Ninth FENET-DLE Workshop

7-8 October 2004

Glasgow, UK

"Advanced FE contact benchmarks- Users Feedback"
(Contact Workshop-3)

Chairman : Prof. Adib Becker
(University of Nottingham, UK)

Overview of Presentation

- Review of current NAFEMS contact benchmarks
- Feedback from FENET Workshop on contact (27-28 February 2002, Copenhagen)
  - Comments on the current NAFEMS contact benchmarks
  - More challenging contact benchmarks
  - Challenges in FE modelling of industrial contact problems
- New (advanced) contact benchmarks

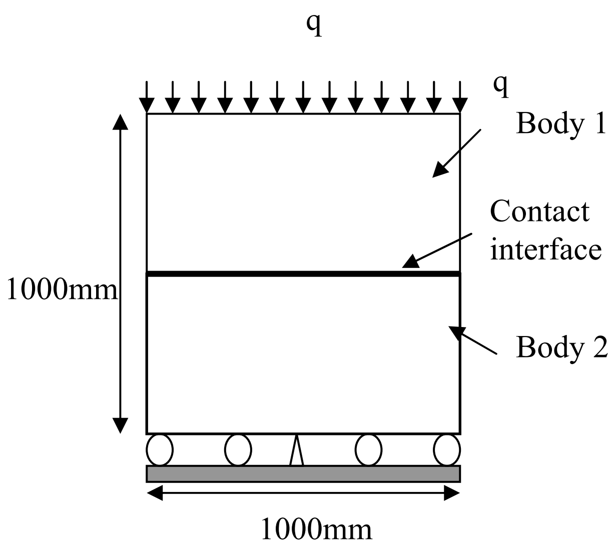
NAFEMS Publications on Contact

- **"FE Analysis of Contact and Friction- A Survey"**
by J E Mottershead
NAFEMS Report R0025 (1993)

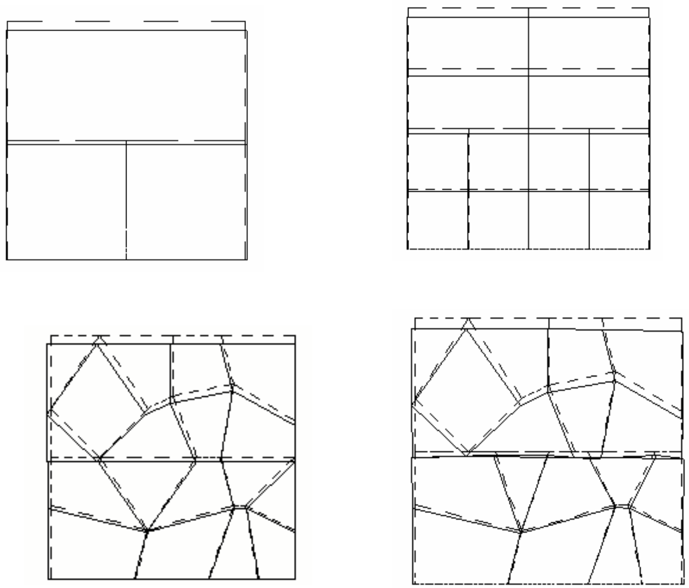
- **"How to undertake Contact and Friction Analysis"**
by A.W.A. Konter
NAFEMS Booklet HT15 (2000)

- **"NAFEMS Benchmark Tests for Finite Element Modelling of Contact, Gapping and Sliding"**
by Q Feng and N K Prinja
NAFEMS Report R0081 (2001)

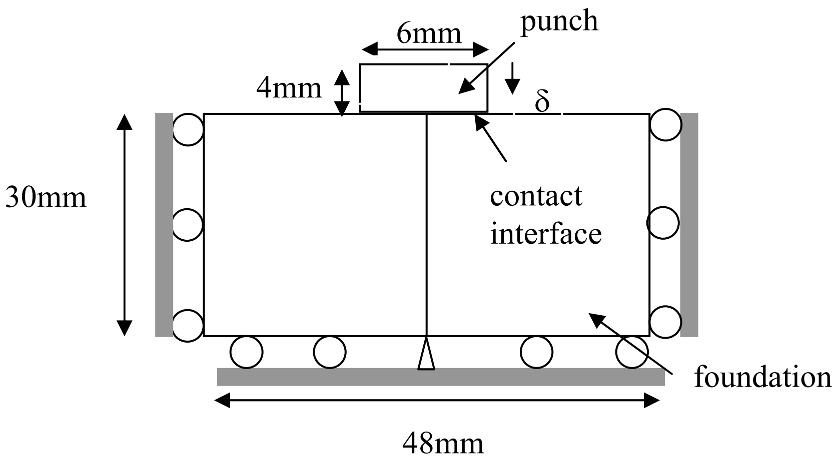
Overview of current contact benchmarks



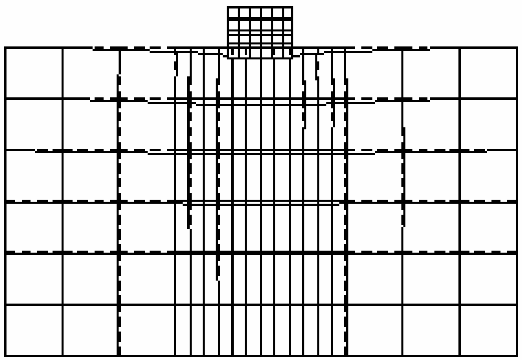
CGS-1: Contact patch test



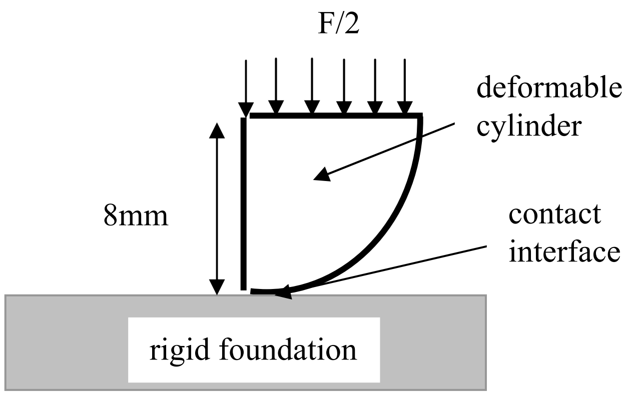
FE meshes



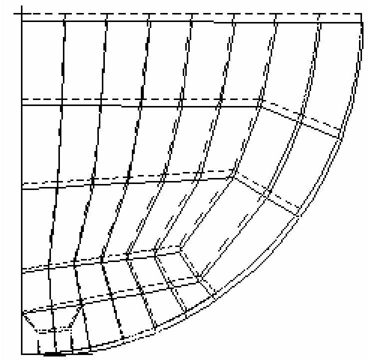
CGS-2: Rigid punch on a deformable foundation



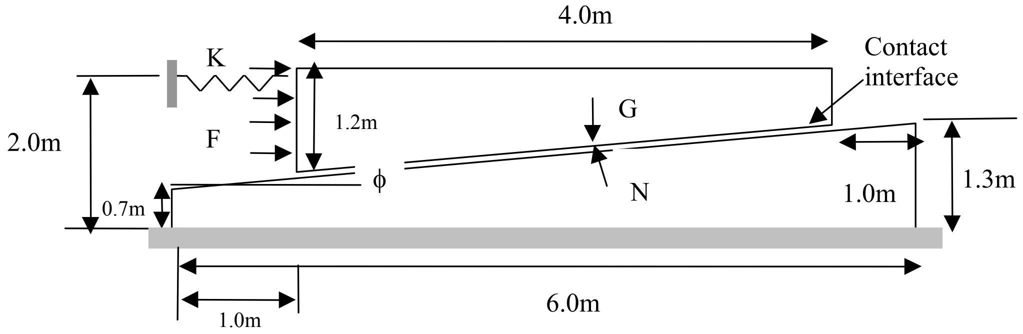
FE mesh



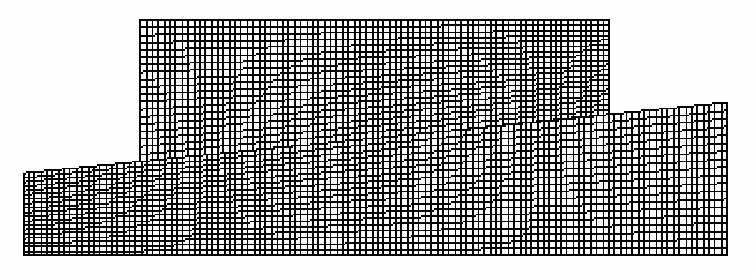
CGS-3: Hertzian contact



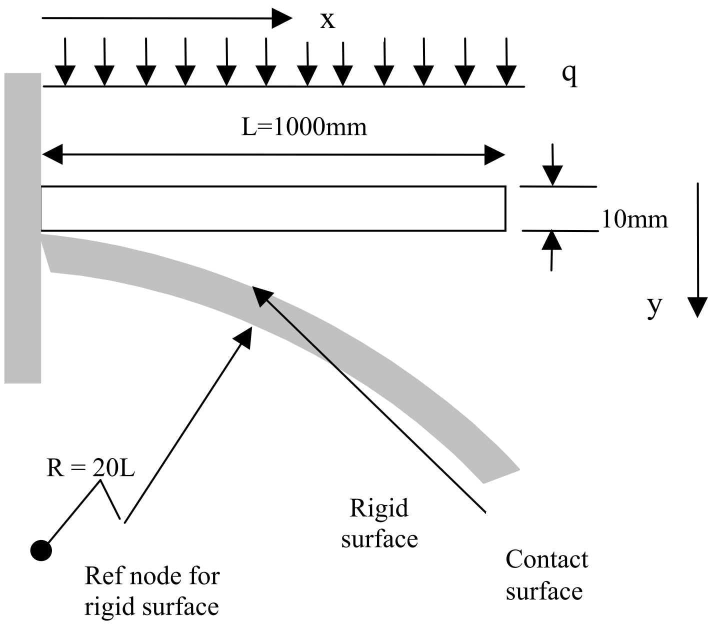
FE mesh

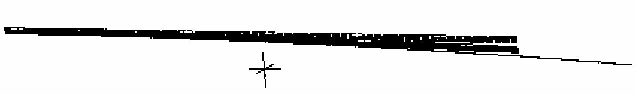


CGS – 4: Sliding wedge



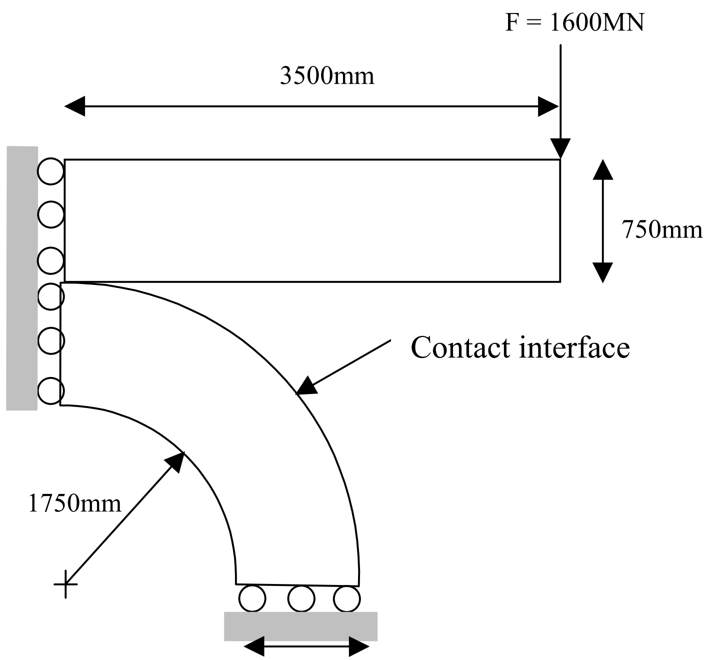
FE mesh

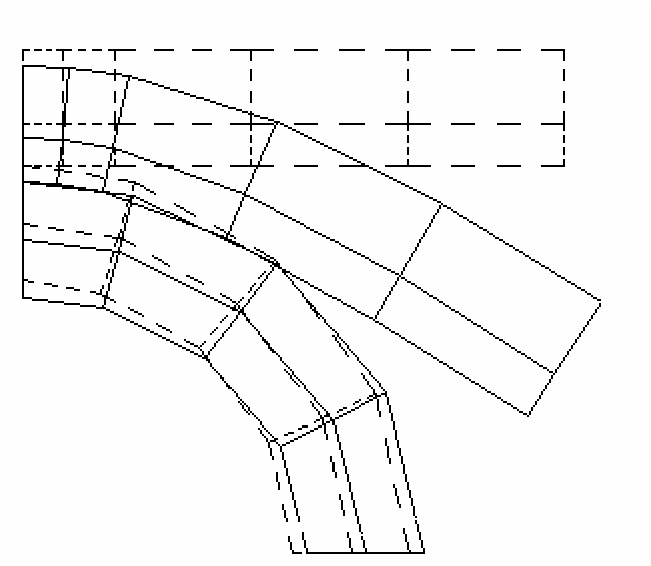




FE mesh

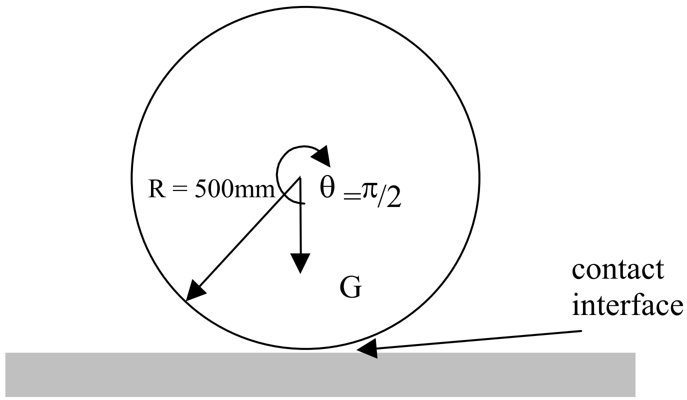
CGS – 5: Cantilever beam loaded against a rigid curvilinear surface

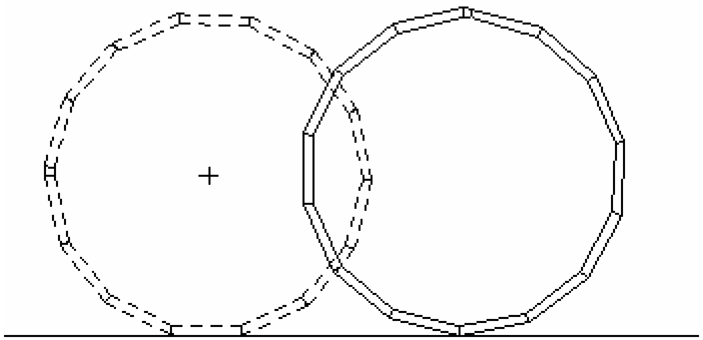




FE mesh

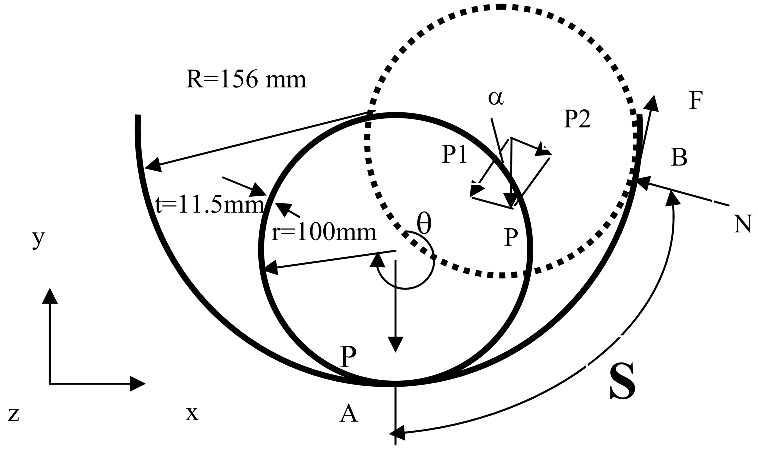
CG-6 Bending of a plate over a stiff cylinder



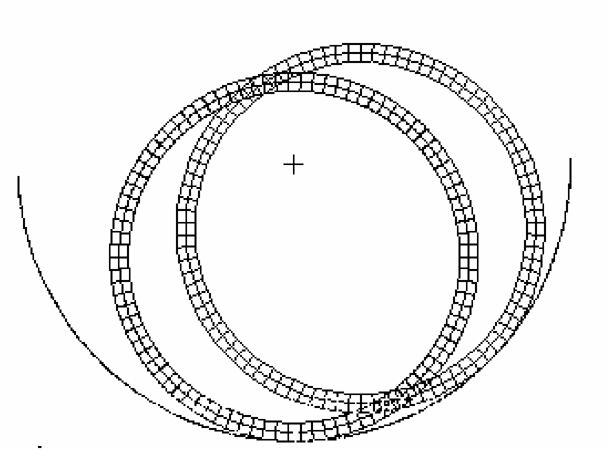


CGS – 7: Sliding and rolling of a ring on a rigid surface

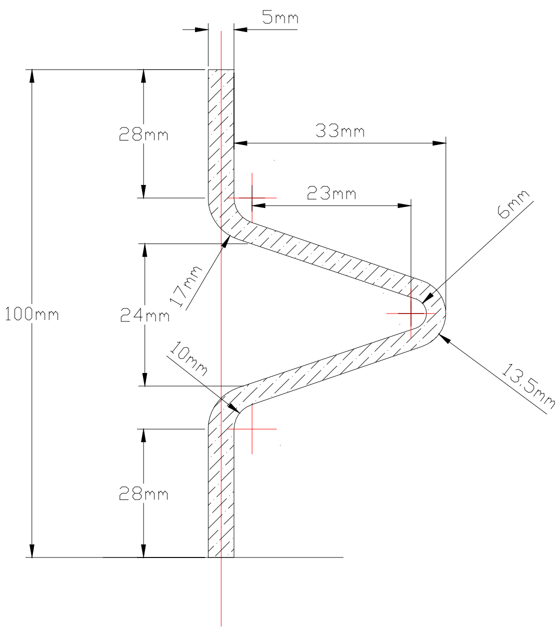
FE mesh



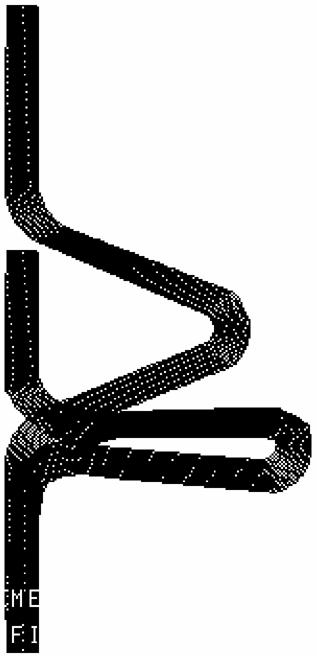
CG8: Two contacting rings



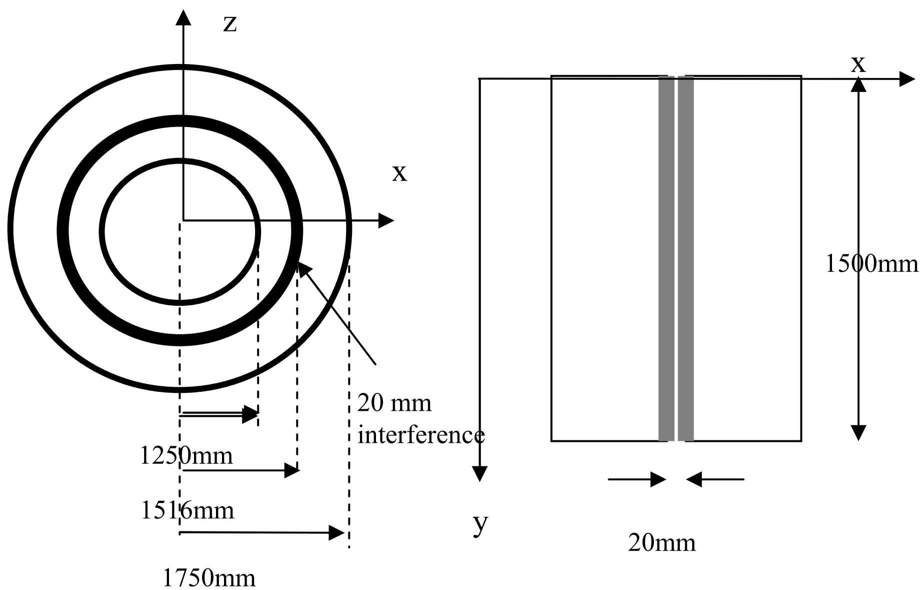
FE mesh



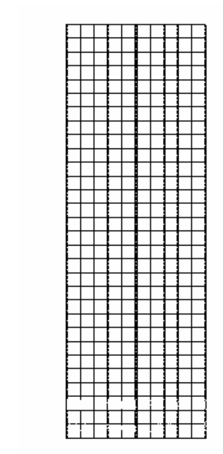
CGS – 9: Buckling of a curved column with self-contact



FE mesh



CGS – 10: Interference between two cylinders



FE mesh

Scope of current NAFEMS benchmarks

- Two-dimensional and axisymmetric problems
- Static and quasi-static contact
- Small strain problems
- Relatively simple geometries
- Non-matching meshes
- Friction, finite sliding
- Mainly linear elastic behaviour (only one plasticity analysis)
- Implicit method used
- Continuum elements or rigid bodies
- No thermal effects
- Contact problems that have analytical solutions or other reference solutions

Feedback from FENET Copenhagen Workshop

(1) Comments on the current NAFEMS contact benchmarks

- Limited in scope, but important as the first step in establishing contact benchmarks
- Can be improved by a clearer definition of data input
- Would benefit from showing solutions from two or more FE codes
- Useful to add a detailed “educational” description of the ‘difficult’ benchmarks.
- Should also consider the ‘curved‘ patch test
- Should show all FE mesh details (all nodal coordinates)

(2) More challenging contact benchmarks

- 3D contact
- Self-contact
- Multi-body contact
- Stick-slip in contact area
- Rotating shaft with no friction
- Compression of rubber
- Shell on shell contact
- Beam contact
- Thermal interaction
- Explicit/Implicit comparison
- 2D/3D Linear vs. quadratic elements
- 3D tetrahedron vs. hex elements
- 3D 27 node brick elements
- Impact (high velocity)
- Dynamic contact (low velocity)
- Large strain contact
- Metal forming

(3) Challenges in FE modelling of industrial contact problems

- Loaded rigid surfaces
- Identification of unknown or unexpected contact regions
- Automation of contact analysis
- Re-meshing during contact analysis
- Visualisation of contact elements
- Informative post-processing diagnostic display
- Improved quadratic elements
- Better friction models
- Experimental verification of FE contact solutions
- Coupled thermo-mechanical contact
- Heat conduction across interfaces
- Cemented joints
- Thin lubricating films

(4) Suggestions for classification of contact by application

(I) **Structural assemblies** e.g. Bolted joints, bearings, gaskets, seals

(ii) **Intermittent contact** e.g. medical devices, flexible pipelines

(iii) **Forming** e.g. Forging, sheet stamping, deep drawing

(iv) **Impact** e.g. crash analysis, drop-testing, IC engine valves

(v) **Collapse** e.g self-contact, crushing of hollow sections

FENET Durability and Life Extension
Advanced Contact Benchmarks

✓ Step1 (Initiate discussion)

- Assemble a small "FENET Working Group on Contact" of interested parties
- Collaborate with the NAFEMS Non-linear Working Group
- Initiate discussions on the development of new advanced contact benchmarks

✓ Step 2 (Agree benchmarks)

- Agree on a list of new contact benchmarks
- Issue a request to FE software vendors and FE users and to run the new contact benchmarks

→ Step 3 (Final workshop)

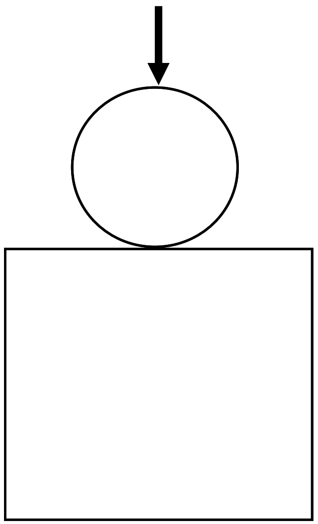
- Launch a further FENET DLE workshop on "Advanced Contact Benchmarks" to report the outcome (Spring 2005)

Step 4 (Report)

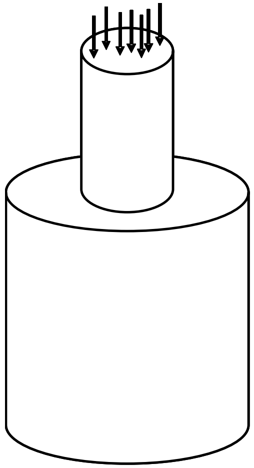
- Issue a formal report on Advanced Contact Benchmarks (July 2005)

New Advanced FE contact Benchmarks

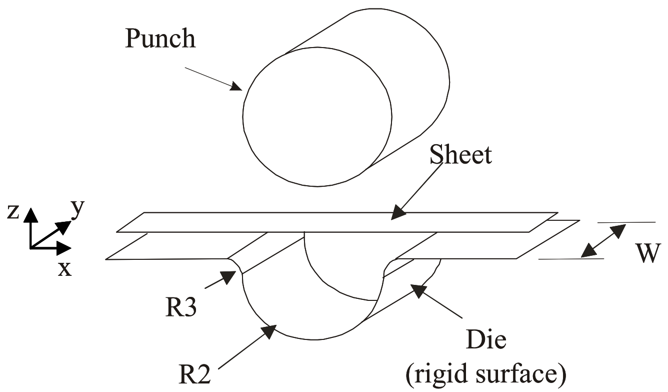
Ref. No.	**Contact Benchmark - 1**
Title	**2D Cylindrical Roller Contact**
Contact Features	- Advancing contact area - Curved contact surfaces - Deformable-deformable contact - Friction stick-slip along the contact line - Comparison of linear and quadratic elements
Geometry	2D Plane strain Cylinder diameter = 100 mm Block height = 200 mm Block width = 200 mm
Material Properties	$E_{punch} = 210$ kN/mm^2 $E_{foundation} = 70$ kN/mm^2 $\nu_{punch} = \nu_{foundation} = 0.3$
Analysis Type	Static linear elastic
Displaceme nt Boundary Conditions	Symmetry displacement constraints (half symmetry) Bottom surface of the foundation is fixed ($u_x = u_y = 0$)
Applied Loads	Vertical point load, F = 35 kN
Element Type	2D plane strain 8-node quadratic elements or 4-node linear elements
Contact Parameters	Coefficient of friction, $\mu = 0$ and 0.1
FE results	1. Plot of contact pressure against distance from centre of contact 2. Plot of tangential traction against distance from centre of contact 3. Plot of relative tangential slip against distance from centre of contact

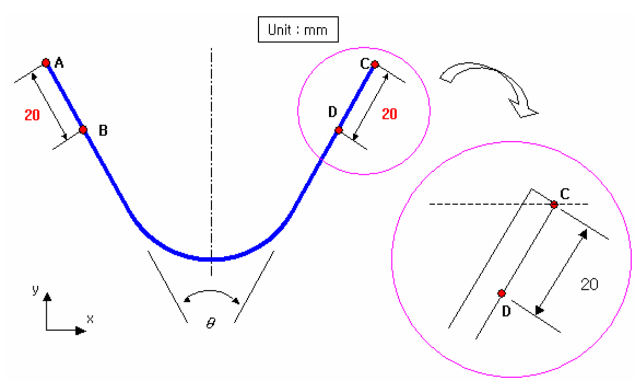


Ref. No.	**Contact Benchmark - 2**
Title	**3D Punch (Rounded edges)**
Contact Features	- 3D contact - Stick/slip behaviour along the contact plane - Comparison of linear and quadratic elements - (Plasticity may be considered)
Geometry	3D Continuum elements (can also be modelled as axisymmetric) Punch diameter = 100 mm Punch height = 100 mm Foundation diameter = 200 mm Foundation height = 200 mm Fillet radius at the edge of the punch contact = 10 mm
Material Properties	$E_{punch} = 210\ kN/mm^2$ $E_{foundation} = 70\ kN/mm^2$ $\nu_{punch} = \nu_{foundation} = 0.3$
Analysis Type	Static linear elastic
Displacement Boundary Conditions	Symmetry displacement constraints (quarter symmetry) Bottom surface of the foundation is fixed ($u_x = u_y = u_z = 0$)
Applied Loads	A uniform pressure (distributed load) applied at the top surface of the punch, $P = 100\ N/mm^2$
Element Type	3D Continuum 20-node quadratic elements 27-node quadratic elements or 8-node linear elements
Contact Parameters	Coefficient of friction, $\mu = 0$ and 0.1
FE results	1. Plot of contact pressure against radial distance from centre of contact 2. Plot of tangential traction against radial distance from centre of contact 3. Plot of relative tangential slip against distance from centre of contact

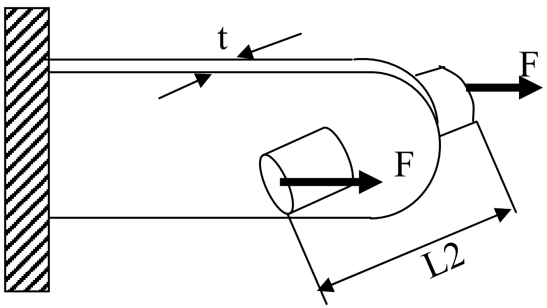


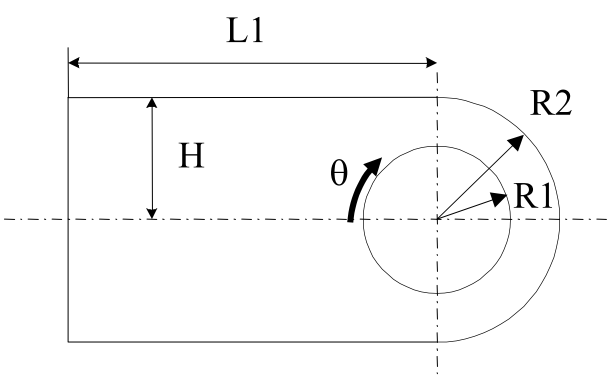
Ref. No.	**Contact Benchmark - 3**
Title	**3D Sheet metal forming**
Contact Features	- Rigid and deformable bodies - Mesh dependency - Elasticity, plasticity and springback - Sliding contact around circular surface
Geometry	3D continuum elements or shell elements Prescribed punch displacement Punch radius 23.5 mm Die radius R2 = 25.0 mm Die shoulder R3 = 4.0 mm Width of tools = 50.0 mm Length of sheet (initially) = 120.0 mm Thickness of sheet = 1.0 mm Width of sheet = 30.0 mm Punch stroke = 28.5 mm
Material Properties	Young's modulus: E = 70.5 kN/mm^2 Poisson's ratio: ν = 0.342 Plasticity (Hollomon hardening) law: $\sigma = K\,\varepsilon^n$ Initial yield stress = 194 N/mm^2 Constant, K = 550.4 N/mm^2 Constant, n = 0.223
Analysis Type	Static Geometric non-linearity Elastic-plastic isotropic hardening
Displacement Boundary Conditions	Symmetry displacement restraints (half symmetry) Bottom surface fixed Prescribed vertical displacement for the punch = 28.5 mm
Applied Loads	No applied forces
Element Type	2D plane strain : 4-node linear continuum elements Shell: 4-node shell elements
Contact Parameters	Coefficient of friction, μ = 0 and 0.1342
FE results	1. Forming angle 2. Angle after release 3. Plot of Punch force against punch displacement





Ref. No.	**Contact Benchmark - 4**
Title	**3D Loaded pin**
Contact Features	- Receding contact area - Curved contact surfaces - Deformable-deformable contact - Friction stick-slip along the contact surface
Geometry	3D Continuum L1 = 200 mm L2 = 20 mm R1 = 50 mm R2 = 100 mm H = 100 mm t = 10 mm
Material Properties	E_{pin} = 210 kN/mm^2 E_{sheet} = 70 kN/mm^2 $\nu_{pin} = \nu_{sheet} = 0.3$
Analysis Type	Static linear elastic
Displacement Boundary Conditions	Symmetry displacement restraints (Quarter symmetry) Left side of the sheet is fixed
Applied Loads	Two equal point forces applied to the pin resulting in a total force on the pin of 100 kN
Element Type	3D Continuum 20-node quadratic elements or 8-node linear elements
Contact Parameters	Coefficient of friction, μ = 0 and 0.1
FE results	1. Plot of contact pressure against angle θ 2. Plot of tangential traction against angle θ 3. Plot of relative tangential slip against angle θ





Ref. No.	**Contact Benchmark - 5**
Title	**3D Steel roller on rubber (Reynolds, 1874)**
Contact Features	3D deformable-deformable contact Rolling contact Incompressible material
Geometry	3D Continuum R = 30 mm H = 20 mm L1 = 60 mm L2 = 240 mm
Material Properties	$E_{steel} = 210\ kN/mm^2$ $E_{rubber} = 10\ N/mm^2$ $\nu_{steel} = 0.3$ $\nu_{rubber} = 0.5$
Analysis Type	Static linear elastic Geometric non-linearity
Displacement Boundary Conditions	Deformation history: - Centre of the roller is fixed in horizontal and vertical direction Time period 0.0 - 1.0 second: - No rotation of roller - Move bottom surface of rubber 3 mm up while keeping x-displacement fixed Time period 1.0 - 2.0 seconds: - Prescribed rotation of steel roller (360 degrees) - Bottom surface of rubber sheet is kept fixed in vertical direction - Sheet is free to move in vertical direction
Applied Loads	No applied forces
Element Type	3D Continuum 20-node quadratic elements or 8-node linear elements
Contact Parameters	Coefficient of friction, $\mu = 0.3$
FE results	Horizontal displacement of the point A after 360 degrees motion