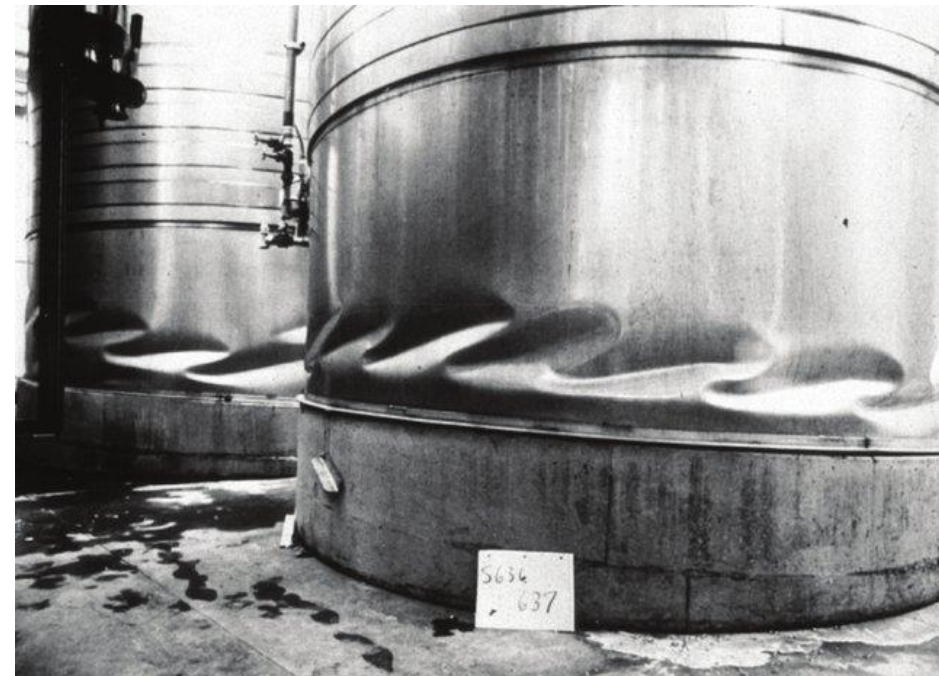




Finite Element Simulation For Mechanical Design

Buckling of thin cylindrical shells

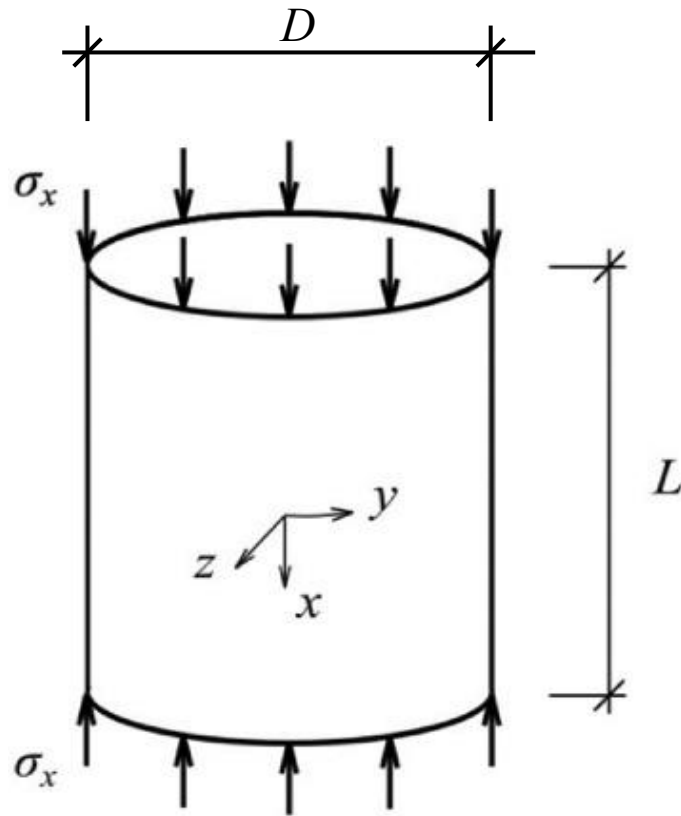
Prof. A. Bernasconi, Dr. L. M. Martulli





Complex phenomenon involving:

- Bifurcation of equilibrium

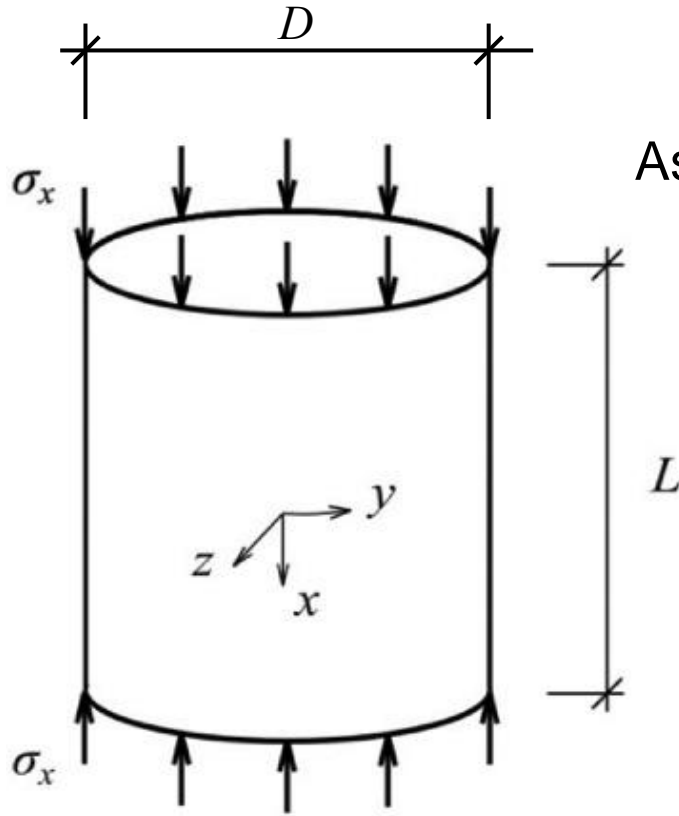


Global instability



Local instability

- Plasticity (for metals)

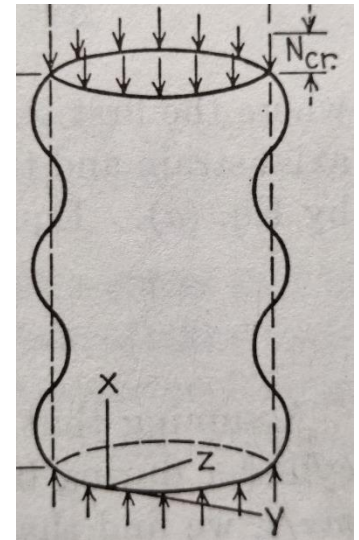


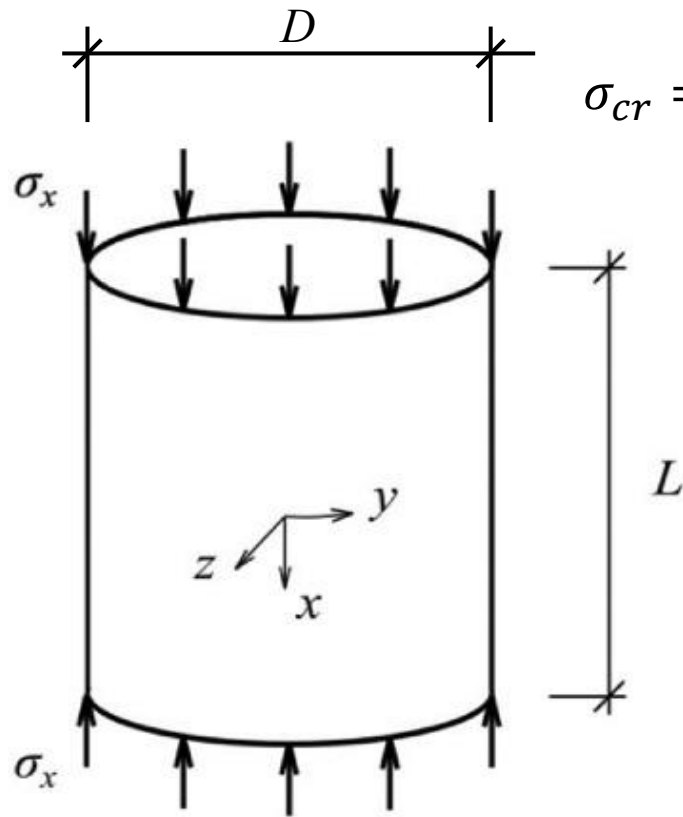
Assumption: $w = -A \sin\left(\frac{m\pi x}{L}\right)$
(axis-symmetric deformation)

$$\sigma_{cr} = \frac{Et}{r\sqrt{3(1-\nu^2)}}$$

Occurring at:

$$\frac{L}{m} = \pi \sqrt[4]{\frac{r^2 t^2}{12(1-\nu^2)}}$$





$$\sigma_{cr} = \frac{Et}{r\sqrt{3(1-\nu^2)}}$$

Occurring at:

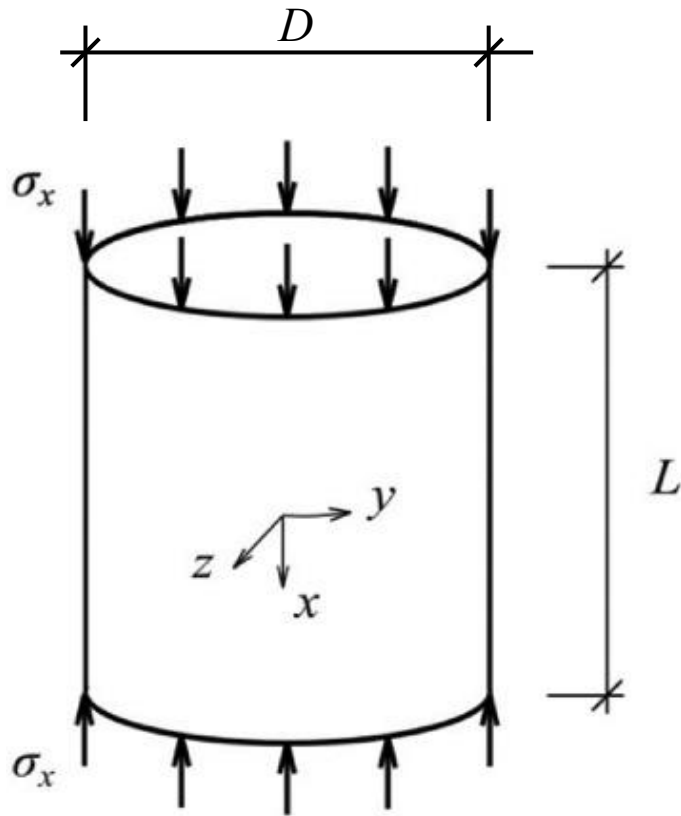
$$\frac{L}{m} = \pi \sqrt[4]{\frac{r^2 t^2}{12(1-\nu^2)}}$$

	A	B	C	D	E
1	r	250 mm			
2	t	2 mm			
3	E	72000 MPa			
4	nu	0.35			
5	L	500 mm			
6					
7	s_cr	355.0081 MPa			
8					
9	A	3141.593 mm^2	L/m		38.99669
10	P_cr	1115.29 kN	m		12.8216



Common settings

6



$D = 500$ mm (mid-diameter)

$L = 500$ mm

$t = 2$ mm

$E = 73100$ Mpa (Alu)

$\nu = 0.35$

Plastic

Hardening: Isotropic

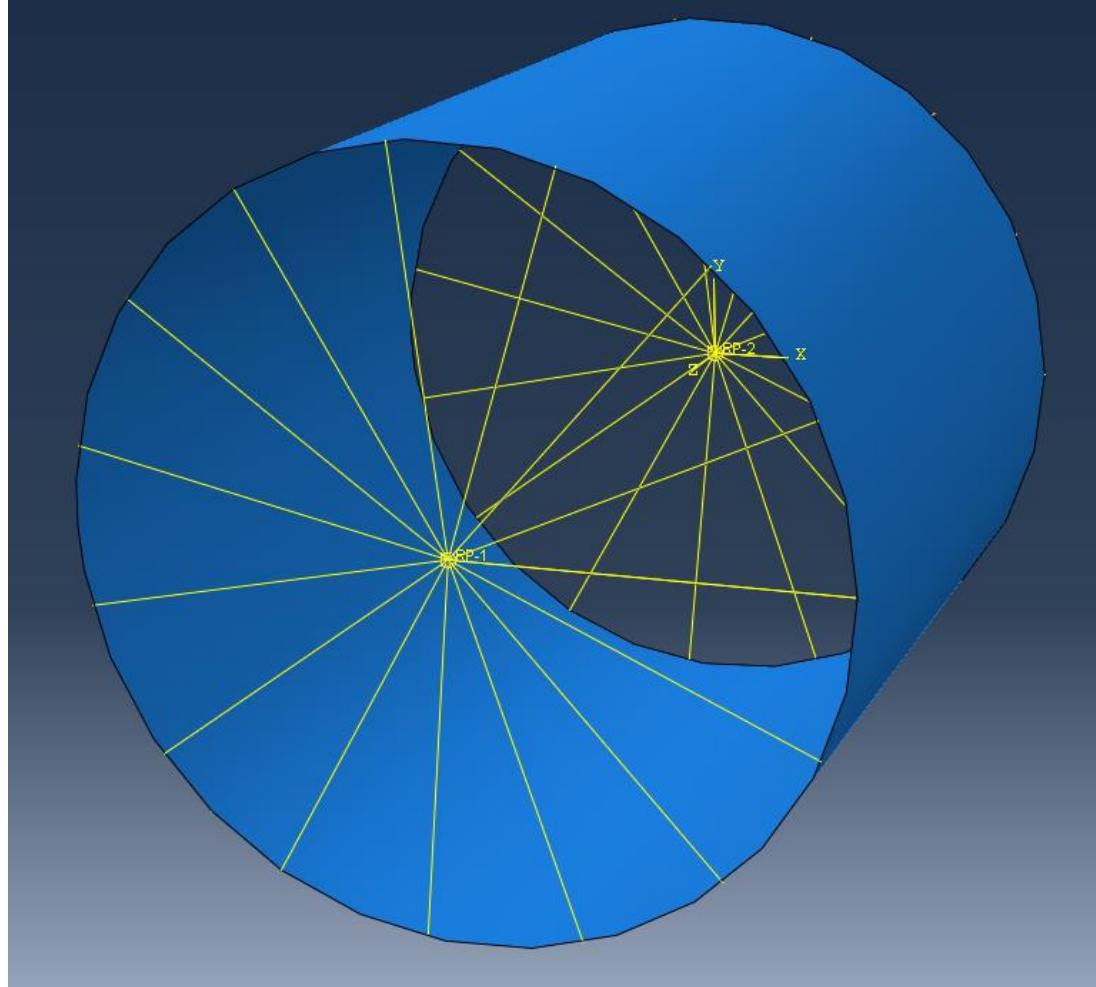
☐ Use strain-rate-dependent data

☐ Use temperature-dependent data

Number of field variables: 0

Data

	Yield Stress	Plastic Strain
1	160	0
2	340	0.3



Coupling edges with RPs

Encastrate one of the two RPs

LINEAR BUCKLING SIMULATIONS



Sim 1: Buckle simulation (coarse mesh)

9

Name: Step-1

Type: Buckle

Basic Other

Description:

NIgeom: Off

Eigsolver: ☐ Lanczos ☒ Subspace

Number of eigenvalues requested: 3

☐ Maximum eigenvalue of interest:

Vectors used per iteration: 6

Maximum number of iterations: 6500

Global Seeds

Sizing Controls

Approximate global size: 10

☒ Curvature control

Maximum deviation factor (0.0 < h/L < 1.0): 0.1

(Approximate number of elements per circle: 8)

Minimum size control

☒ By fraction of global size (0.0 < min < 1.0) 0.1

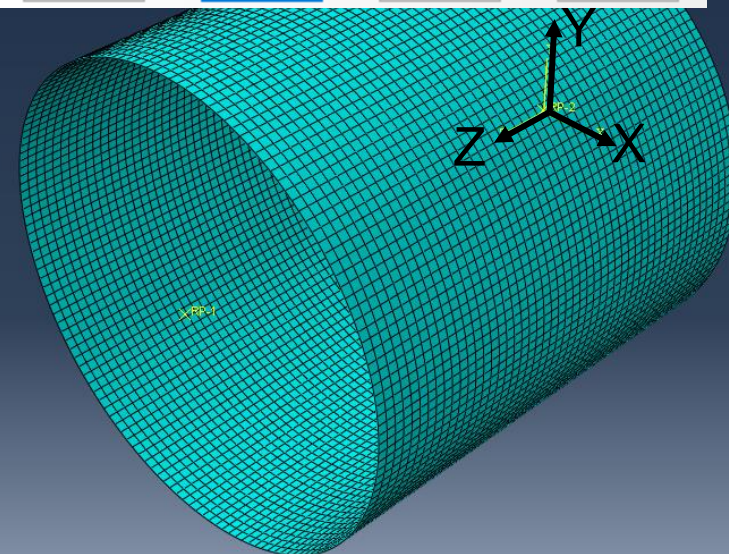
☐ By absolute value (0.0 < min < global size) 1

OK

Apply

Defaults

Cancel



On the free RP:

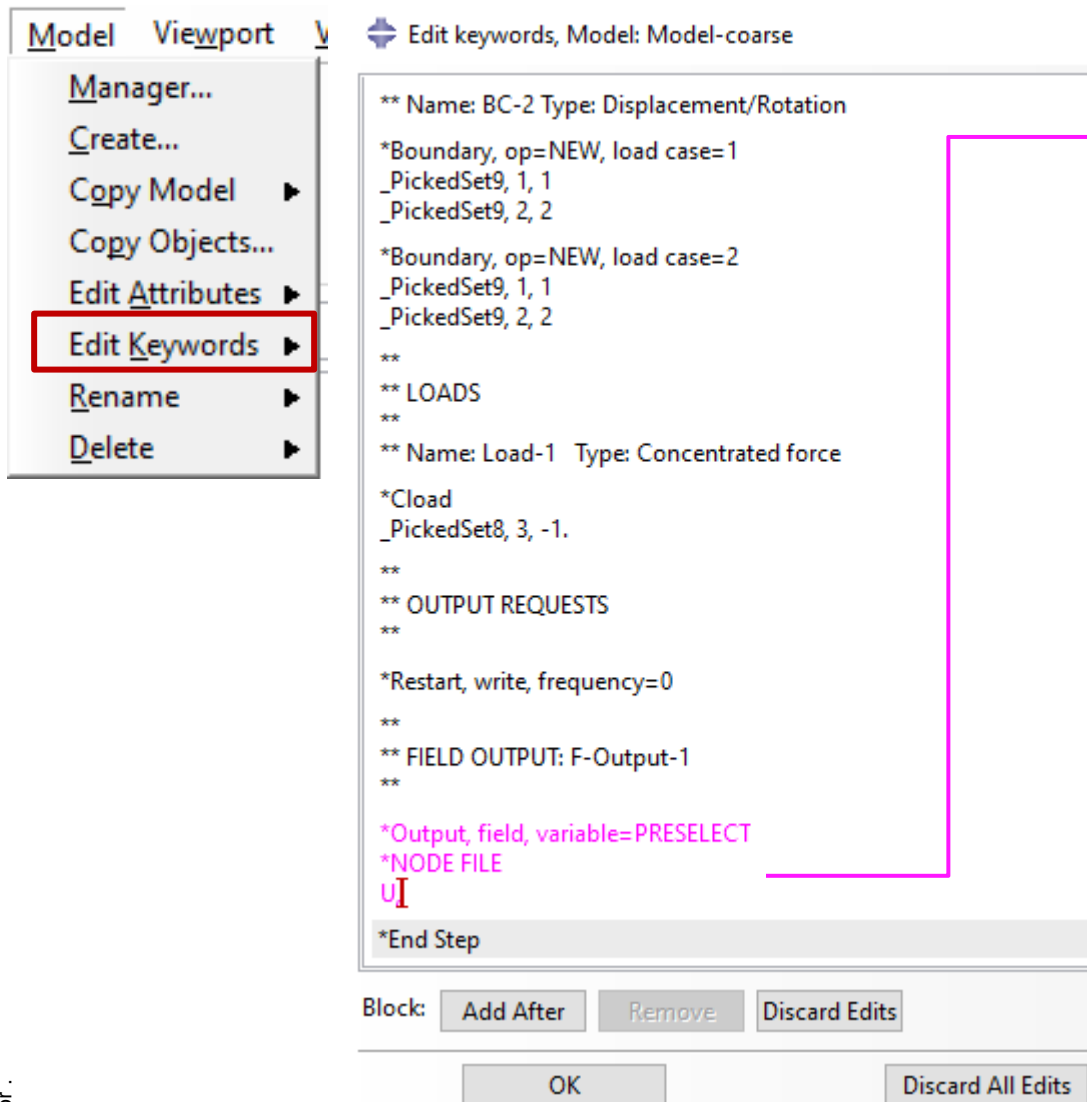
$$U_Y = U_Y = UR_X = UR_Y = UR_Z = 0$$

$$P_Z = -1$$



Sim 1: Buckle simulation (coarse mesh)

10



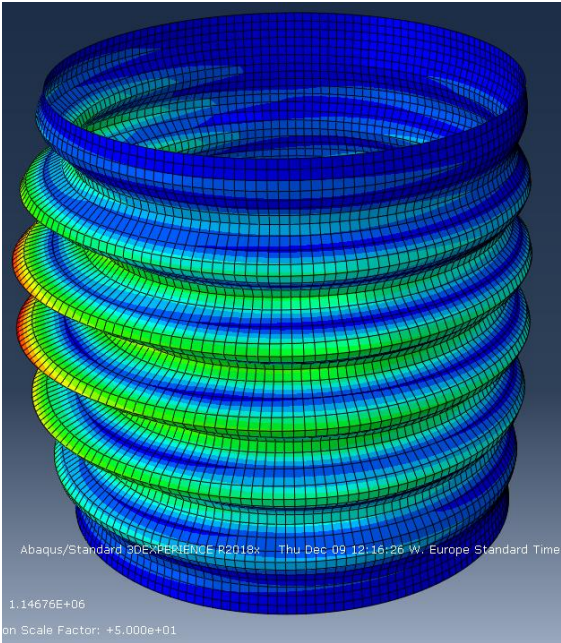
Abaqus will create a file (.fil) in which the nodal displacements will be stored.

Note: files with .fil extension are not editable with text editors

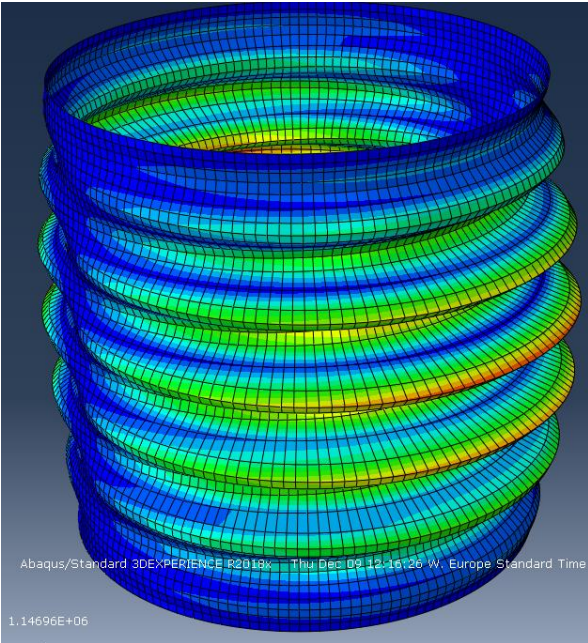


Sim 1: Buckle simulation (coarse mesh)

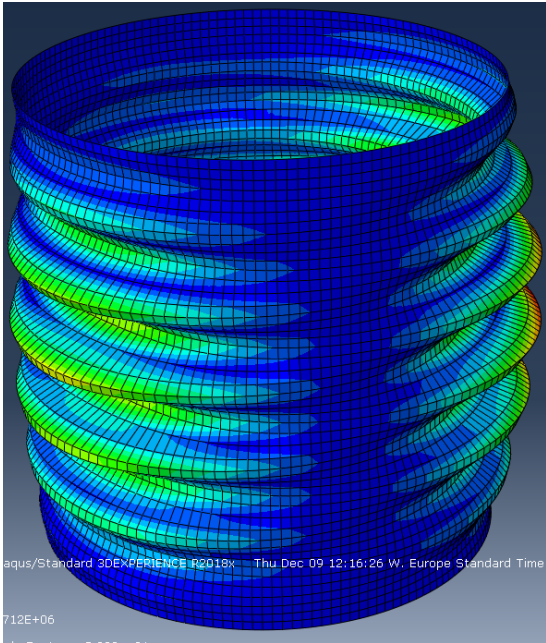
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Step: Step-1
Mode 1: EigenValue = 1.14676E+06



Step: Step-1
Mode 2: EigenValue = 1.14696E+06



Step: Step-1
Mode 3: EigenValue = 1.14712E+06

Lin_buckle.com	09/12/2021 12:04	MS-DOS Applicati...	3 KB
Lin_buckle.dat	09/12/2021 12:13	DAT File	9,016 KB
<input checked="" type="checkbox"/> Lin_buckle.fil	09/12/2021 12:13	FIL File	11,679 KB
Lin_buckle.inp	09/12/2021 12:03	INP File	2,594 KB
Lin_buckle.ipm	09/12/2021 12:13	IPM File	5 KB
Lin_buckle.log	09/12/2021 12:13	Text Document	1 KB
<input checked="" type="checkbox"/> Lin_buckle.msg	09/12/2021 12:13	Outlook Item	144 KB
Lin_buckle.odb	09/12/2021 12:13	ODB File	4,921 KB
Lin_buckle.prt	09/12/2021 12:13	PRT File	2,099 KB
Lin_buckle.sim	09/12/2021 12:13	SIM File	1,119 KB
Lin_buckle.sta	09/12/2021 12:13	STA File	1 KB



Analytical calculation:

10	P_{cr}	1115.29 kN	m	12.8216
----	----------	------------	---	---------



Sim 2: Buckle simulation (fine mesh)

12

Name: Step-1

Type: Buckle

Basic Other

Description:

Nonlinear: Off

Eigensolver: ☐ Lanczos ☒ Subspace

Number of eigenvalues requested: 3

☐ Maximum eigenvalue of interest:

Vectors used per iteration: 6

Maximum number of iterations: 6500

Global Seeds

Sizing Controls

Approximate global size: 5

☒ Curvature control

Maximum deviation factor (0.0 < h/L < 1.0): 0.1

(Approximate number of elements per circle: 8)

Minimum size control

☒ By fraction of global size (0.0 < min < 1.0) 0.1

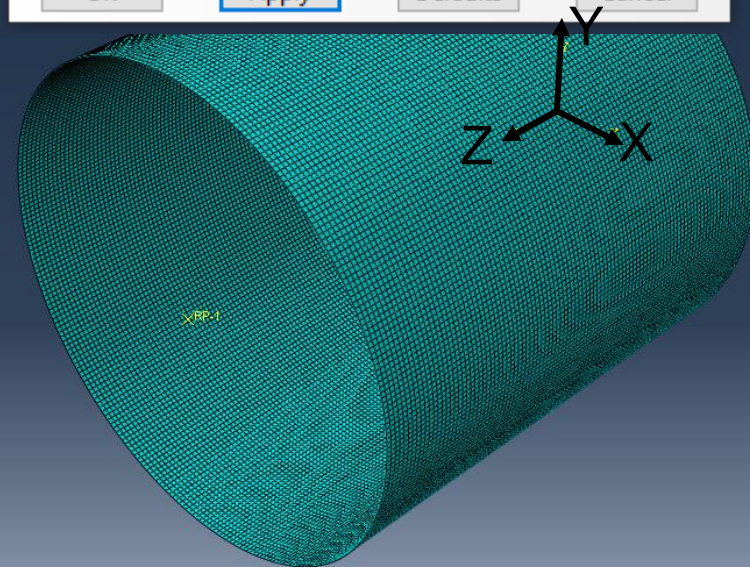
☐ By absolute value (0.0 < min < global size) 0.5

OK

Apply

Defaults

Cancel



On the free RP:

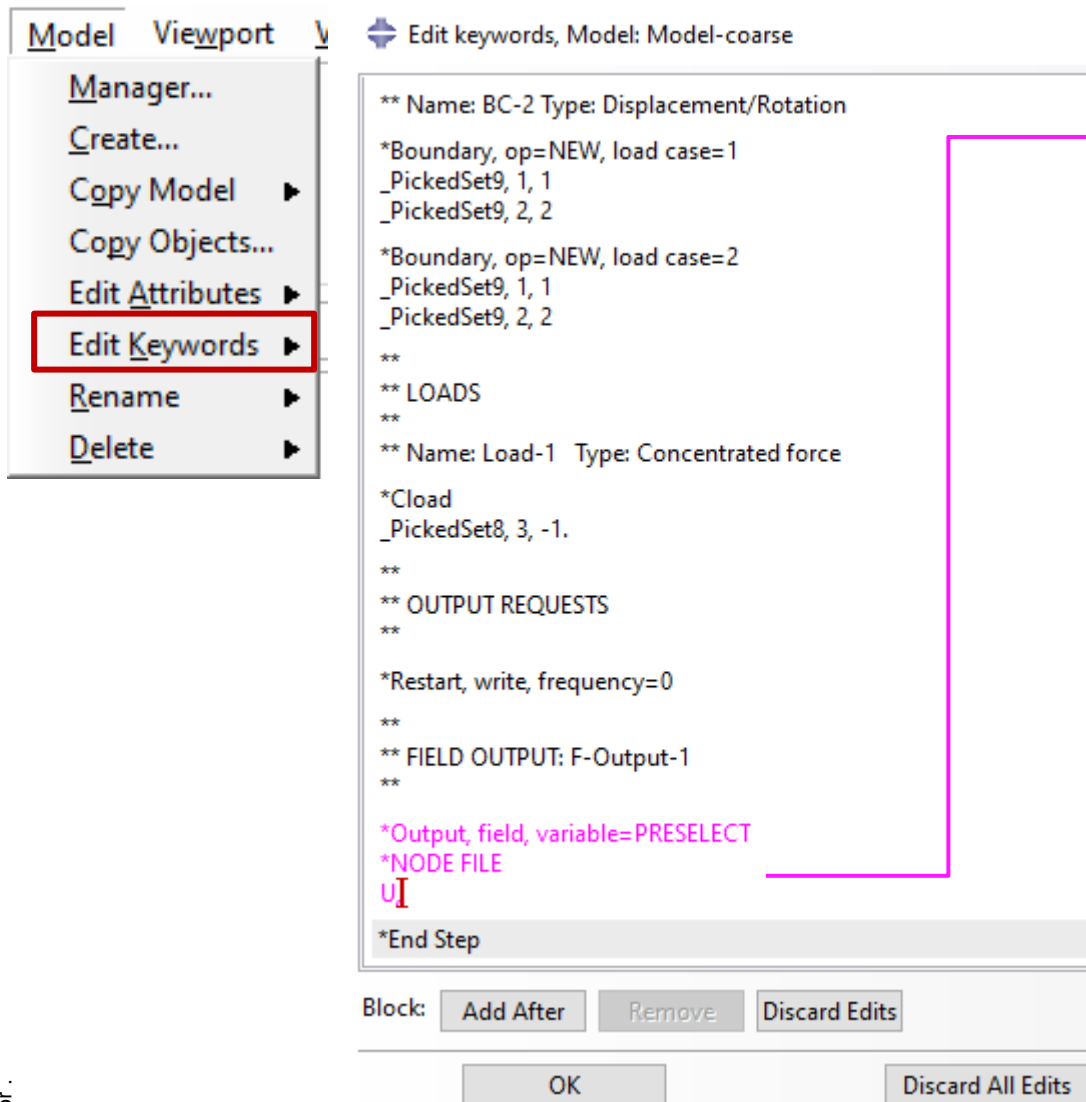
$$U_Y = U_Y = UR_X = UR_Y = UR_Z = 0$$

$$P_Z = -1$$



Sim 2: Buckle simulation (fine mesh)

13



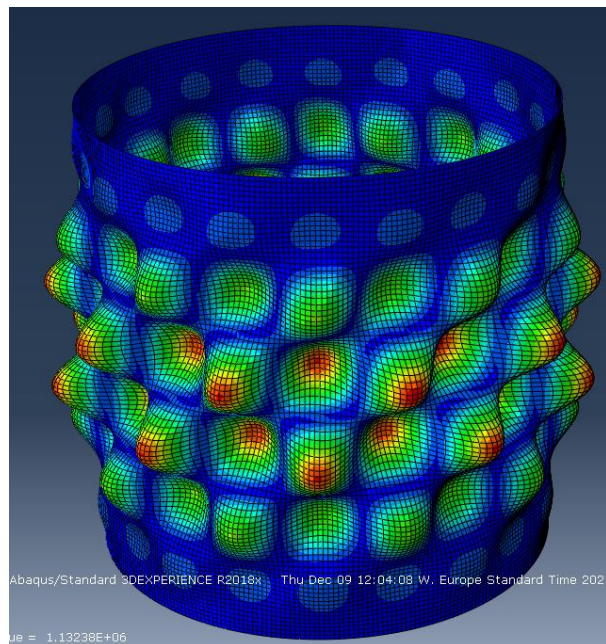
Abaqus will create a file (.fil) in which the nodal displacements will be stored.

Note: files with .fil extension are not editable with text editors

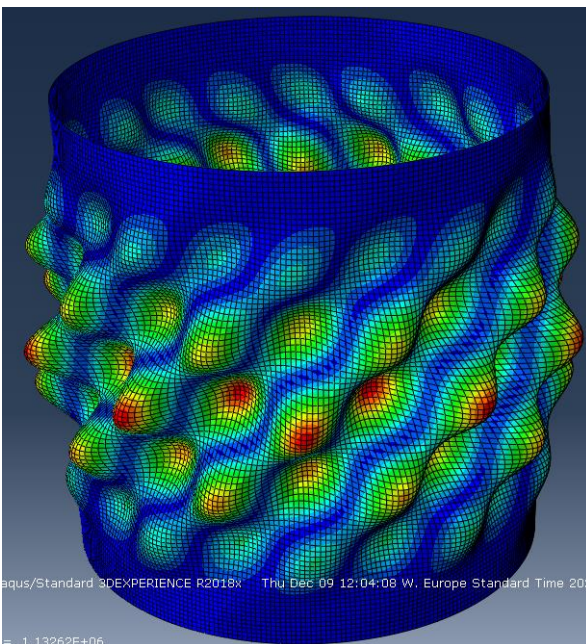


Sim 2: Buckle simulation (fine mesh)

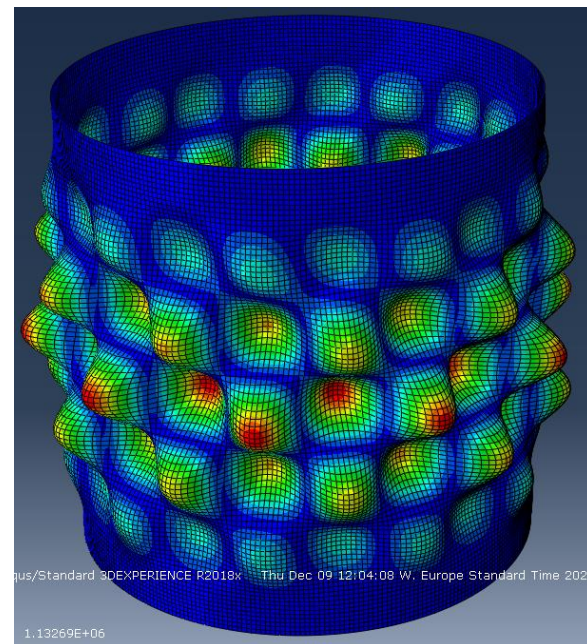
14



Step: Step-1
Mode 1: EigenValue = 1.13238E+06



Step: Step-1
Mode 2: EigenValue = 1.13262E+06



Step: Step-1
Mode 3: EigenValue = 1.13269E+06

Previous values with coarse mesh:

Step: Step-1
Mode 1: EigenValue = 1.14676E+06

Step: Step-1
Mode 2: EigenValue = 1.14696E+06

Step: Step-1
Mode 3: EigenValue = 1.14712E+06

Analytical calculation:

10 P_{cr}

1115.29 kN

NASA/SP-8007-2020/REV 2



Buckling of Thin-Walled Circular Cylinders

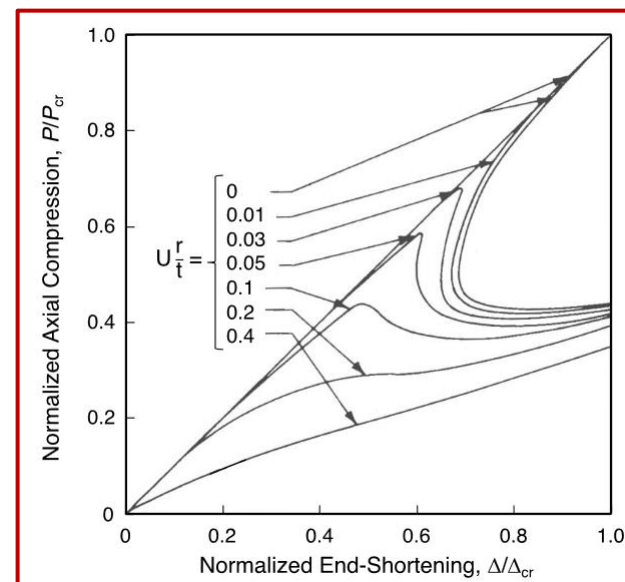
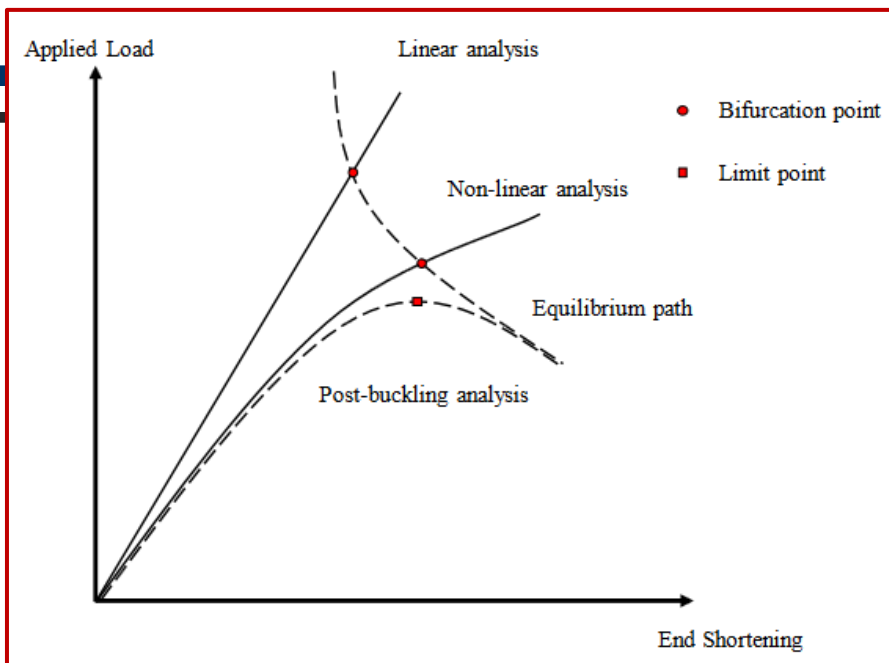
September 1965

August 1968 – first revision

November 2020 – second revision

National Aeronautics and
Space Administration

Langley Research Center
Hampton, Virginia 23681-2199

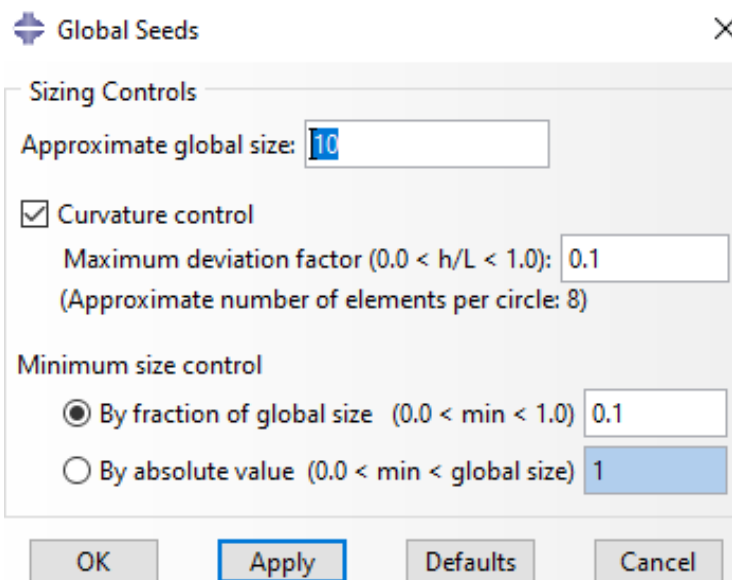


NON-LINEAR CRUSHING SIMULATIONS WITH IMPERFECTIONS



Sim 3: Non-linear crushing (coarse)

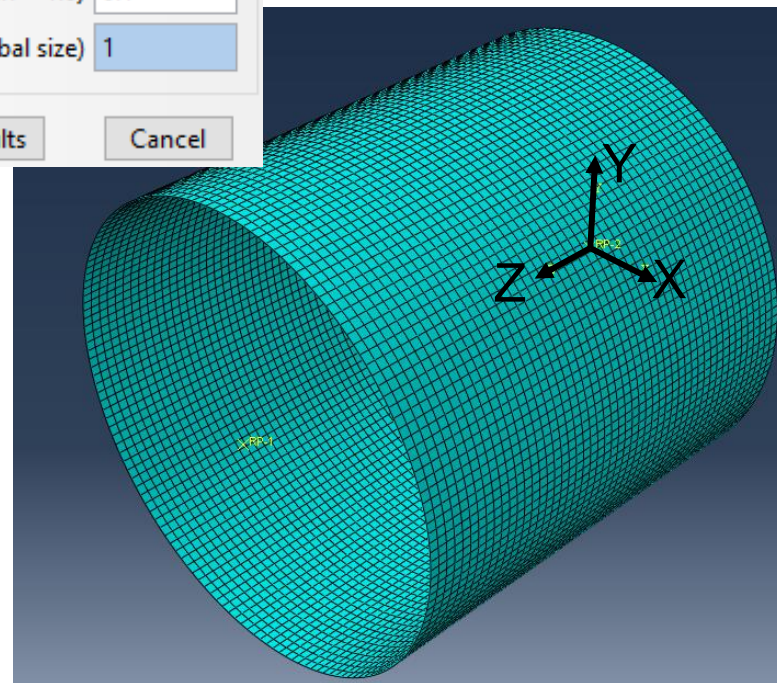
17



On the free RP:

$$U_Y = U_Y = UR_X = UR_Y = UR_Z = 0$$


$$P_z = -1.2E+06$$





Sim 3: Non-linear crushing (coarse)

18


 Edit Step

Name: Step-1

Type: Static, Riks

Basic Incrementation Other

Description:

Nlgeom: On 

☐ Include adiabatic heating effects

Stopping criteria

☐ Maximum load proportionality factor:

☐ Maximum displacement: DOF:

Node Region:

Name: Step-1

Type: Static, Riks

Basic Incrementation Other

Type: ☒ Automatic ☐ Fixed

Maximum number of increments: 1000

	Initial	Minimum	Maximum
Arc length increment	0.001	1E-05	1

Estimated total arc length: 1

Note: Used only to compute the initial load proportionality factor



Sim 3: Non-linear crushing (coarse)

19

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Edit Contact Property ✕

Name: IntProp-1

Contact Property Options

Tangential Behavior

Normal Behavior

Mechanical Thermal Electrical

Tangential Behavior

Friction formulation: Frictionless

Name: IntProp-1

Contact Property Options

Tangential Behavior

Normal Behavior

Mechanical Thermal Electrical

Normal Behavior

Pressure-Overclosure: "Hard" Contact

Constraint enforcement method: Default

☒ Allow separation after contact

Edit Interaction ✕

Name: Int-1

Type: General contact (Standard)

Step: Step-1 (Static, Riks)

Contact Domain

Included surface pairs:

☒ All* with self

☐ Selected surface pairs: None

Excluded surface pairs: None

* "All" includes all exterior faces and feature edges. It excludes analytical rigid surfaces, beam segments, and reference points.

Attribute Assignments

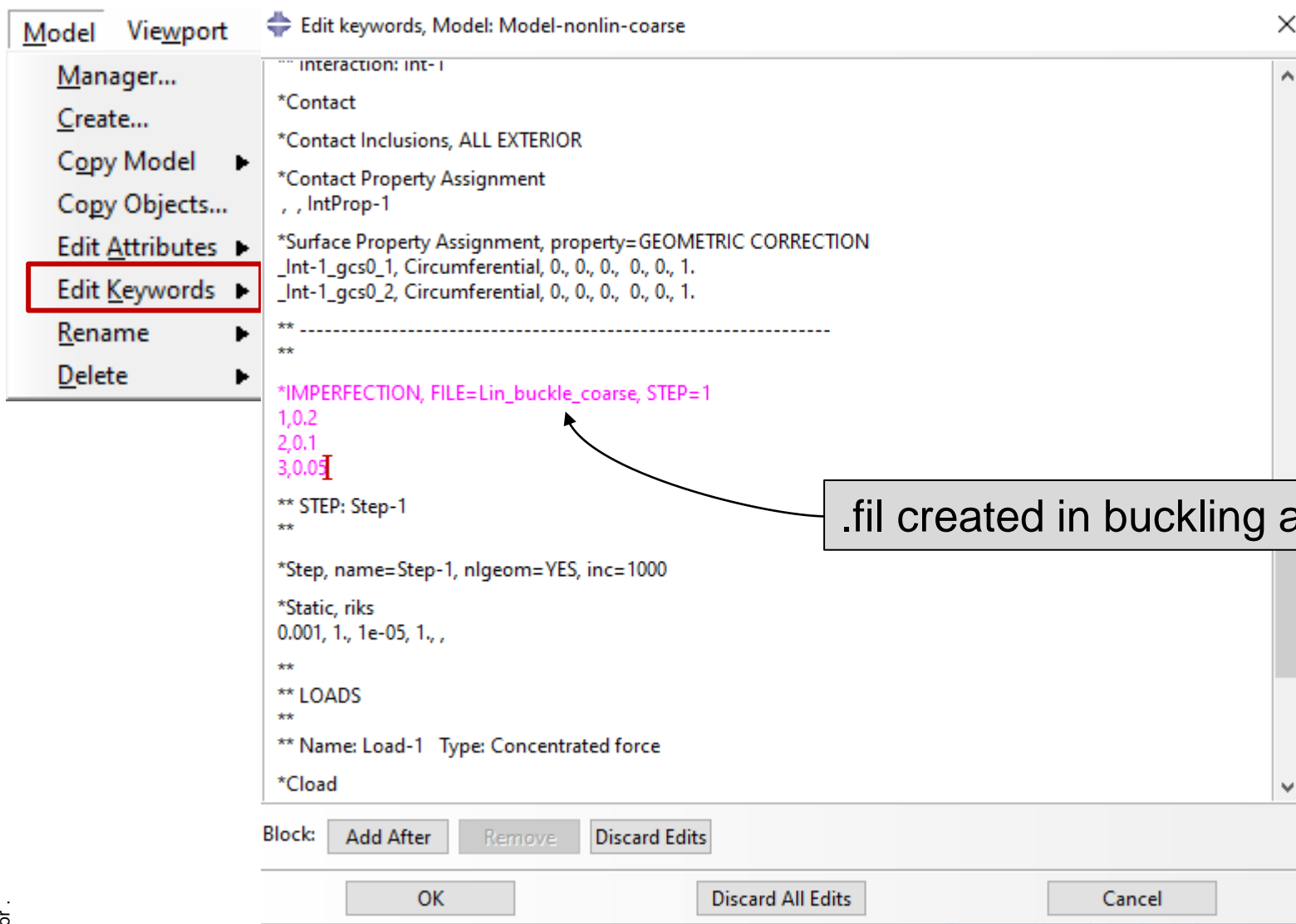
Contact Properties	Surface Properties	Contact Formulation
Global property assignment: IntProp-1	Individual property assignments: None	Initialization assignments: None
	Stabilization assignments: None	

OK Cancel



Sim 3: Non-linear crushing (coarse)

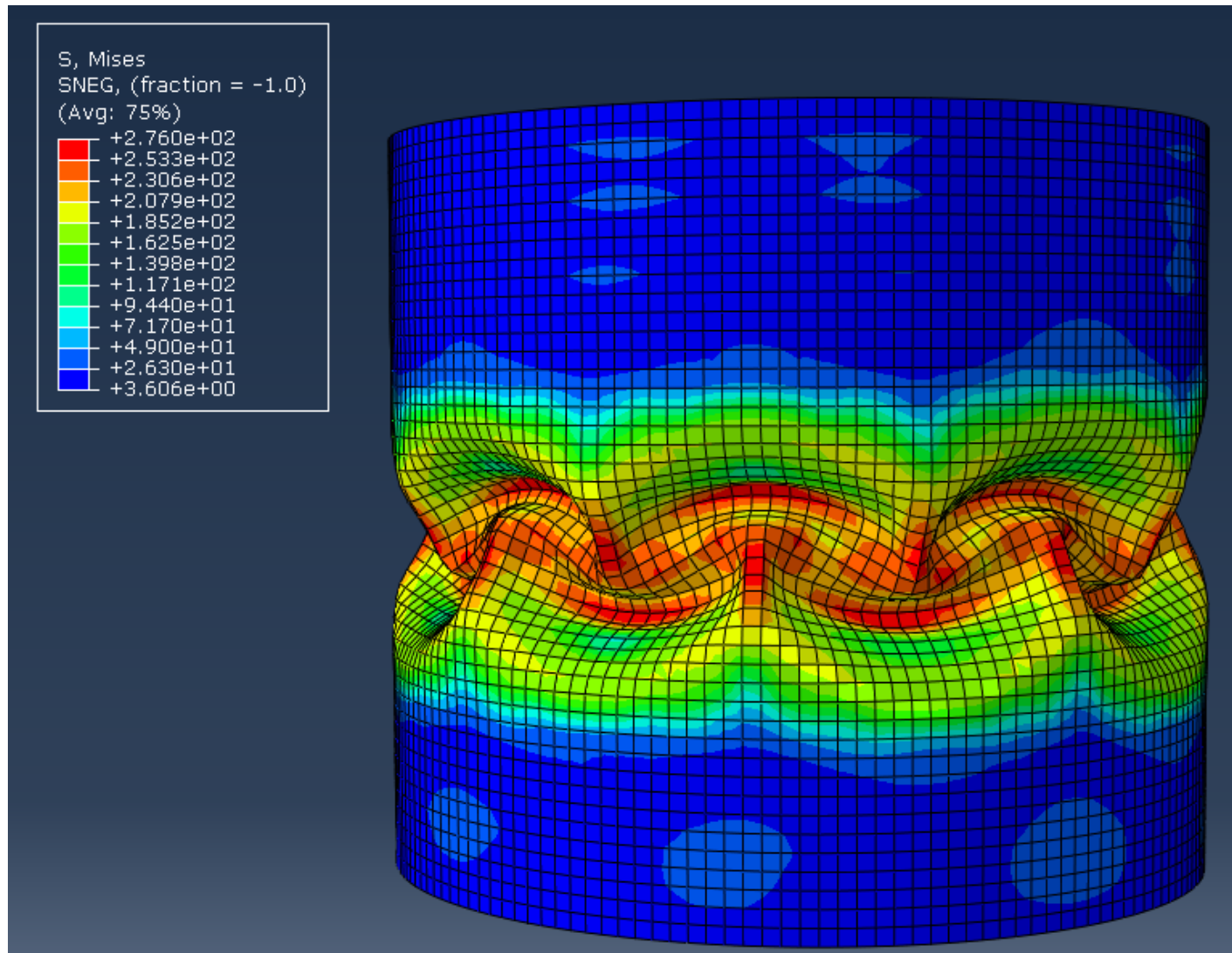
20





Sim 3: Non-linear crushing (coarse)

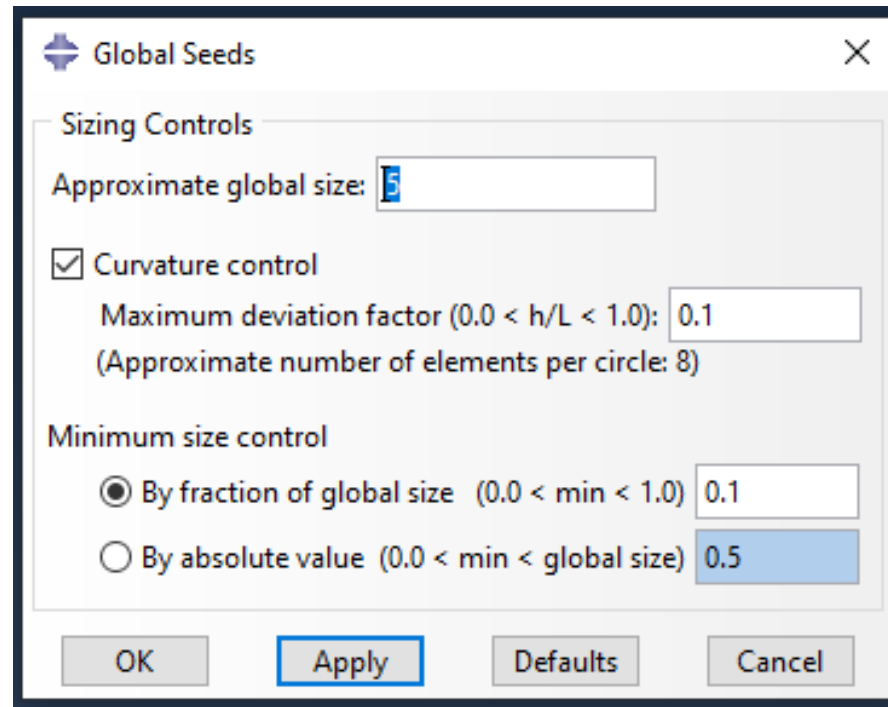
21





Sim 4: Non-linear crushing (fine)

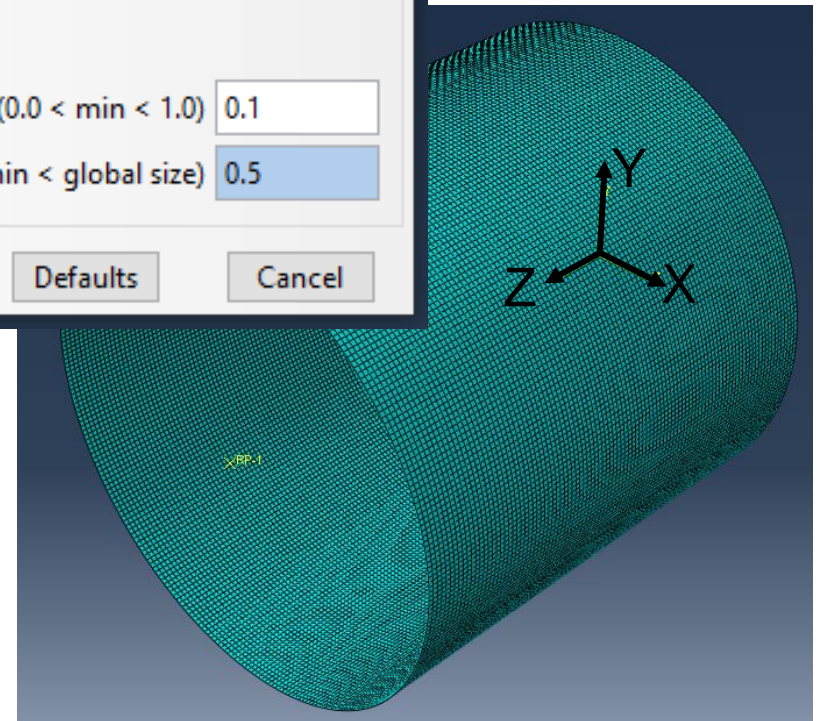
22



On the free RP:

$$U_Y = U_Y = UR_X = UR_Y = UR_Z = 0$$


$$P_z = -1.2E+06$$





Sim 4: Non-linear crushing (fine)

23


 Edit Step

Name: Step-1

Type: Static, Riks

Basic Incrementation Other

Description:

Nlgeom: On 

☐ Include adiabatic heating effects

Stopping criteria

☐ Maximum load proportionality factor:

☐ Maximum displacement:

DOF:

Node Region:

Name: Step-1

Type: Static, Riks

Basic Incrementation Other

Type: ☒ Automatic ☐ Fixed

Maximum number of increments: 1000

	Initial	Minimum	Maximum
Arc length increment	0.001	1E-05	1

Estimated total arc length: 1

Note: Used only to compute the initial load proportionality factor



Sim 4: Non-linear crushing (fine)

24

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Edit Contact Property ✕

Name: IntProp-1

Contact Property Options

Tangential Behavior

Normal Behavior

Mechanical

Thermal

Electrical

Tangential Behavior

Friction formulation:

Frictionless

Name: IntProp-1

Contact Property Options

Tangential Behavior

Normal Behavior

Mechanical

Thermal

Electrical

Normal Behavior

Pressure-Overclosure:

"Hard" Contact

Constraint enforcement method:

Default

☒ Allow separation after contact

Edit Interaction ✕

Name: Int-1

Type: General contact (Standard)

Step: Step-1 (Static, Riks)

Contact Domain

Included surface pairs:
☒ All* with self
☐ Selected surface pairs: None

Excluded surface pairs: None

* "All" includes all exterior faces and feature edges. It excludes analytical rigid surfaces, beam segments, and reference points.

Attribute Assignments

Contact Properties

Surface Properties

Contact Formulation

Global property assignment:

IntProp-1

Individual property assignments: None

Initialization assignments: None

Stabilization assignments: None

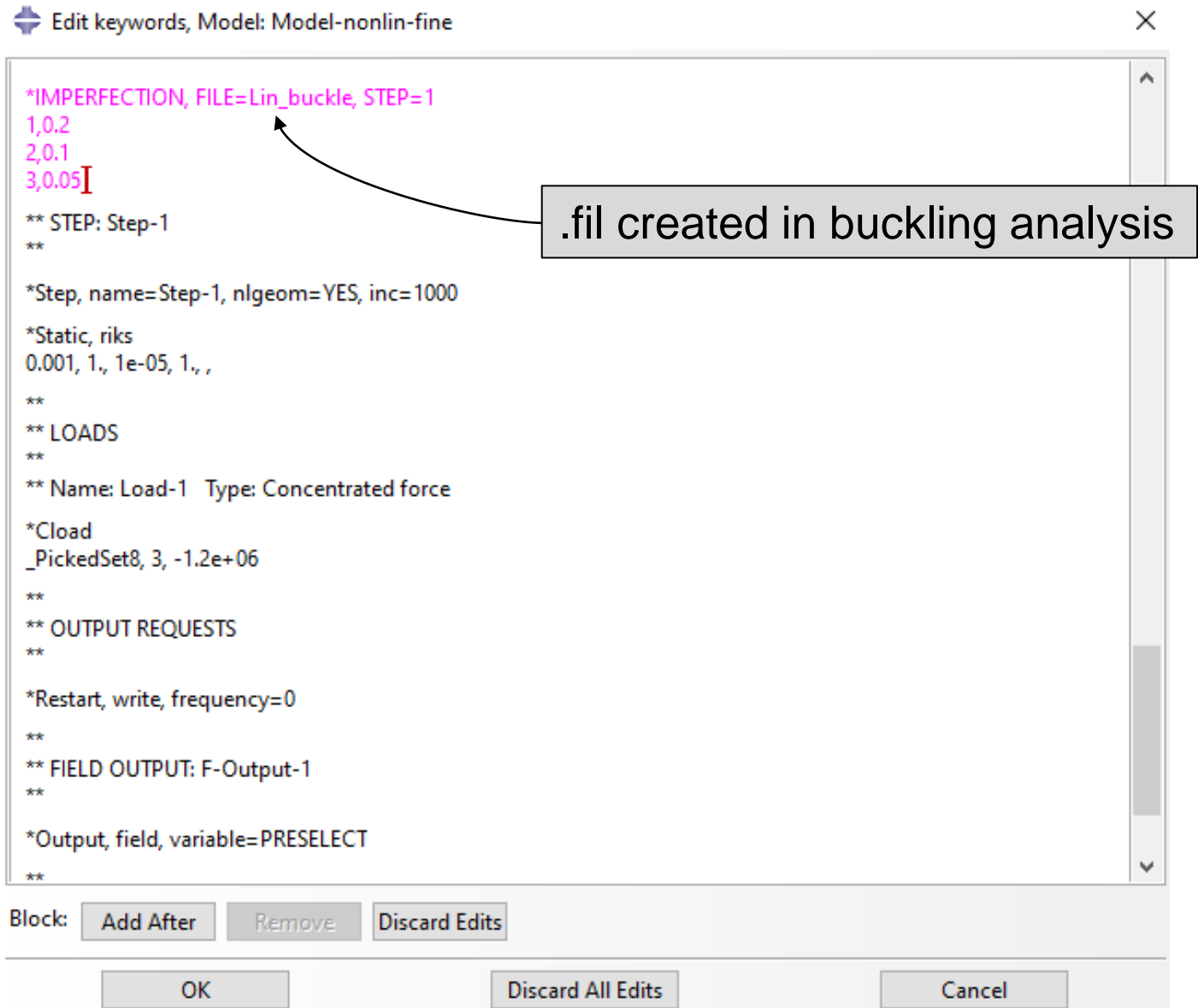
OK

Cancel



Sim 4: Non-linear crushing (fine)

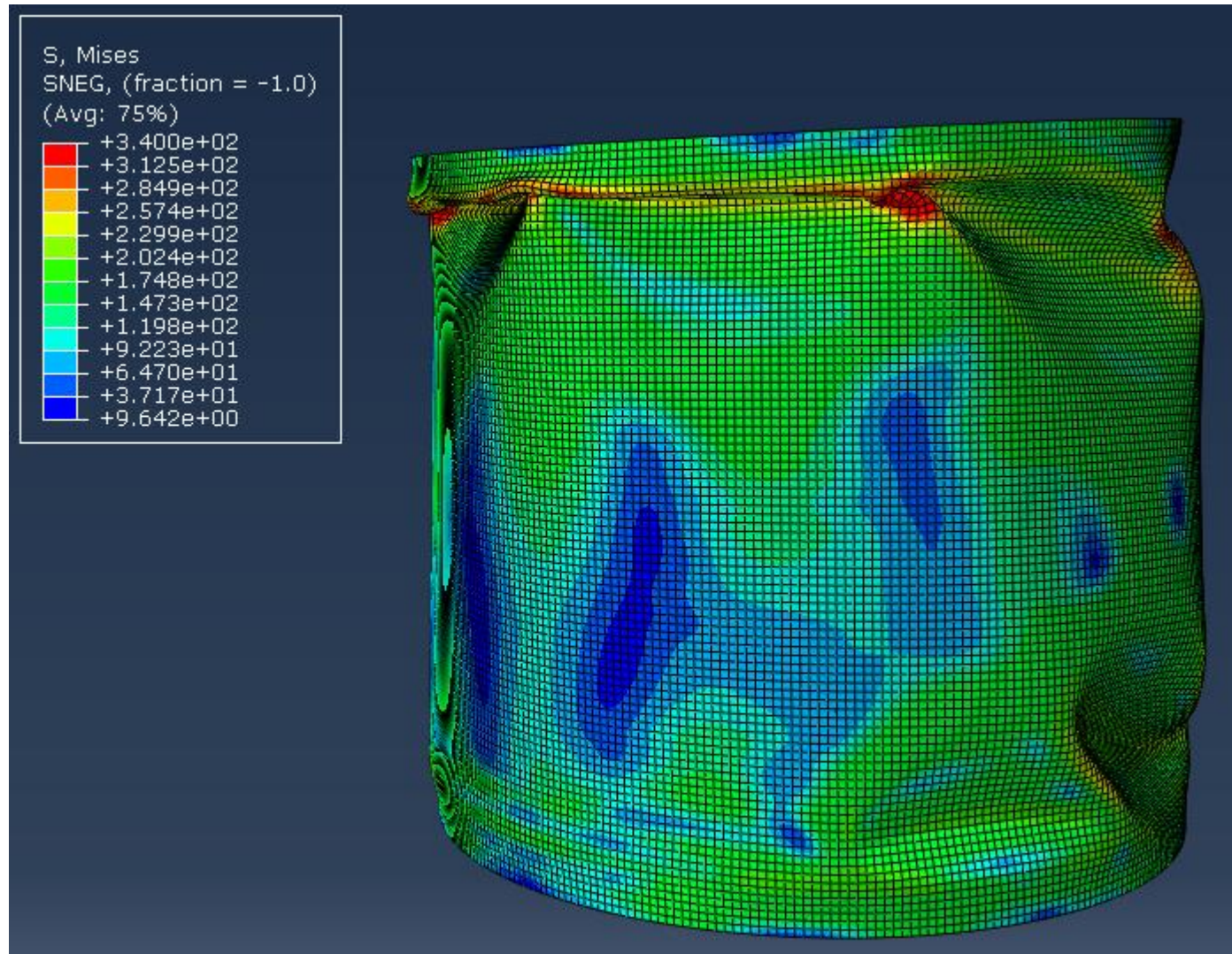
25





Sim 4: Non-linear crushing (fine)

26





Comparison of solutions

27

