

FEM METHOD VALIDATION

PrePoMax + CalculiX on five standard benchmarks

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Scope

Solver	CalculiX
Pre / post-processor	PrePoMax
Benchmarks	Four NAFEMS tests (TNSB Rev. 3) and one Code_Aster test (SSNV104)
Analysis types	Linear elastic static (3D solids); plane stress (shell elements); nonlinear contact; thermo-mechanical; modal
Unit system	mm, MPa, N; tonne for mass; °C for temperature
Reported value	Finest verified discretisation, provided the solution is physically admissible
Reading method	Nodal query on the solved model, shown in the corresponding figure

Summary of results

Case	Benchmark	Analysis type and validated output	Reference	Computed	Deviation
1	NAFEMS LE10	Linear elastic, 3D solids — σ_{yy} at D	-5.38 MPa	-5.354 MPa	-0.48%
2	NAFEMS LE1	Plane stress, shell elements — σ_{yy} at D	+92.7 MPa	92.56 MPa	-0.15%
3	SSNV104	Nonlinear contact — σ_{zz} at contact pole	-2798.3 MPa	-3024 MPa	+8.1%
4	NAFEMS LE11	Thermo-mechanical, 3D solids — σ_{zz} at A	-105 MPa	-104.9 MPa	-0.1%
5	NAFEMS FV32	Modal — first six natural frequencies	44.623 to 391.44 Hz	44.62433 to 391.4510 Hz	+0.001% to +0.049%

Note — In case 1 convergence is not monotonic: the coarser discretisation returns -5.379 MPa (-0.02%). In case 3 the reported run is not the closest to the reference; see the case for the admissibility criterion.

Case 1 — NAFEMS LE10: Thick plate under pressure

Analysis type	Linear elastic static, 3D solids
Elements tested	Second-order tetrahedra
Features tested	Double symmetry; uniform pressure load; stress output on a constrained edge
Geometry	Outer ellipse $(x/3.25)^2 + (y/2.75)^2 = 1$; inner ellipse $(x/2)^2 + y^2 = 1$; thickness 0.6 m (600 mm), fully modelled; one quarter modelled by double symmetry
Material	$E = 210000 \text{ MPa}$; $\nu = 0.3$
Boundary conditions	Face DCD'C': $u_y = 0$. Face ABA'B': $u_x = 0$. Face BCB'C': $u_x = 0$, $u_y = 0$. Mid-plane: $u_z = 0$
Loading	Uniform pressure of 1 MPa on the upper surface
Units	mm, MPa, N
Validated output	σ_{yy} (S22) at point D, coordinates (2000, 0, 600), upper surface
Reference value	-5.38 MPa — NAFEMS TNSB Rev. 3, test LE10

Results

Run	Element	Order	Nodes	σ_{yy} [MPa]	Deviation
v1	Tetrahedra	2nd	30,000	-5.379	-0.02%
v2	Tetrahedra	2nd	300,000	-5.354	-0.48%

Note — Convergence is not monotonic. Point D lies on an edge where the nature of the constraint changes; the deviation ranges between 0.02% and 0.48% with mesh refinement.

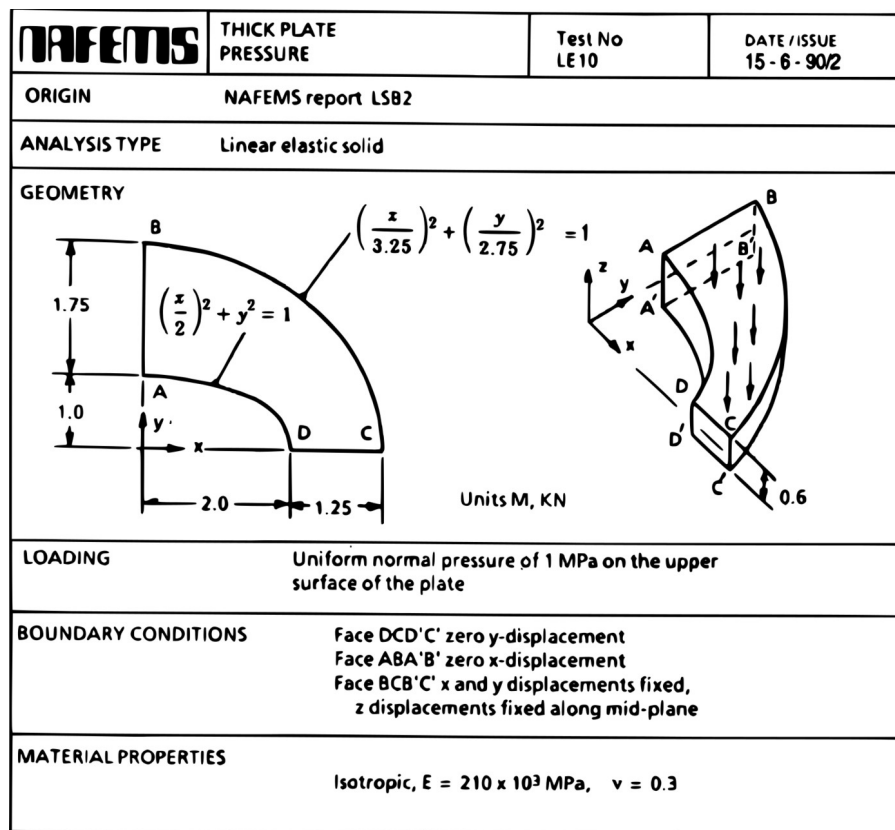


Figure 1 — NAFEMS LE10 benchmark sheet: geometry, points A/B/C/D, loading and boundary conditions. Source: seamless.com/finno/cases/012-nafems-le10/.

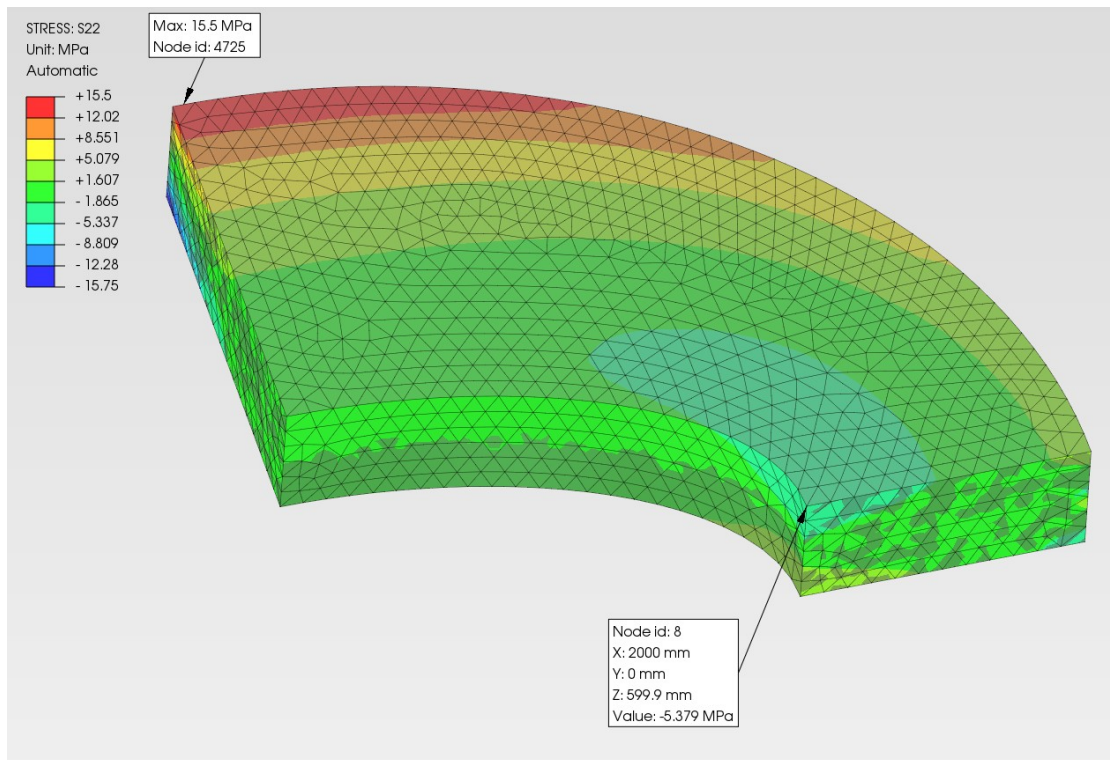


Figure 2 — run v1, 30,000-node mesh: S22 field and nodal query at point D, -5.379 MPa.

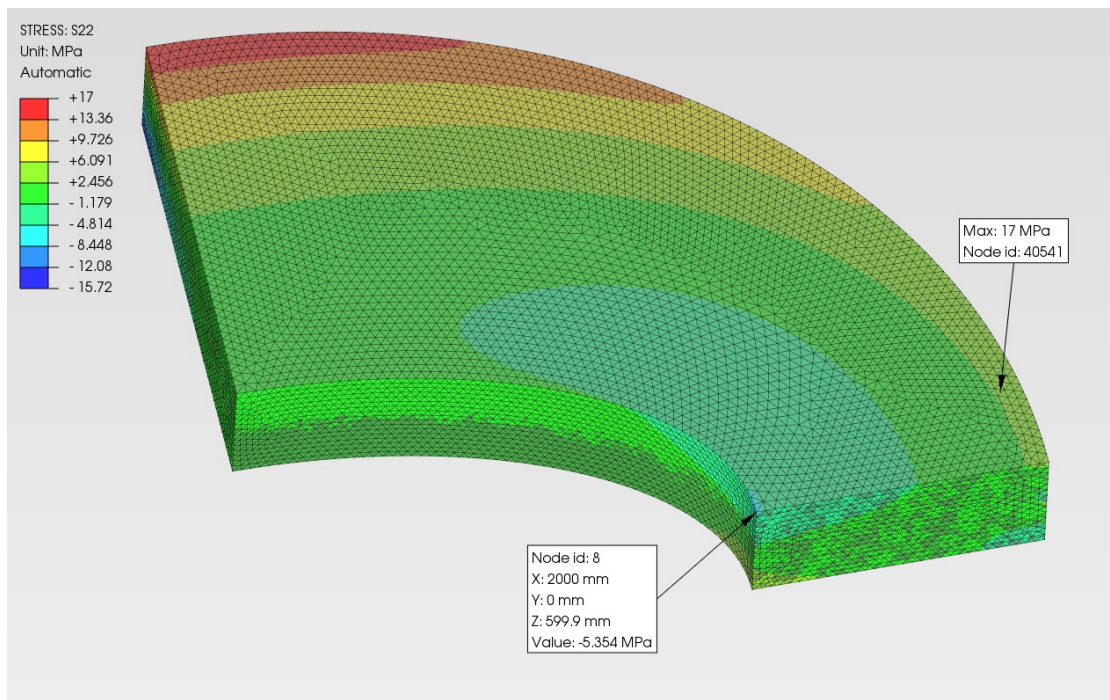


Figure 3 — run v2, 300,000-node mesh: nodal query at the same point D, -5.354 MPa.

Case 2 — NAFEMS LE1: Elliptic membrane, plane stress

Analysis type	Linear elastic static, plane stress
Elements tested	Tria3 and Tria6 shell elements
Features tested	Element order at constant mesh; stress concentration on a curved edge; edge traction on shells
Geometry	Outer ellipse semi-axes 3250 and 2750 mm; inner ellipse semi-axes 2000 and 1000 mm; thickness 0.1 m (100 mm) declared in the section; one quarter modelled by double symmetry
Vertices	A (0, 1000); B (0, 2750); C (3250, 0); D (2000, 0)
Material	E = 210000 MPa; $\nu = 0.3$
Boundary conditions	Edge AB (x = 0): $u_x = 0$. Edge CD (y = 0): $u_y = 0$. Surface: $u_z = 0$
Loading	Uniform outward traction of 10 MPa on outer edge BC, applied as a normal shell edge load of 1000 N/mm (10 MPa $\times$ 100 mm thickness)
Units	mm, MPa, N
Validated output	σ_{yy} (S22) at point D, coordinates (2000, 0)
Reference value	+92.7 MPa — NAFEMS TNSB Rev. 3, test LE1

Results

Run	Element	Order	Nodes	σ_{yy} [MPa]	Deviation
v4	Tria3	1st	2,000	67.64	-27.0%
v1	Tria6	2nd	2,000	88.03	-5.0%
v2	Tria6	2nd	8,000	91.48	-1.3%
v3	Tria6	2nd	50,000	92.56	-0.15%

Note — Runs v4 and v1 share the same mesh and differ only in element order. Convergence is monotonic from below; the four runs were repeated in two separate sessions and returned values identical to the second decimal place.

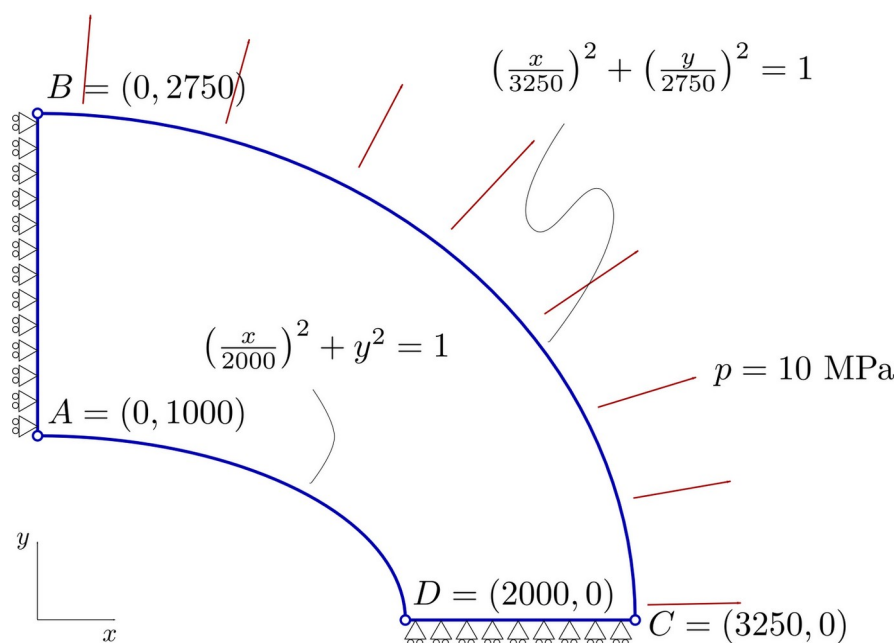


Figure 4 — NAFEMS LE1 geometry: the two ellipses, points A, B, C, D, symmetry constraints and the 10 MPa traction on the outer edge.

Source: seamless.com/finno/cases/010-nafems-le1/.

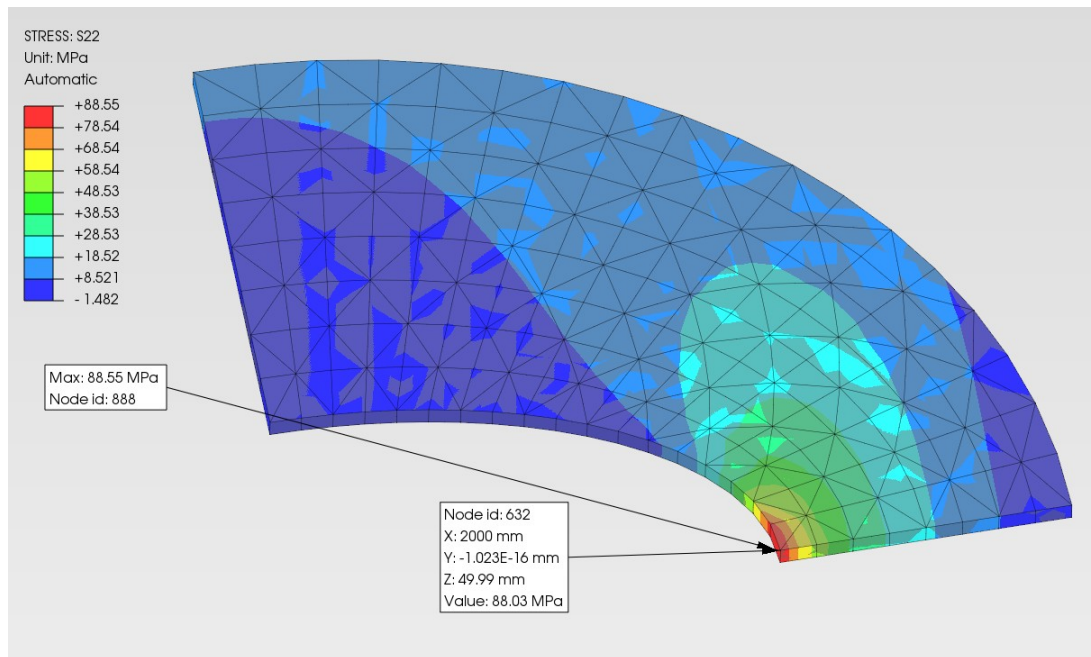


Figure 5 — run v1, Tria6 on 2,000 nodes: 88.03 MPa.

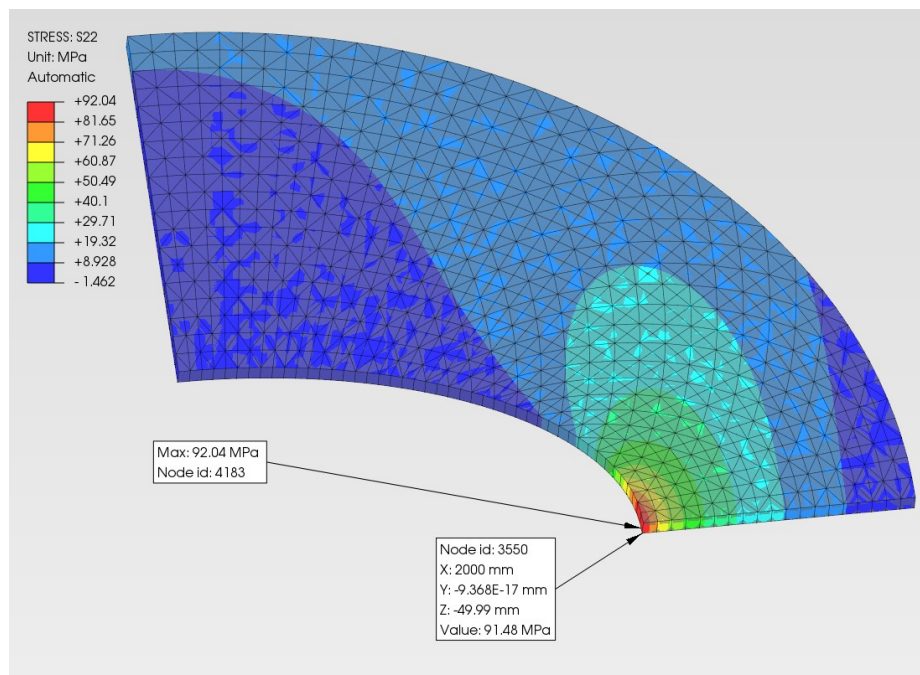


Figure 6 — run v2, Tria6 on 8,000 nodes: 91.48 MPa.

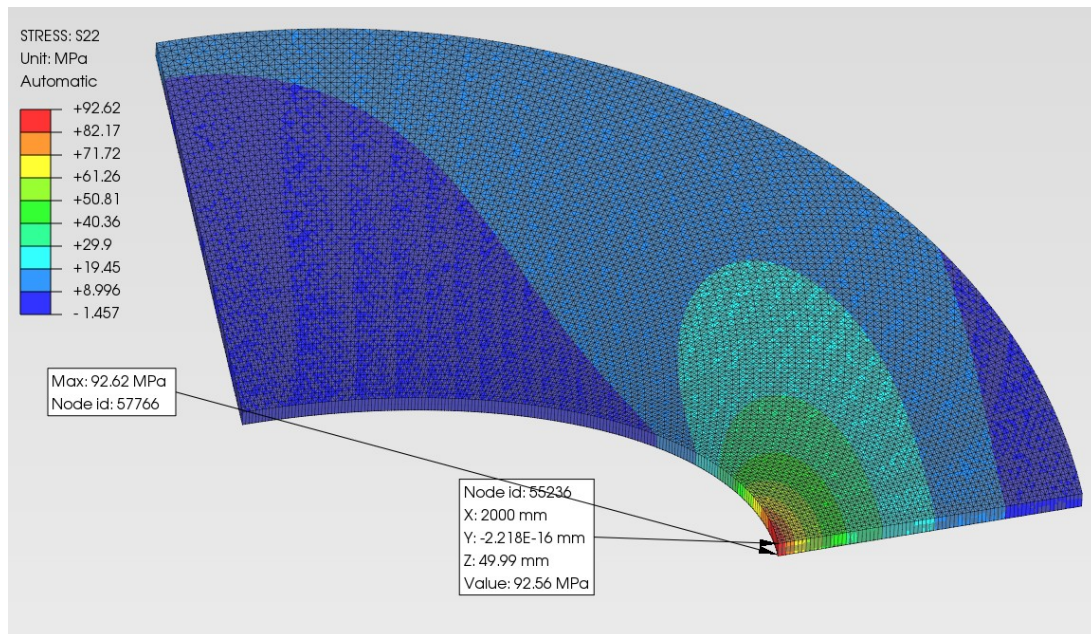


Figure 7 — run v3, Tria6 on 50,000 nodes: 92.56 MPa.

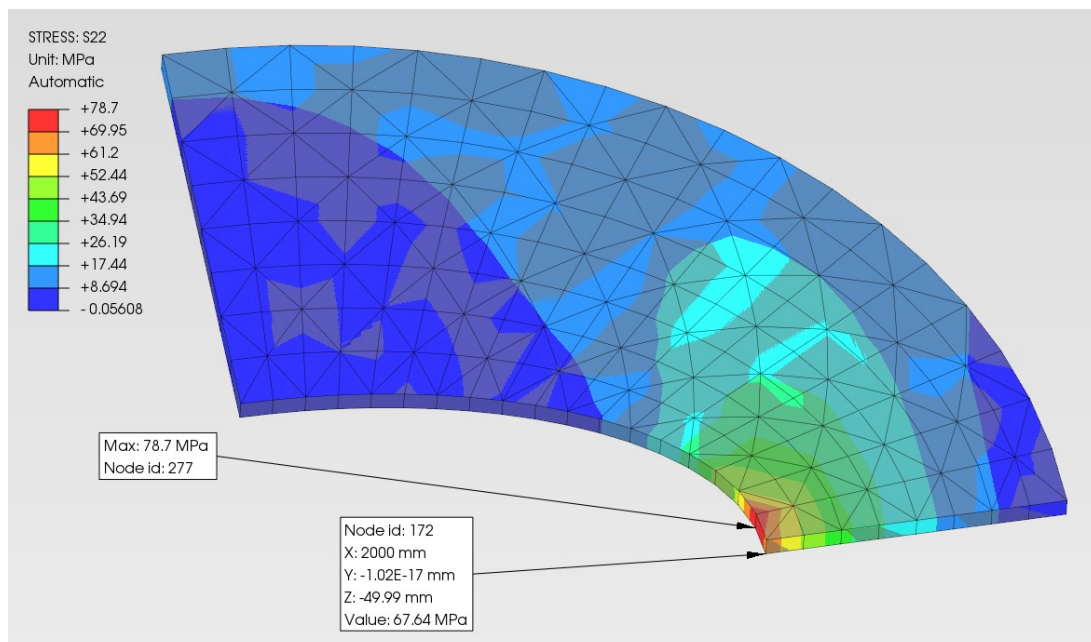


Figure 8 — run v4, Tria3 on the same mesh as v1: 67.64 MPa.

Case 3 — SSNV104: Hertzian contact between two spheres

Analysis type	Nonlinear static, contact
Elements tested	Linear tetrahedra with local refinement at the contact vertex, applied symmetrically on both spheres
Features tested	Frictionless contact; linear pressure-overclosure behaviour; displacement-controlled loading; contact stiffness sensitivity
Geometry	Two identical spheres of radius 50 mm in point contact; one eighth of each sphere modelled by triple symmetry, as two separate bodies
Material	Both spheres: $E = 20000 \text{ MPa}$; $\nu = 0.3$
Boundary conditions	Faces on plane $x = 0$ of both spheres: $u_x = 0$. Faces on plane $y = 0$ of both spheres: $u_y = 0$
Loading	Prescribed displacements: $u_z = -2 \text{ mm}$ on the top face of the upper sphere and $u_z = +2 \text{ mm}$ on the bottom face of the lower sphere; total approach 4 mm
Contact	Frictionless; linear pressure-overclosure with declared stiffness K ; gap conductance not used
Step	Static, automatic incrementation, initial increment 0.1 s, max 100 increments, min $1e-5$; nlgeom off. Convergence reached in 6 increments with no cutbacks
Units	mm, MPa, N
Validated output	σ_{zz} (S33) at the contact pole, coordinates (0, 0, 50)
Reference value	-2798.3 MPa — analytical (Hertz theory), $\sigma_{zz} = -(E/\pi) \cdot [1/(1-\nu^2)] \cdot \sqrt{(2h/R)}$ with $h = 4 \text{ mm}$. Benchmark: Code_Aster SSNV104

Results

Run	Nodes	$K \text{ [N/mm}^3\text{]}$	$\sigma_{zz} \text{ [MPa]}$	Deviation	COPEN
v1	9,000	2×10^4	-2881	+3.0%	-0.152 mm
v2	9,000	2×10^5	-3024	+8.1%	negligible
v3	60,000	2×10^5	-3025	+8.1%	negligible

Note — Run v1 gives the smallest deviation but with 0.152 mm of overclosure between the surfaces, 3.8% of the imposed approach; v2 is therefore reported as representative. At constant K , a tenfold increase in nodes changes the result by 0.03%; at constant mesh, one order of magnitude on K changes it by 5.1%. The peak stress is overestimated by 8.1%, while contact radius (8–10 mm against 10 mm theoretical) and pressure distribution are reproduced correctly.

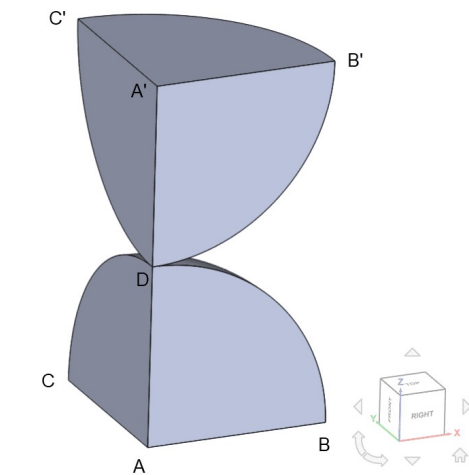


Figure 9 — model of the two spheres: one eighth of each sphere by triple symmetry, as two separate bodies in contact at point D. Source: simscale.com/docs/validation-cases/hertzian-contact-between-two-spheres/.

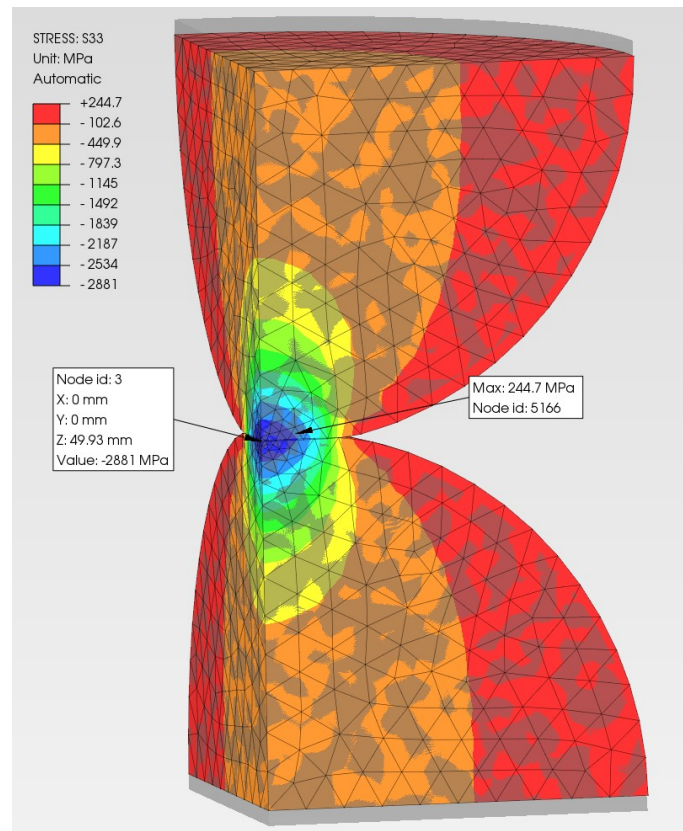


Figure 10 — run v1, 9,000 nodes with $K = 2 \times 10^4 \text{ N/mm}^3$: -2881 MPa.

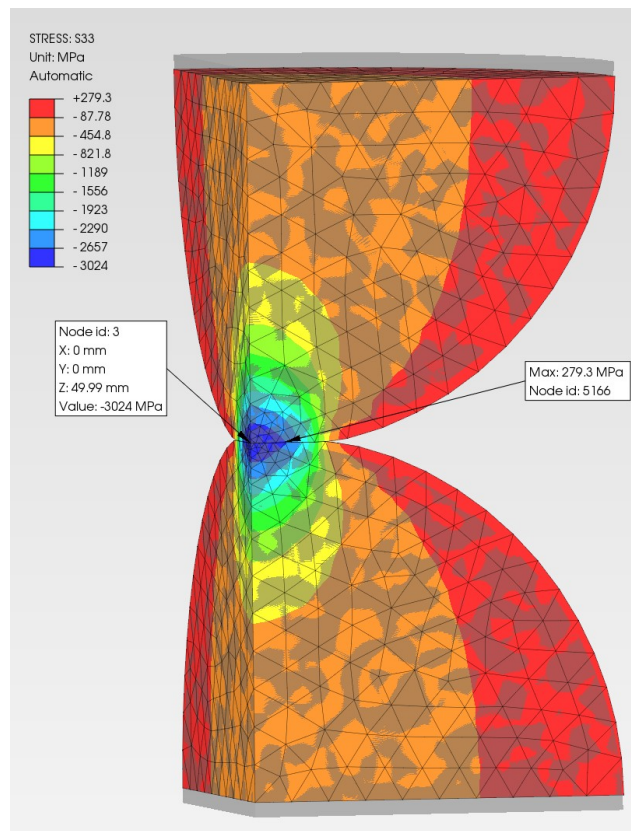


Figure 11 — run v2, same mesh with $K = 2 \times 10^5 \text{ N/mm}^3$: -3024 MPa.

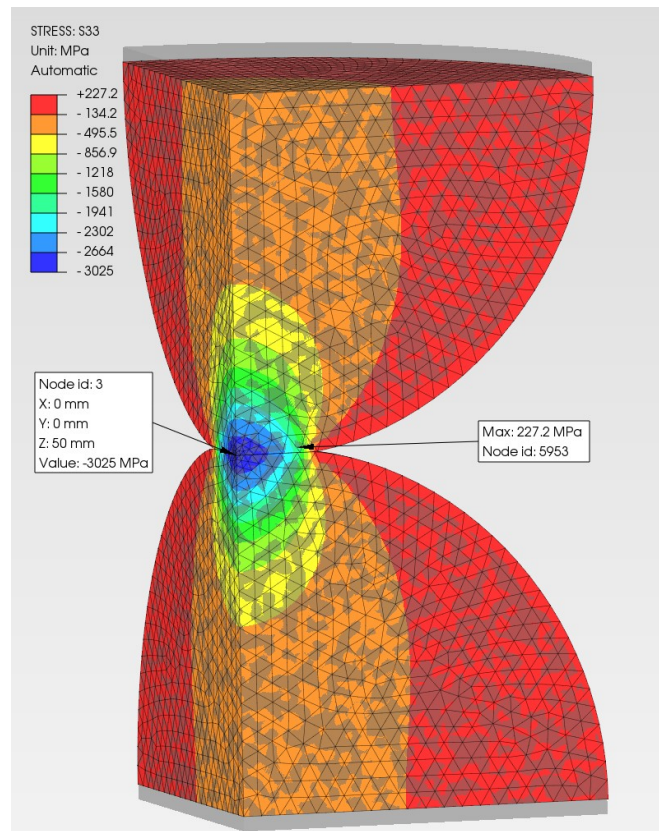


Figure 12 — run v3, 60,000 nodes with the same K as v2: -3025 MPa.

Case 4 — NAFEMS LE11: Solid cylinder / taper / sphere, temperature loading

Analysis type	Linear thermo-mechanical, 3D solids
Elements tested	Second-order recombined mesh, predominantly hexahedral in regular regions (Gmsh, 2D Frontal-Delaunay and 3D Delaunay algorithms)
Features tested	Prescribed temperature field; axial restraint at both ends; double symmetry
Geometry	Solid of revolution: cylindrical portion, conical taper and spherical cap; inner cylinder radius 1000 mm; one quarter modelled by 90° revolution of the profile
Material	E = 210000 MPa; $\nu = 0.3$; $\alpha = 2.3\text{e-}4$ /°C; zero temperature 0 °C
Boundary conditions	Plane x = 0: $u_x = 0$. Plane y = 0: $u_y = 0$. Bottom face (z = 0): $u_z = 0$. Top face H1H'I': $u_z = 0$
Loading	Prescribed temperature field over the whole domain, $T(x, y, z) = \sqrt{(x^2 + y^2)} + z$, reference temperature 0 °C. Entered as a thermal mapping distribution: =Sqrt(Pow((x/1000),2)+Pow((y/1000),2))+(z/1000)
Step	Linear static, single increment; the temperature is prescribed data, not an unknown
Units	mm, MPa, N, °C
Validated output	σ_{zz} (S33) at point A, coordinates (1001, 0, 0), inner cylinder surface at mid-height
Reference value	-105 MPa — NAFEMS TNSB Rev. 3, test LE11

Results

Run	Mesh	Order	Nodes	σ_{zz} [MPa]	Deviation
v1	Recombined	2nd	15,000	-102.2	-2.7%
v2	Recombined, fine	2nd	100,000	-104.9	-0.1%

Note — Convergence is monotonic towards the reference value.

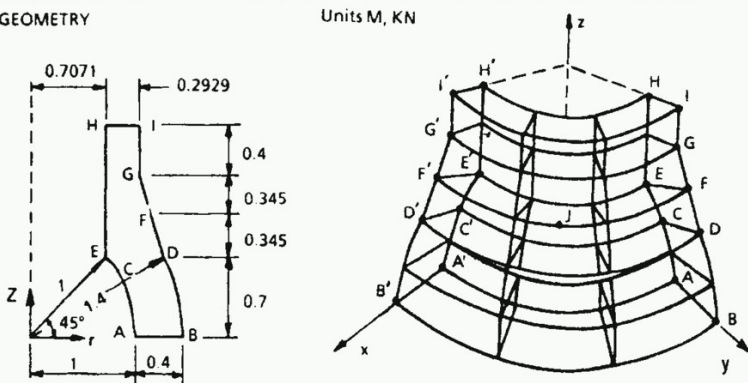
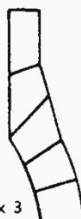
NAFEMS	SOLID CYLINDER / TAPER / SPHERE - TEMPERATURE	Test No LE11	DATE / ISSUE 15-6-90/2
ORIGIN	NAFEMS report LSB2		
ANALYSIS TYPE	Linear elastic solid		
GEOMETRY	Units M, KN		
			
LOADING	Linear temperature gradient in the radial and axial direction $T\text{ }^{\circ}\text{C} = (x^2 + y^2)^{1/2} + z$		
BOUNDARY CONDITIONS	Symmetry on xz-plane i.e. zero y-displacement Symmetry on yz-plane i.e. zero x-displacement Face on xy-plane zero z-displacement Face HH'I' zero z-displacement		
MATERIAL PROPERTIES	Isotropic, $E = 210 \times 10^3 \text{ MPa}$, $\nu = 0.3$ $\alpha = 2.3 \times 10^{-4} / ^{\circ}\text{C}$		
ELEMENT TYPES	Solid hexahedra, wedges and tetrahedra		
MESHES	 		
OUTPUT	Direct stress σ_{zz} at point A	TARGET -105 MPa (refined axisymmetric)	

Figure 13 — NAFEMS LE11 benchmark sheet: revolution profile, temperature field, boundary conditions and target value at point A. Source: onscale.com, NAFEMS thermo-mechanical validation case.

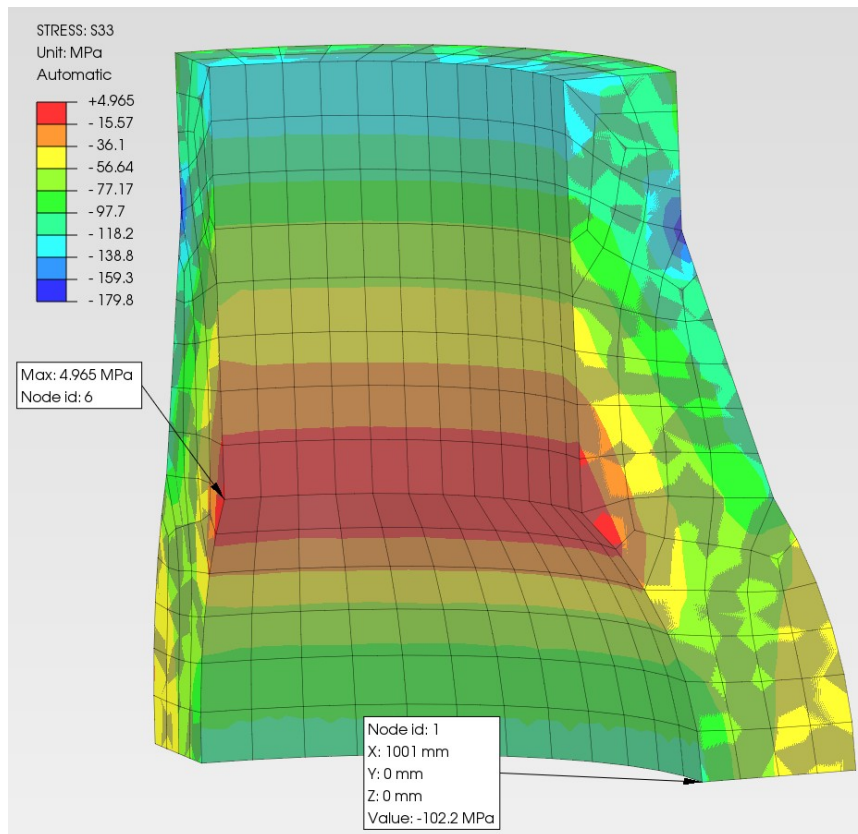


Figure 14 — run v1, 15,000 nodes: S33 field and nodal query at point A, -102.2 MPa.

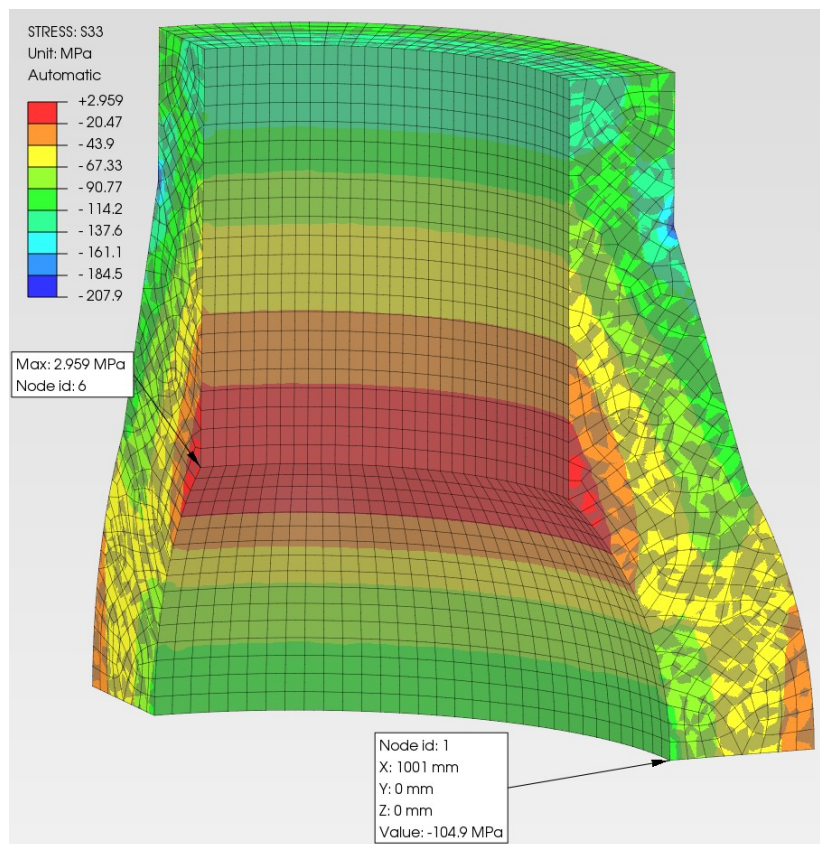


Figure 15 — run v2, 100,000 nodes: -104.9 MPa.

Case 5 — NAFEMS FV32: Cantilevered tapered membrane

Analysis type	Modal (natural frequencies)
Features tested	Eigenvalue extraction with no applied load; in-plane behaviour of a tapered cantilever
Geometry	Trapezoidal membrane: length 10 m; width 5 m at the clamped end and 1 m at the free end; thickness 0.05 m declared in the section
Material	$E = 200 \text{ GPa}$; $\nu = 0.3$; density 8000 kg/m^3
Boundary conditions	Clamped on the wide edge: $u_x = u_y = 0$; out-of-plane displacements blocked at all nodes
Step	Frequency step, 6 modes requested, 10 extracted
Mesh	1,150 nodes
Validated output	First six natural frequencies
Reference values	NAFEMS TNSB Rev. 3, test FV32

Results

Mode	Computed [Hz]	NAFEMS [Hz]	Deviation
1	44.62433	44.623	+0.002%
2	130.0499	130.03	+0.015%
3	162.7012	162.70	+0.001%
4	246.1271	246.05	+0.031%
5	380.0865	379.90	+0.049%
6	391.4510	391.44	+0.003%

Note — Modes 7 to 10, not tabulated by the benchmark: 523.363, 564.979, 607.0121 and 661.4978 Hz.

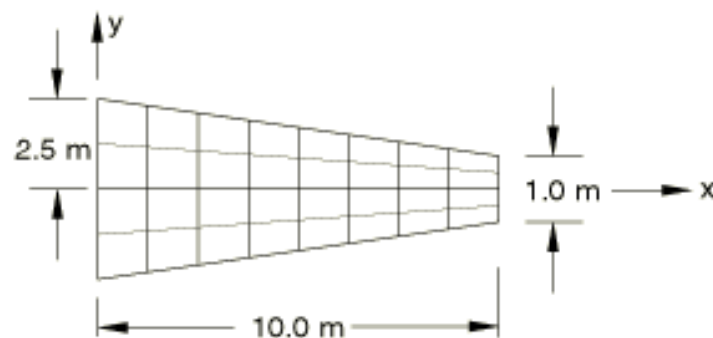


Figure 16 — NAFEMS FV32 geometry: tapered membrane, length 10 m, clamped on the wide edge. Source: help.altair.com, case OS-V 0440.