

Local additional element masses can be applied as follows:

- mu_1 translational mass per unit volume
- mu_2 translational mass per unit volume

- mu_3 translational mass per unit volume

Additional Stiffness

Global additional element stiffness can be applied as follows:

- su_x translational stiffness per unit volume
- su_y translational stiffness per unit volume
- su_z translational stiffness per unit volume

Local additional element stiffness can be applied as follows:

- su_1 translational stiffness per unit volume
- su_2 translational stiffness per unit volume
- su_3 translational stiffness per unit volume

Element Output

Displacements

Element output displacements are:

- u_1 displacement
- u_2 displacement
- u_3 displacement

Strains

Element output strains are:

- ε_{11} normal strain
- ε_{22} normal strain
- ε_{33} normal strain
- ε_{12} shear strain
- ε_{13} shear strain
- ε_{23} shear strain

Stresses

Element output stresses are:

- σ_{11} normal stress
- σ_{22} normal stress
- σ_{33} normal stress
- σ_{12} shear stress
- σ_{13} shear stress
- σ_{23} shear stress

Forces

No internal element forces are available for this element.

Element 31 - Ten-node Solid Element

Element Characteristics

Mechanics

This is a three dimensional, tetrahedral, solid element. Isotropic or Orthotropic linear material models can be used with this element. Element stiffness, mass and stability matrices are evaluated by four-point Gaussian integration in each local direction.

Geometry and Nodes

Element has tetrahedral geometry and ten nodes with counterclockwise order starting from the vertex nodes. Three coordinates for each vertex node in global x, y and z direction are given as input.

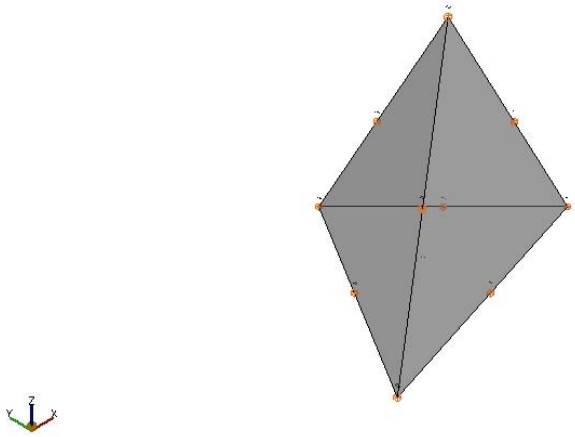


Figure – Element 31

Interpolation

Element has triquadratic-Lagrange interpolation functions.

Degrees of Freedom

Global dofs (per node) are:

- u_x displacement
- u_y displacement
- u_z displacement

Local dofs (per node) are:

- u_1 displacement
- u_2 displacement
- u_3 displacement

Element Assignments

Mechanical Loading

Distributed global loads can be applied as follows:

- f_x force per unit volume (uniform)
- f_y force per unit volume (uniform)
- f_z force per unit volume (uniform)
- Gravity loading in global x, y or z direction

Distributed local loads can be applied as follows:

- f_1 force per unit volume (uniform)
- f_2 force per unit volume (uniform)
- f_3 force per unit volume (uniform)
- Gravity loading in local 1, 2 or 3 direction

Temperature Loading

Element can be loaded with constant temperature.

Additional Mass

Global additional element masses can be applied as follows:

- mu_x translational mass per unit volume
- mu_y translational mass per unit volume
- mu_z translational mass per unit volume

Local additional element masses can be applied as follows:

- mu_1 translational mass per unit volume

- mu_2 translational mass per unit volume
- mu_3 translational mass per unit volume

Additional Stiffness

Global additional element stiffness can be applied as follows:

- su_x translational stiffness per unit volume
- su_y translational stiffness per unit volume
- su_z translational stiffness per unit volume

Local additional element stiffness can be applied as follows:

- su_1 translational stiffness per unit volume
- su_2 translational stiffness per unit volume
- su_3 translational stiffness per unit volume

Element Output

Displacements

Element output displacements are:

- u_1 displacement
- u_2 displacement
- u_3 displacement

Strains

Element output strains are:

- ε_{11} normal strain
- ε_{22} normal strain
- ε_{33} normal strain
- ε_{12} shear strain
- ε_{13} shear strain
- ε_{23} shear strain

Stresses

Element output stresses are:

- σ_{11} normal stress
- σ_{22} normal stress
- σ_{33} normal stress
- σ_{12} shear stress
- σ_{13} shear stress
- σ_{23} shear stress

Forces

No internal element forces are available for this element.