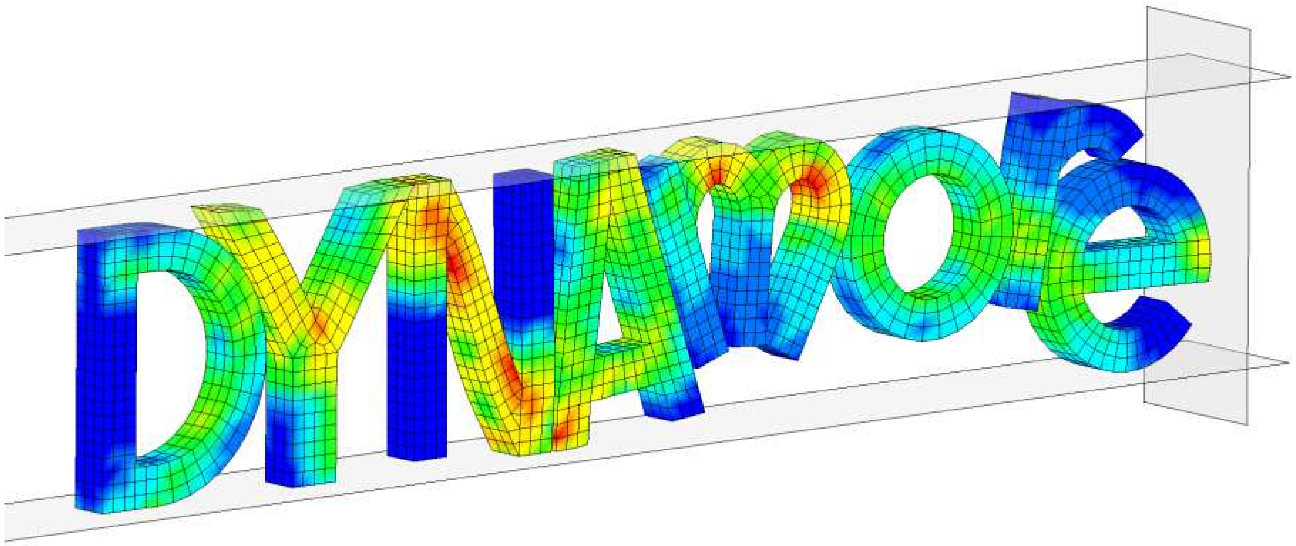
New features in LS-DYNA R7.1.1

- Newest release - published in April 2014
- Robust production version is R6.1.2
- Presentation about major new solid mechanics features:
  Material Models, Element Technology, Metal Forming, Occupant Safety, Implicit, Discrete Element Method, General Enhancements

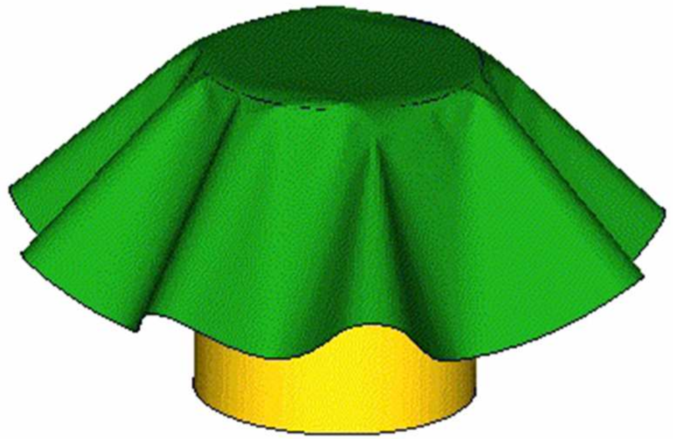


Material Models

*MAT_FABRIC(034) bending stiffness

- Additional rotational resistance to model coating of the fabric
- More realistic behavior of coated fabrics, e.g. airbags, seat cover, folding tops, ...
- New parameters ECOAT, SCOAT, TCOAT on *MAT_FABRIC
- ...will be available for implicit in next release

without bending stiffness



***with** bending stiffness*

*MAT_SPOTWELD(100)

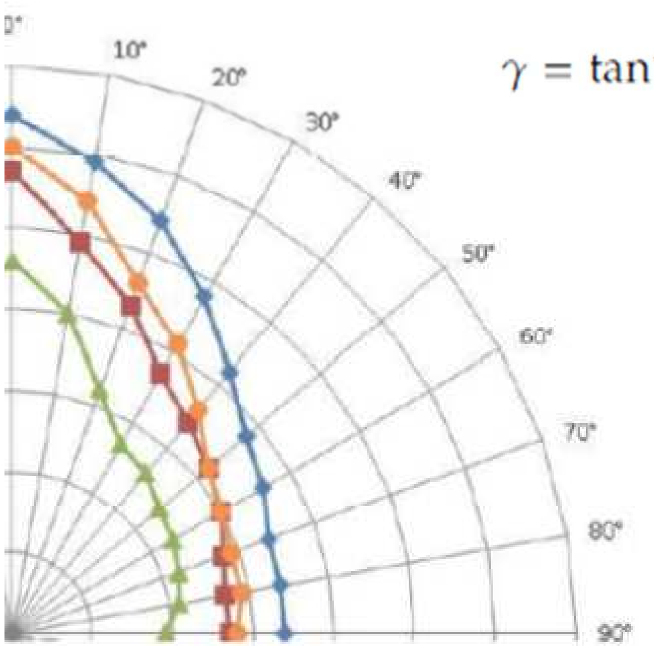
- New failure model OPT=11 for beam elements, where failure depends on loading direction via curves

OPT = 11 invokes a resultant force based failure criterion for beams. With corresponding load curves or tables LCT and LCC, resultant force at failure F_{fail} can be defined as function of loading direction γ (curve) or loading direction γ and effective strain rate $\dot{\varepsilon}$ (table):

$$F_{\text{fail}} = f(\gamma) \quad \text{or} \quad F_{\text{fail}} = f(\gamma, \dot{\varepsilon})$$

with the following definitions for loading direction (in degree) and effective strain rate:

$$\gamma = \tan^{-1}\left(\left|\frac{F_{\text{shear}}}{F_{\text{axial}}}\right|\right), \quad \dot{\varepsilon} = \left[\frac{2}{3}\left(\dot{\varepsilon}_{\text{axial}}{}^{2} + \dot{\varepsilon}^{2}_{\text{shear}}\right)\right]^{1/2}$$

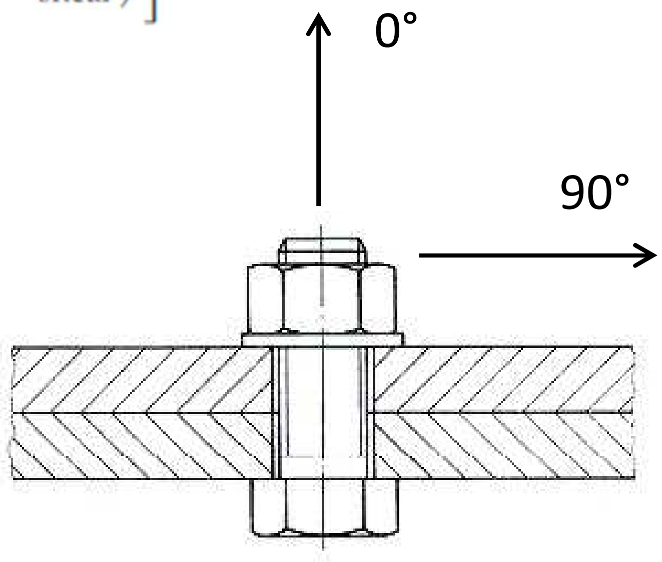


ISO thread

round thread

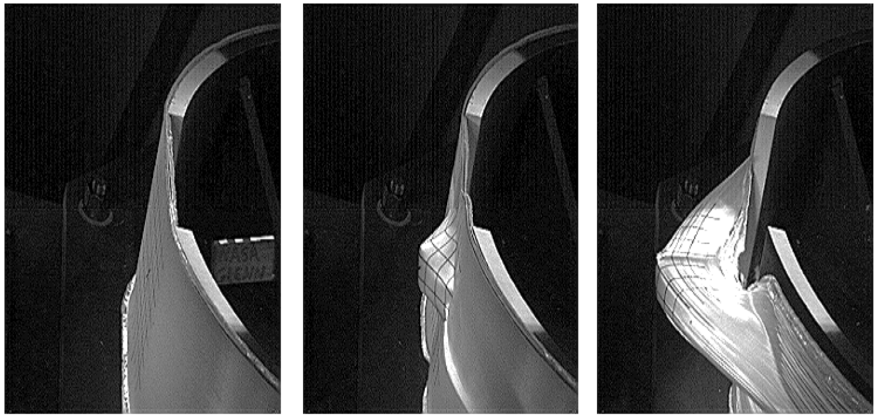
trapezoidal thread

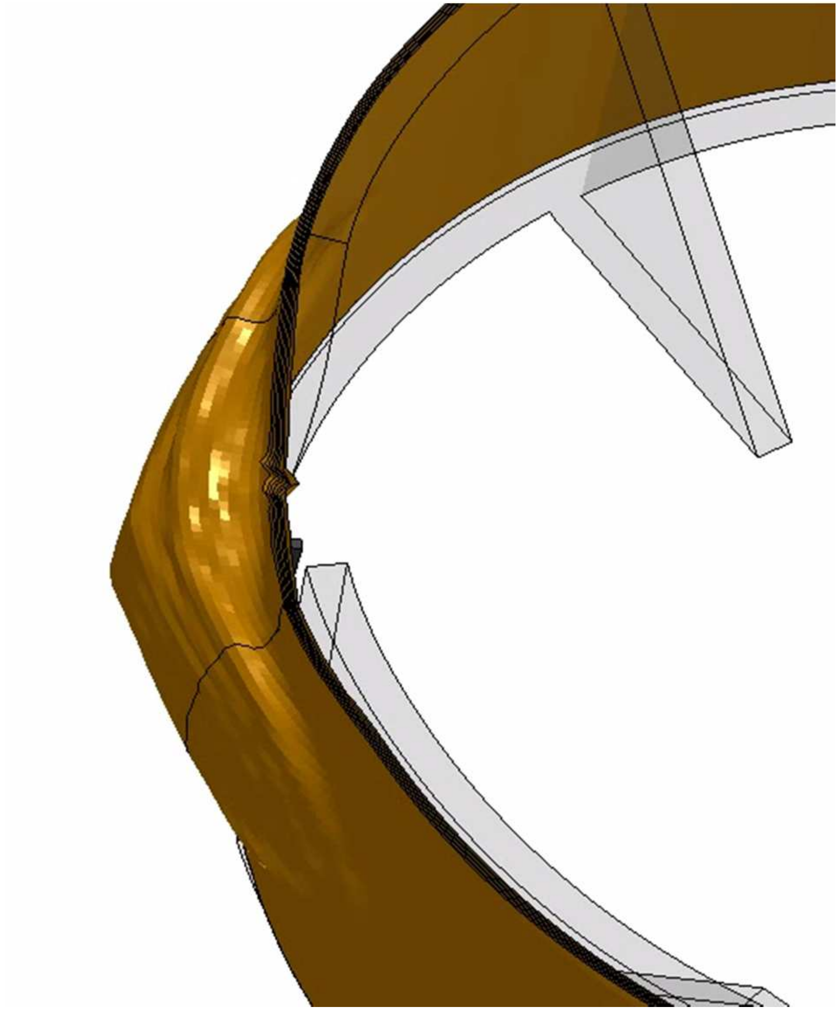
buttress thread



*MAT_DRY_FABRIC(214) for high strength woven fabrics

- Applications: propulsion engine containment, body armor, personal protections





*MAT_ADD_COHESIVE

- Usually cohesive elements (ELFORM = 19, 20, 21, and 22 of *SECTION_SOLID) can only be used with a small subset of materials (138, 184, 185, 186, 240).
- But with this additional keyword, a bigger amount of standard 3-d material models can be used (e.g. 15, 24, 41-50, 81, 103, 120, 123, 124, 168, 187, 188, 224, 225, 252, …), that would only be available for solid elements in general.
- Therefore, assumptions of inhibited lateral expansion and in-plane shearing are used:

$$\begin{bmatrix}\delta_1\\ \delta_2\\ \delta_3\end{bmatrix} \Rightarrow \begin{bmatrix}\dot{\varepsilon}_{xx}\\ \dot{\varepsilon}_{yy}\\ \dot{\varepsilon}_{zz}\\ \dot{\varepsilon}_{xy}\\ \dot{\varepsilon}_{yz}\\ \dot{\varepsilon}_{zx}\end{bmatrix} = \begin{bmatrix}0\\ 0\\ \dot{\delta}_3/(t+\delta_3)\\ 0\\ \dot{\delta}_2/(t+\delta_3)\\ \dot{\delta}_1/(t+\delta_3)\end{bmatrix} \xrightarrow{\text{e.g. *MAT\_024}} \begin{bmatrix}\sigma_{xx}\\ \sigma_{yy}\\ \sigma_{zz}\\ \sigma_{xy}\\ \sigma_{yz}\\ \sigma_{zx}\end{bmatrix} \Rightarrow \begin{bmatrix}t_1\\ t_2\\ t_3\end{bmatrix} = \begin{bmatrix}\sigma_{zx}\\ \sigma_{yz}\\ \sigma_{zz}\end{bmatrix}$$

displacements in cohesive element

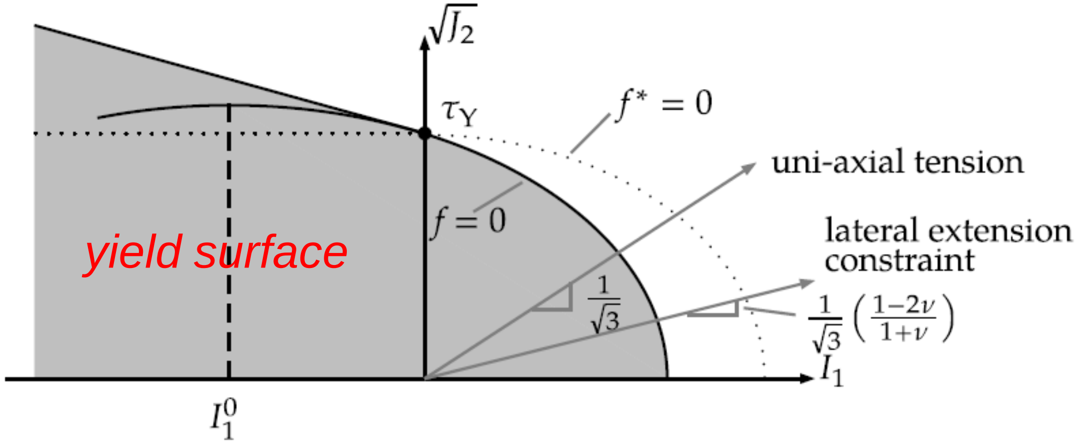
3-dim. strain rates

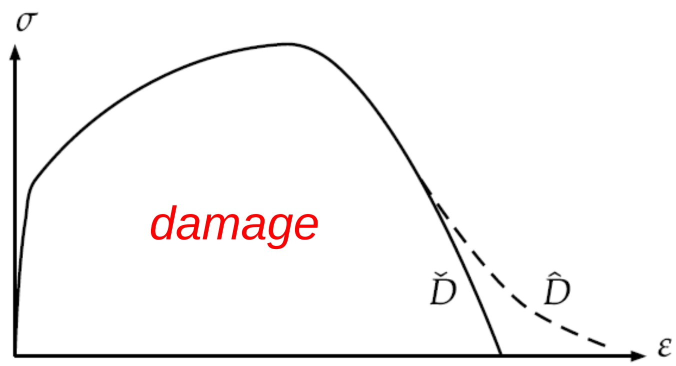
3-dim. stresses

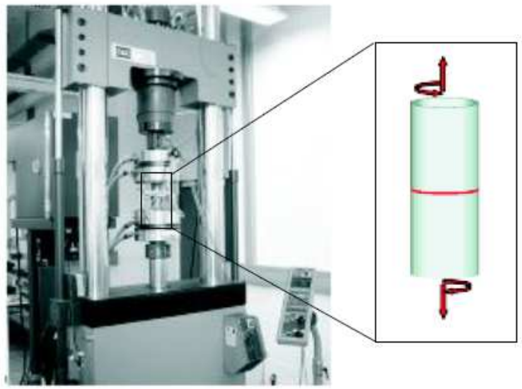
tractions in cohesive element

*MAT_TOUGHENED_ADHESIVE_POLYMER(252)

- New material model for crash optimized high-strength adhesives under combined shear and tensile loading
  - Drucker-Prager-Cap type plasticity + rate dependence + damage + failure
  - well suited for combination with *MAT_ADD_COHESIVE

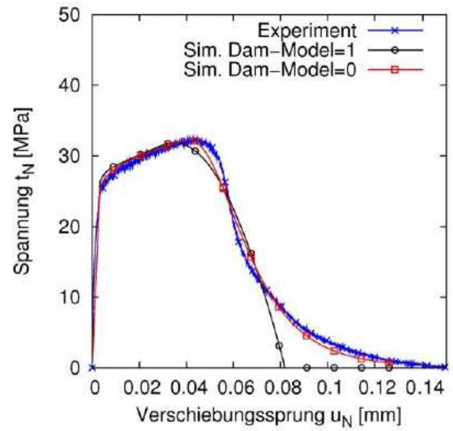






Model developed in German FAT* project: good agreement between experiments and simulation

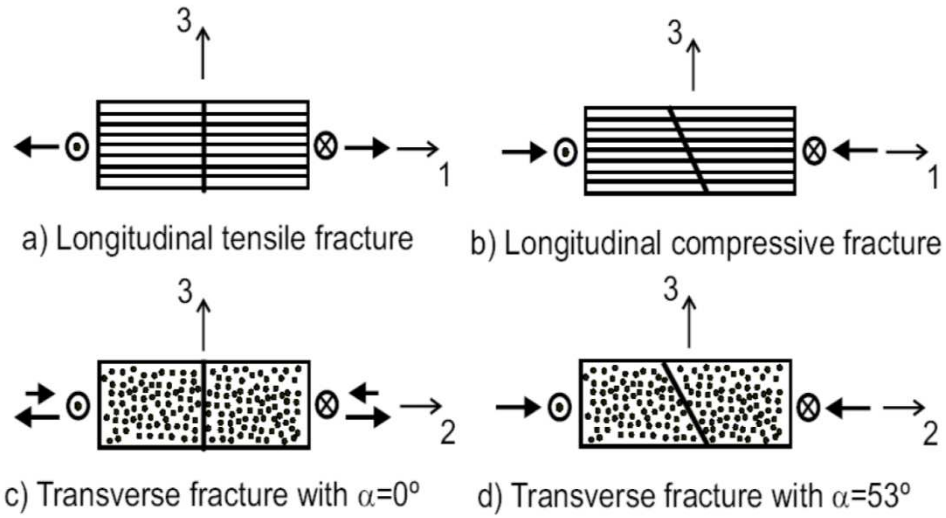
*Research Association for Automotive Technology

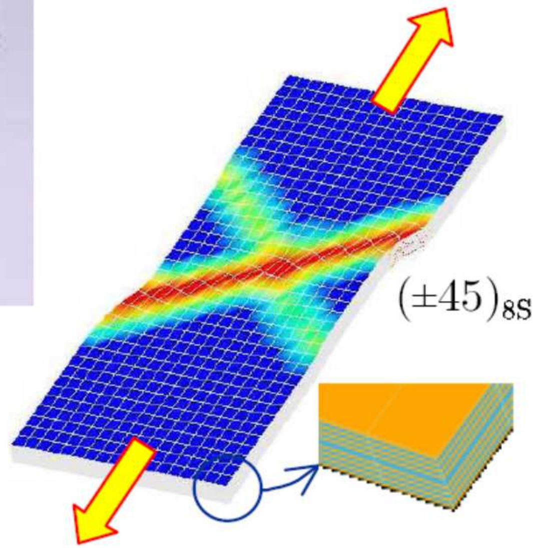


*MAT_LAMINATED_FRACTURE_DAIMLER_PINHO(261)

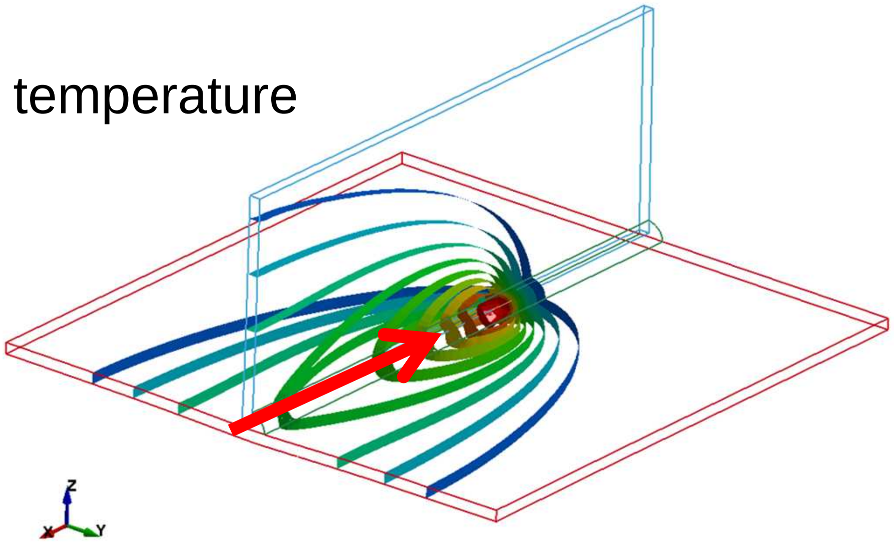
*MAT_LAMINATED_FRACTURE_DAIMLER_CAMANHO(262)

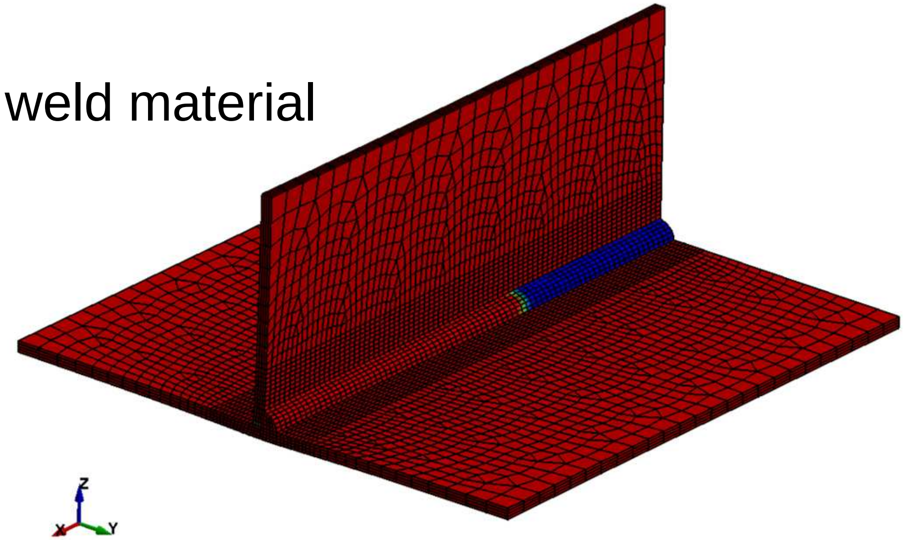
- Two new material models for laminated fiber-reinforced composites
- Based on physical models for each failure mode
- Nonlinear in-plane shear behavior
- Implemented for thin shells, thick shells, and solid elements





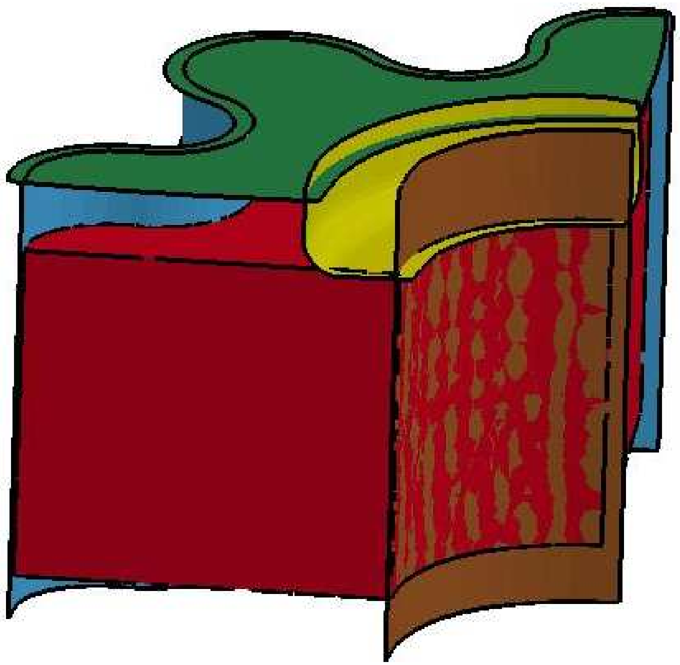
*MAT_CWM(270): Computational Welding Mechanics

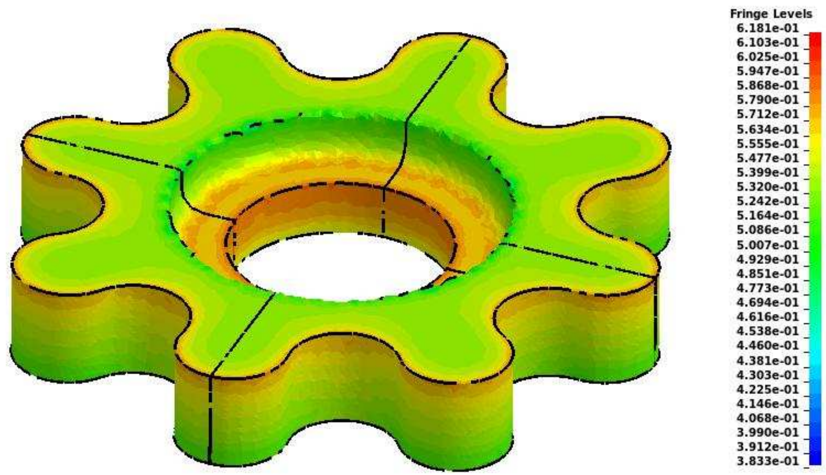




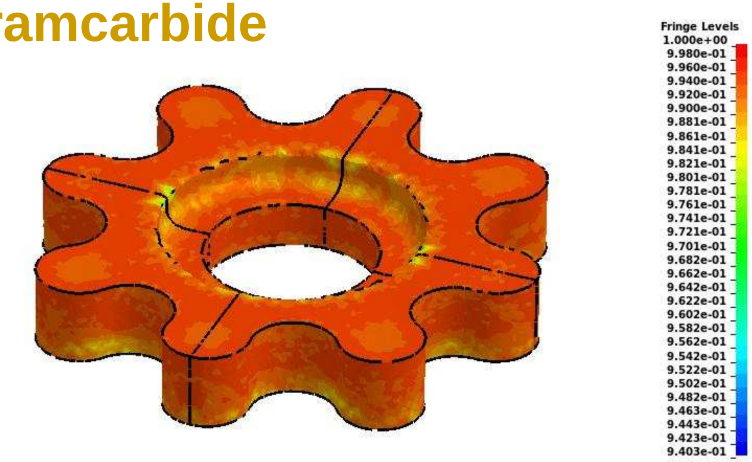
- Temperature created weld material
- Initial ”ghost” material (very low stiffness) becomes weld material (elasto-plastic) during temperature increase
- Supports birth of material and annealing in addition to standard elastic-plastic thermal material properties

*MAT_POWDER(271) for compaction and sintering of cemented carbides



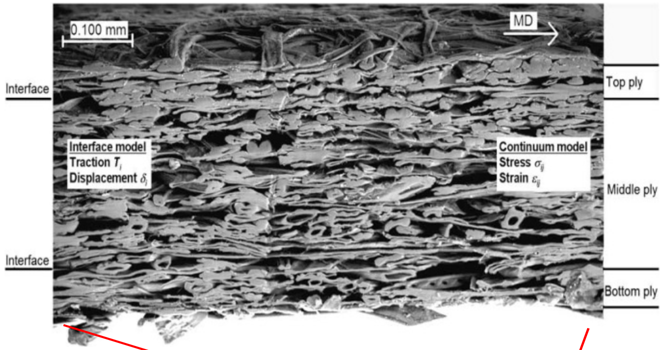


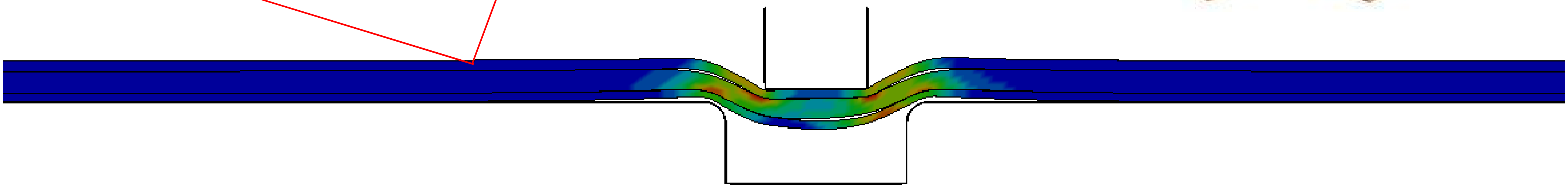
Relative density of wolframcarbide



- Metal powder → Solid component
- Intended to be used in two stages:
  1. Pure mechanical compaction
  2. Thermo-mechanical sintering

*MAT_PAPER(274) for modeling of paperboard



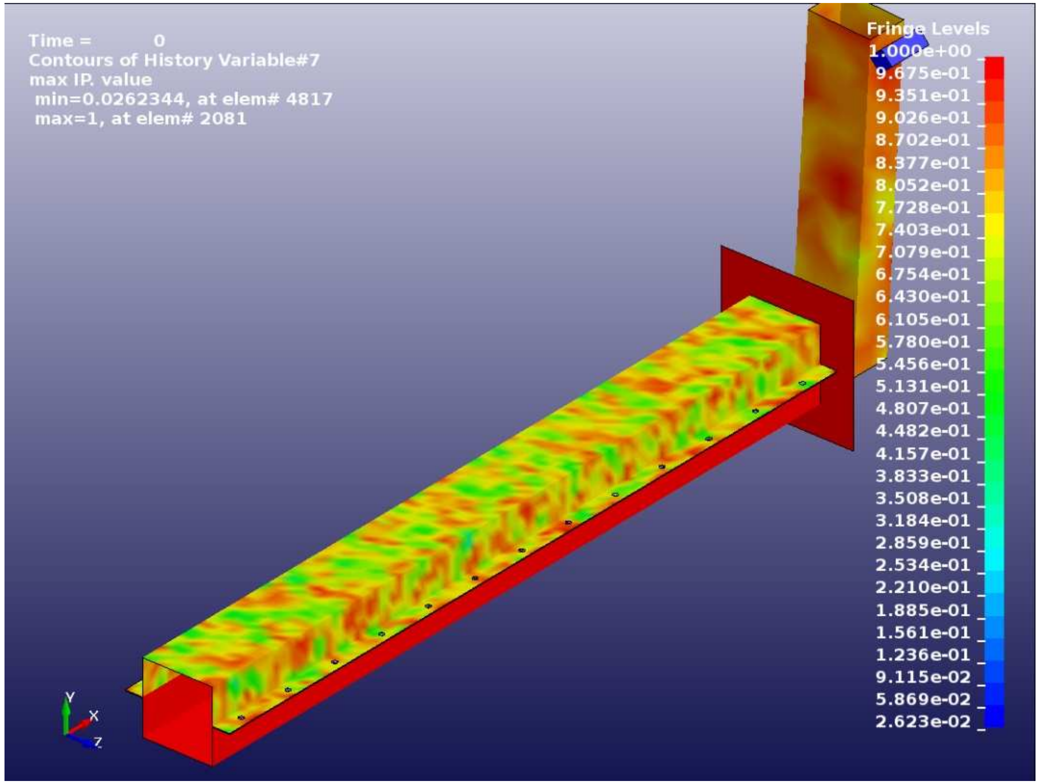


- Orthotropic elastoplastic model based on Xia (2002) and Nygards (2009)
- For paperboard (e.g. packaging), a strongly heterogeneous material
- Creasing simulation with delamination of individual plies shown above
- Available for solid and shell elements
- Has shown to reproduce experimental data well

Stochastic Variations of Material Properties

- Permits random variations of the material yield strength and failure strain

- Options for the spatial variation:
  - Uniform scale factor of 1.0 everywhere
  - Uniform random distribution on a specified interval
  - Gaussian distribution
  - Specified probability distribution function
  - Specified cumulative distribution function



→ *DEFINE_STOCHASTIC_VARIATION
*MAT_*name*_STOCHASTIC

*MAT_*name*_STOCHASTIC Option

- Available for materials:
  - *MAT_ELASTIC_PLASTIC_HYDRO (10)
  - *MAT_JOHNSON_COOK (15)
  - *MAT_PIECEWISE_LINEAR_PLASTICITY (24)
  - *MAT_PLASTICITY_WITH_DAMAGE_{*OPTION*} (81)
  - *MAT_SIMPLIFIED_JOHNSON_COOK (98)

- Available for solids, shells, and beams.

- Yield surface and plastic strain to failure are scaled by *DEFINE_STOCHASTIC_VARIATION

- $\sigma_y = f(x)\sigma_y$ and $\bar{\epsilon}^p = g(x)\bar{\epsilon}^p$ where the $f(x)$ and $g(x)$ are the specified stochastic spatial variations.

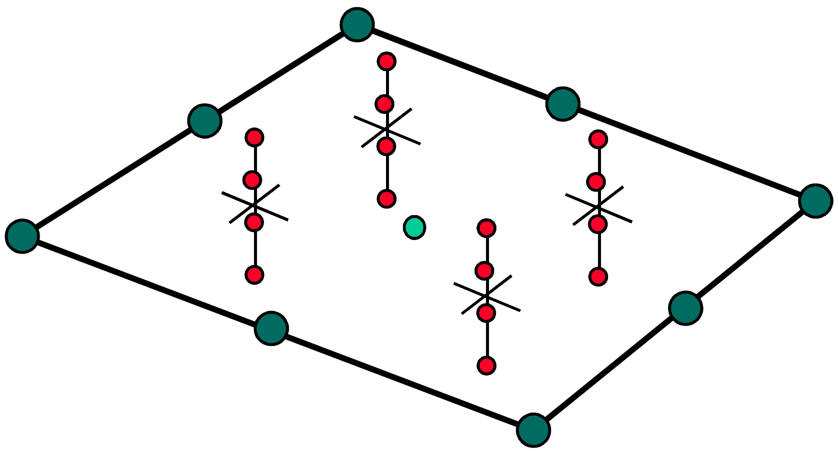
More Material Model Updates

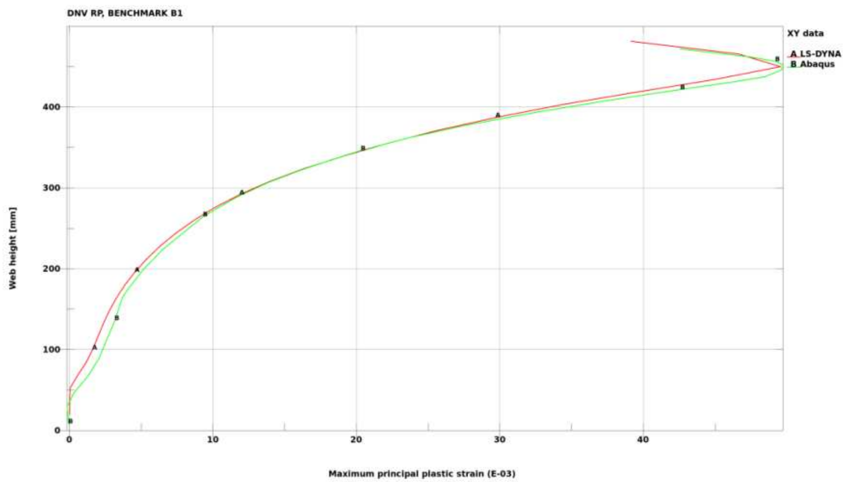
- Enable regularization curve LCREGD of *MAT_ADD_EROSION to be used with standard (non-GISSMO) failure criteria
- Added materials 103 and 187 for tetrahedron type 13
- New _MOISTURE option to *MAT_GENERAL_VISCOELASTIC(76) solids
- Prestressing and failure criteria to *MAT_CABLE_DISCRETE(71)
- New options to *MAT_LAMINATED_COMPOSITE_FABRIC(58): rate dependent strengths and failure strains, transverse shear damage
- New features for *MAT_SHAPE_MEMORY(30): curves/table for loading and unloading, strain rate dependence
- Added viscoplastic option to *MAT_ANISOTROPIC_ELASTIC_PLASTIC(157)

Element Technology

Higher order shell elements

- ELFORM=23: 8-noded quadrilateral
- ELFORM=24: 6-noded triangle
- SHL4_TO_SHL8 option on *ELEMENT_SHELL
  converts 4-noded element to 8-noded correspondence
- ESORT on *CONTROL_SHELL supported
- Implicit capabilities and contacts supported





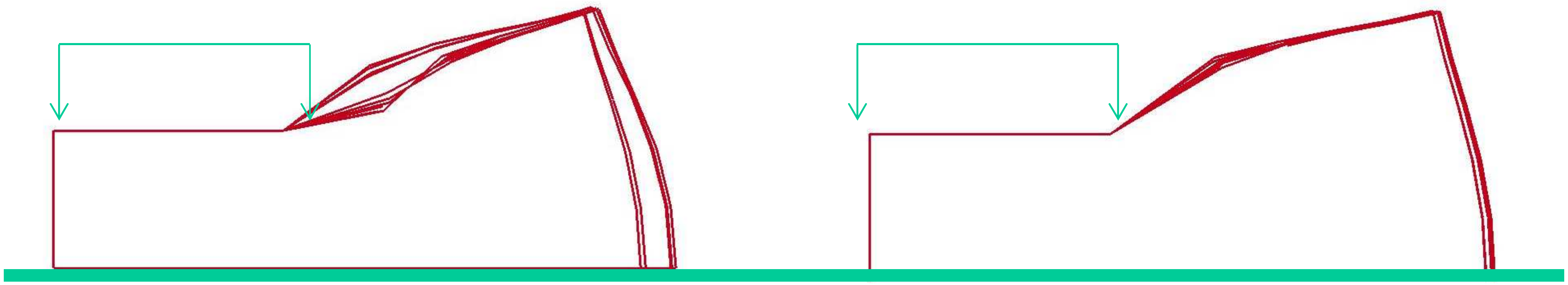
Cosserat point hexahedron

- Brick element using Cosserat Point Theory
- Implemented as solid element type 1 with hourglass type 10 (since R7.0.0)
- Hourglass is based on a total strain formulation
- Hourglass constitutive coefficients determined to get correct results for
  - Coupled bending and torsion
  - High order hourglass deformation
  - Skewed elements
- Seems to be a good alternative for rubber materials and coarse meshes
- NEW: 10 node Cosserat Point Theory tetrahedron is now available in R7.1.1

Cosserat 10-noded tetrahedron

- Accompanying the Cosserat Hexahedron, a 10-noded Cosserat Tetrahedron is available: ELFORM=16 + IHQ=10
- The Cosserat Point Elements (CPE) seem less mesh sensitive than other elements as examplified in the simulation below

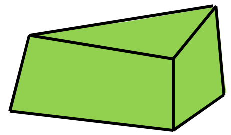
Plane strain compression of an incompressible hyperelastic material, a rigid plate is used for the compression. The problem is solved with several different mesh topologies (10-noded tets) and the sensitivity to different mesh orientations are shown.



Fully integrated tetrahedron ***CPE tetrahedron***

Miscellaneuos Enhancements

- New pentahedra cohesive elements (*SECTION_SOLID: ELFORM=21 & 22)
  - ELFORM=21 is the pentahedra version of ELFORM=19
  - ELFORM=22 is the pentahedra version of ELFORM=20



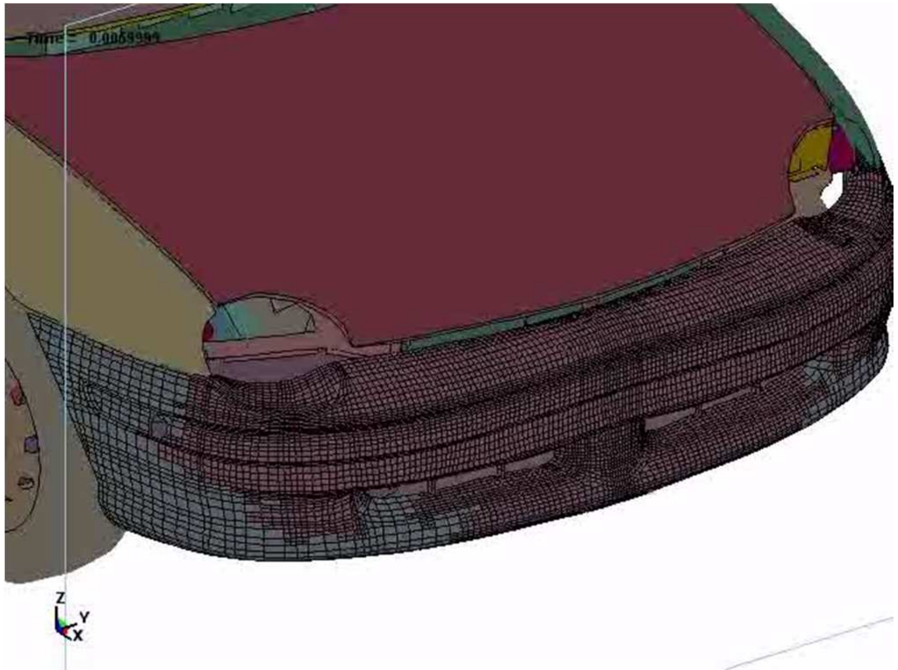
- *CONTROL_SHELL: NFAIL1 and NFAIL4 supported in coupled thermo-mechanical simulations
  - Delete distorted elements instead of error termination

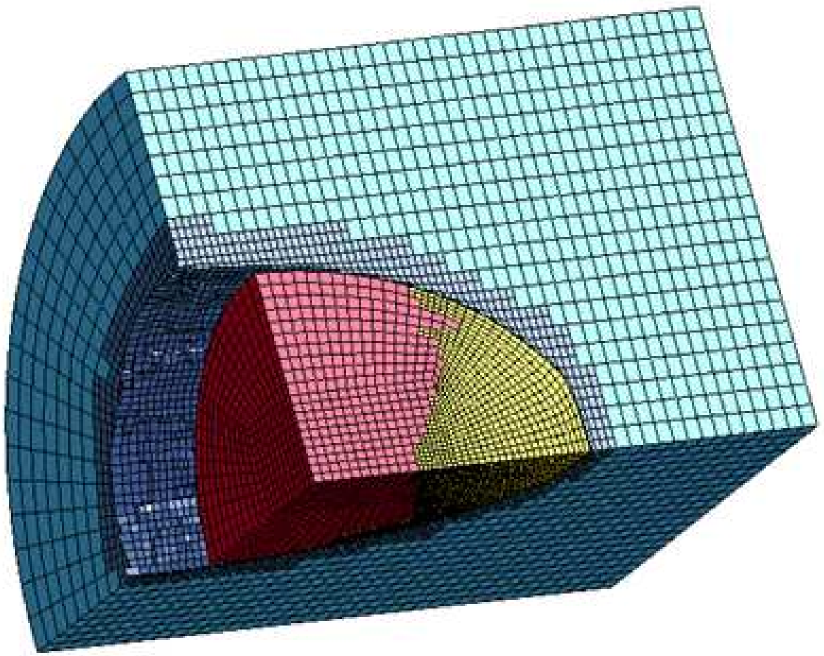
- New characteristic length calculation for higher order tets (ELFORM=16)
  - Length was originally assuming mid-side nodes at center between corner nodes and led to non-conservative time steps

- *CONTROL_SHELL: new option INTPERR
  - Terminate if *INITIAL_STRESS_SHELL and *SECTION_SHELL do not match up in terms of integration points

*CONTROL_REFINE_...

- Available for shells (_SHELL), solids (_SOLID), and ALE elements (_ALE)
- Adaptive refinement based on certain criteria (e.g. stress, energy, user-defined)
- Refinement possible during initialization or during the run
- Refinement can be reversed: coarsening
- Supports *CONTACT and *BOUNDARY_PRESCRIBED_MOTION

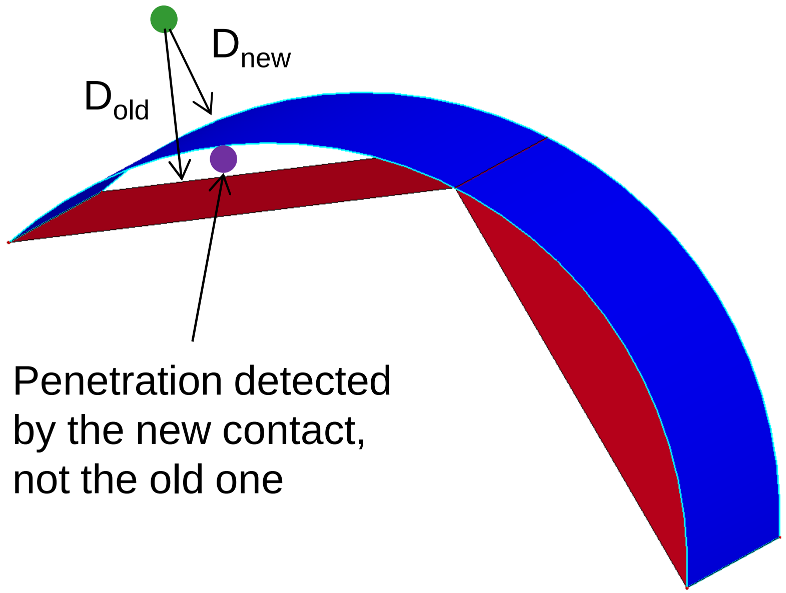




*CONTACT_ERODING_SINGLE_SURFACE

Isogeometric Analysis

- Isogeometric shells with NURBS: ELFORM=201 on *SECTION_SHELL
- Recent progress
  - Elements now run in MPP with excellent scaling.
  - Multi-patch analysis with thin shells by selectively adding rotational DOF at patch boundaries.
  - Added conventional mass-scaling for generalized shells
  - Improved post-processing capabilities
  - NURBS based contact algorithm (IGACTC on *CONTROL_CONTACT) enables better representation of real contact surface

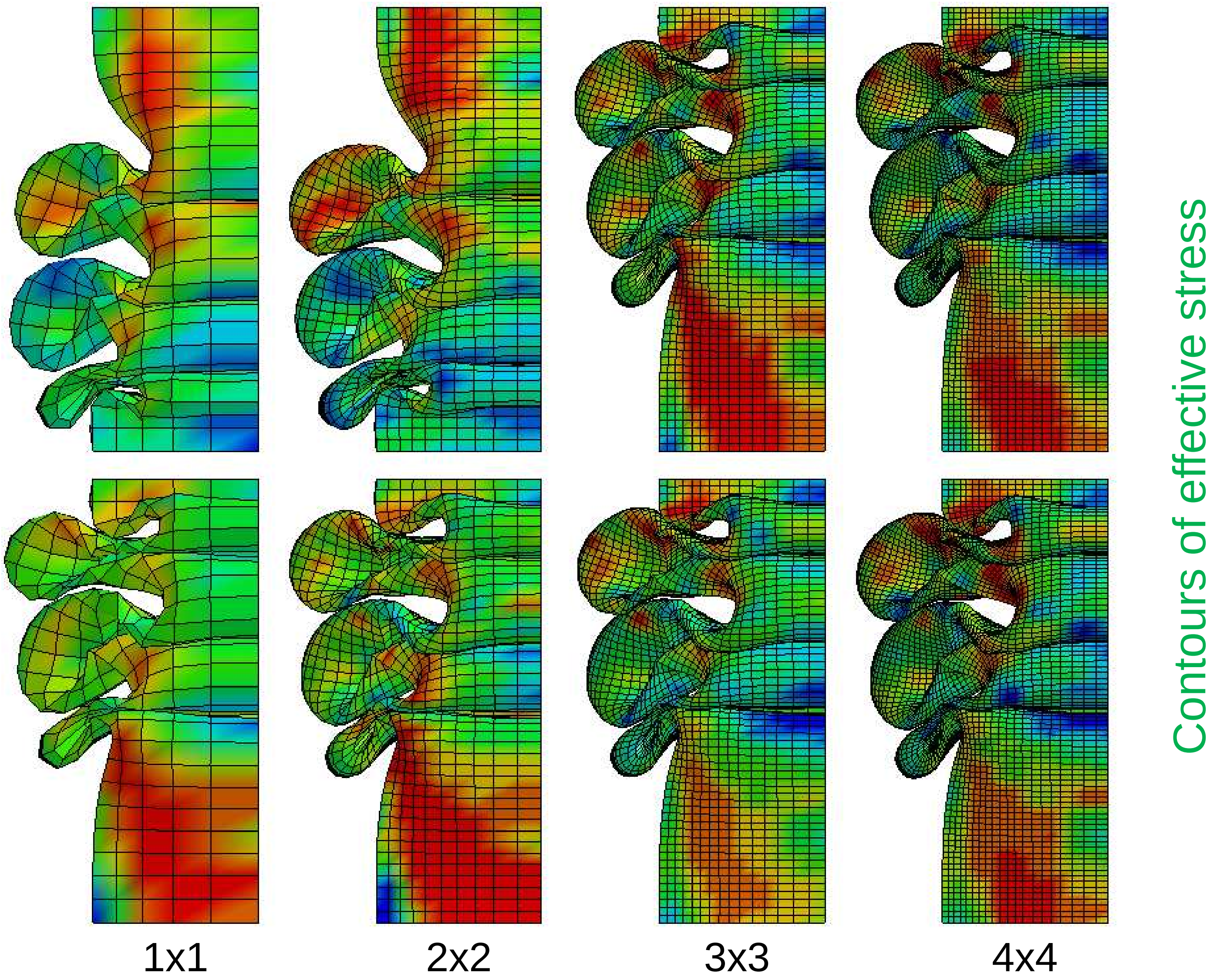


NURBS-based contact: Example

Old Contact:
Interpolation
elements

New Contact:
NURBS

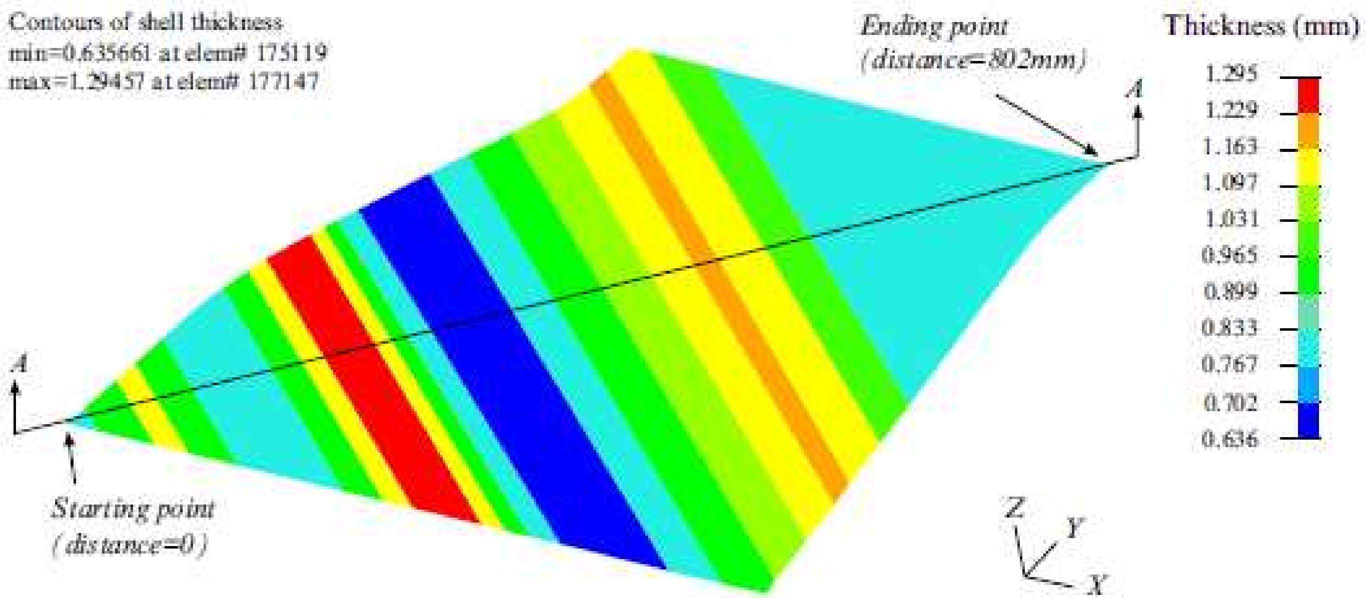
… and faster!



Forming Related Features

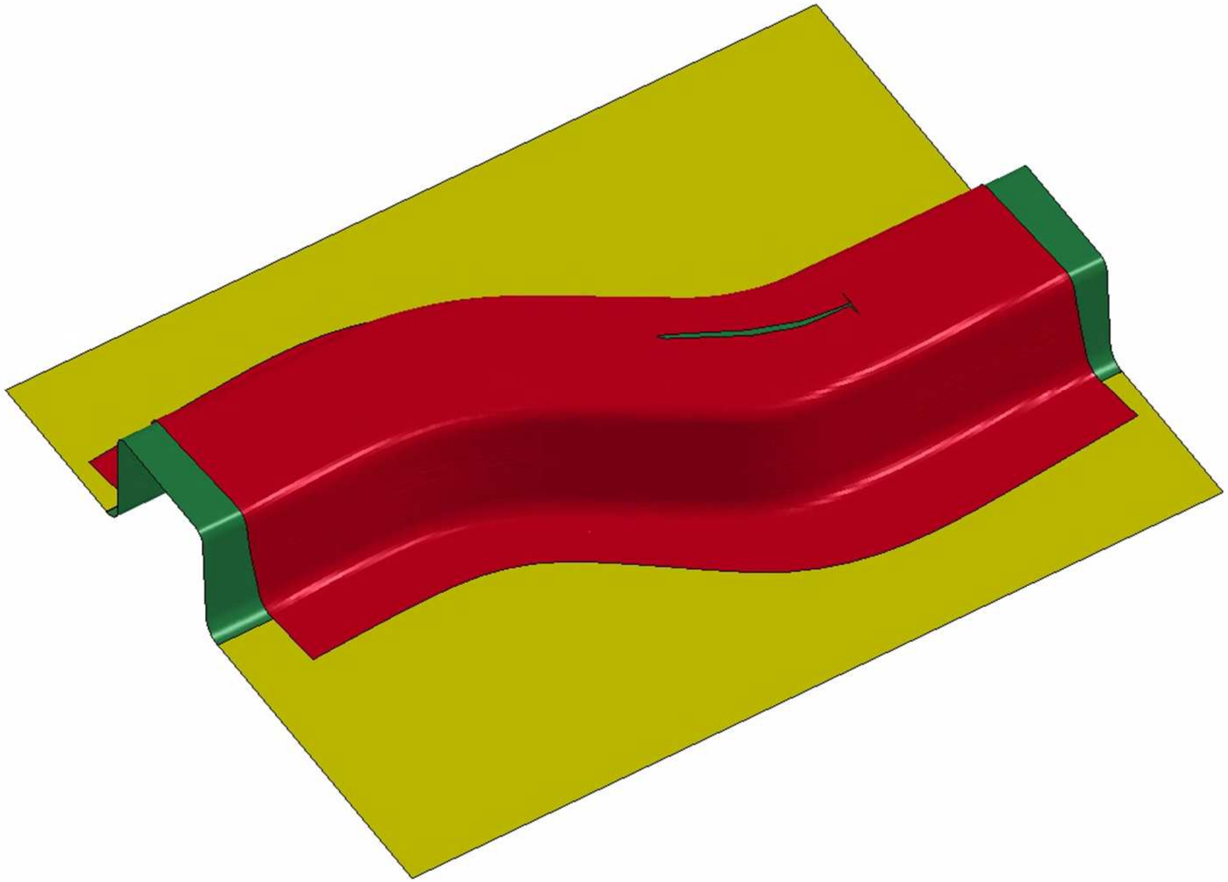
*CONTROL_FORMING_INITIAL_THICKNESS

- The initial thickness of Tailor rolled blank can vary along rolling direction
- To specify a varying thickness field across a sheet blank



*ELEMENT_LANCING

- Cuts an interior section of the metal without removing the section (e.g. for stress relief)
- Two types supported: instant and progressive
- Used together with *DEFINE_CURVE_TRIM_3
- Recent progress
  - Allow multiple curve intersections during lancing
  - Allow multiple lancing locations
  - Allow lancing boundary to be a closed loop



*CONTROL_FORMING_OUTPUT

- More friendly output control for D3PLOT and INTFOR
- Certain state deformations (e.g. “home position”) can be important
- Distances for each flanging steels to the matching tools for d3plot output is specified in a curve ID

```
*CONTROL_FORMING_OUTPUT
$ -------1---------2---------3---------4---------5
$      CID      NOUT      TBEG      TEND   Y1/LCID
      1116        10  &clstime  &endtime      -980
      1117        10  &clstime  &endtime      -980
      1118        10  &clstime  &endtime      -980
      1119        10  &clstime  &endtime      -980
*CONTROL_FORMING_OUTPUT_INTFOR
$ -------1---------2---------3---------4---------5
$      CID      NOUT      TBEG      TEND   Y1/LCID
      1116        10  &clstime  &endtime      -980
      1117        10  &clstime  &endtime      -980
      1118        10  &clstime  &endtime      -980
      1119        10  &clstime  &endtime      -980
```

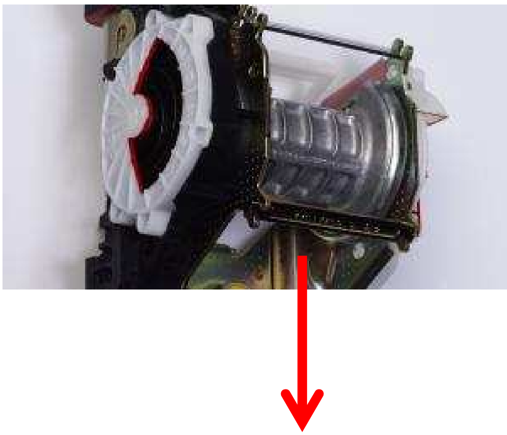
```
*DEFINE_CURVE
980
23.0
19.0
15.0
13.5
13.0
5.0
3.0
2.5
2.0
1.0
```

Occupant Safety

*ELEMENT_SEATBELT_PRETENSIONER

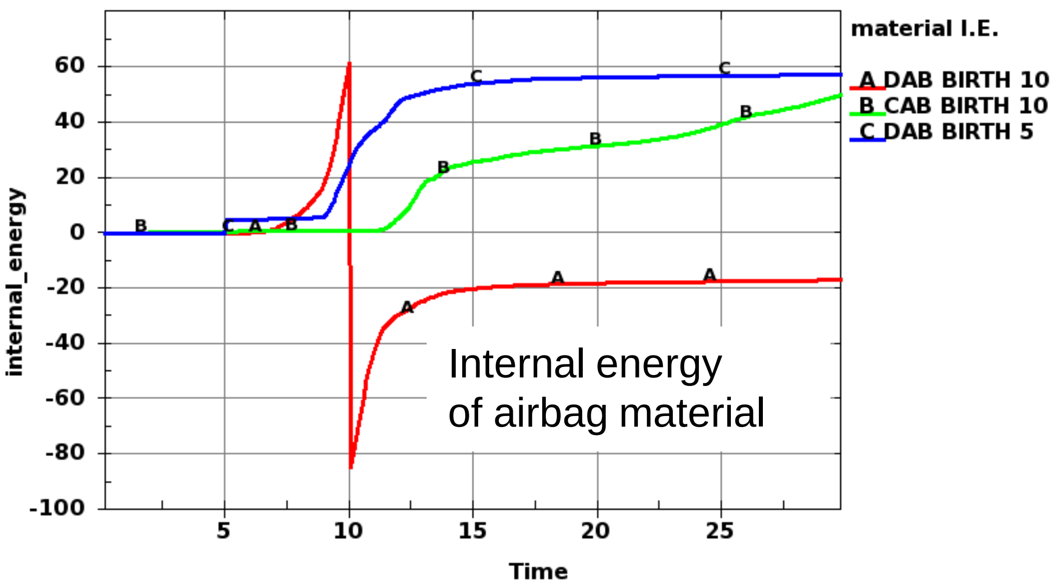
- Pull-in or belt load history of pretensioners could vary when different size of dummies are used, or pretensioners are activated at different times.
- Different pretensioner models are needed for different crash scenario.
- A pretension-energy based option is added. This allows a single pretensioner model to be used for various scenarios.

→ New pretensioner types SBPRTY=8 (retractor pretensioner) and SBPRTY=9 (buckle or anchor pretensioner)



*AIRBAG/*MAT_FABRIC: Material-dependent birth times

- A single definition of birth time using *AIRBAG_REFERENCE_GEOMETRY _BIRTH is applied to **all** reference geometry definitions, i.e., all reference geometry definitions share the same birth time.
- In a model involving more than one airbag model, each airbag has its own firing time, and therefore needs its own birth time for its reference geometry definition.
- RGBRTH in *MAT_FABRIC is used to define material dependent birth time.



*SENSOR_DEFINE_FUNCTION

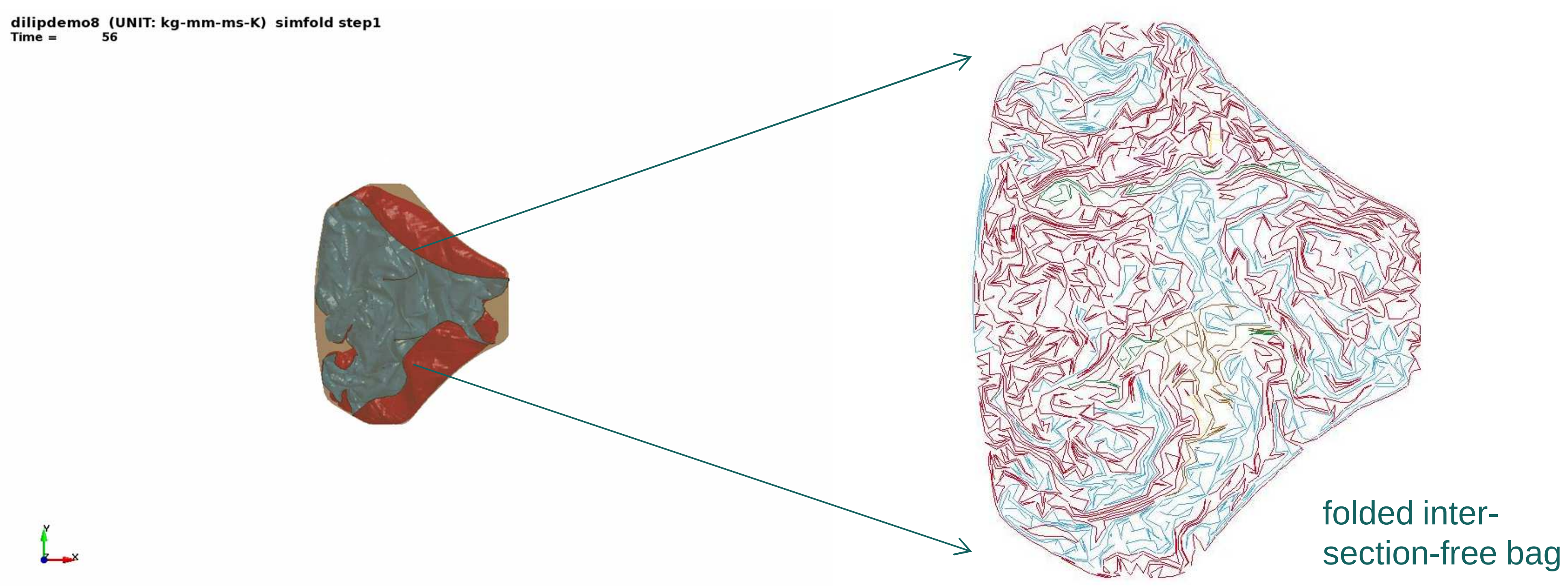
- The value associated with this sensor is computed by performing mathematical calculations defined in *DEFINE_FUNCTION, with the information obtained from other sensors
- This could replace *SENSOR_DEFINE_CALC-MATH, which can only perform limited mathematical calculations
- Up to 15 *DEFINE_SENSORs can be referenced in defining a mathematical operation

*SENSOR_DEFINE_MISC

- Trace the value of a miscellaneous item, MTYPE .eq.
  - ANGLE: Angular accelerometer sensor tracing the angle between two lines
  - RETRACTOR: Seatbelt retractor payout rate
  - RIGIDBODY: Accelerometer sensor tracing the kinematics of a rigid body
  - TIME: Current analysis time
- This card replaces *SENSOR_DEFINE_ANGLE

*CONTACT: SOFT=2 and DEPTH=45

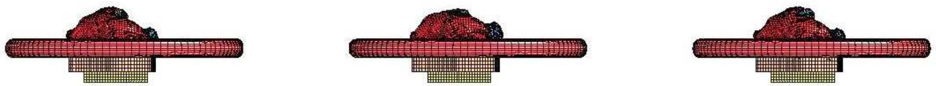
- Based on Splitting Pinball Method, Belytschko and Yeh, 1993
- Able to treat numerous contact situations in a consistent way, including those posing difficulties for node-to-segment contact.
- The new option is gaining popularity among users because of its robustness when handling complicated contact like folded airbag.



*CONTACT: SOFT=2 and DEPTH=45

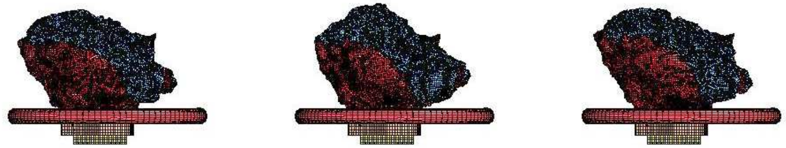
- Deployment of the folded bag using various number of CPUs

time = 10.0 ms



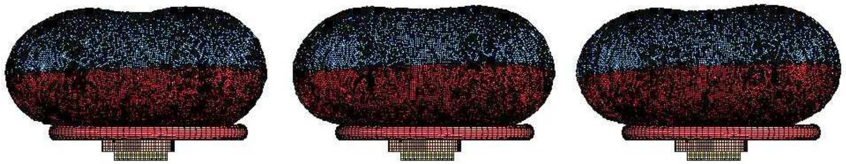
8 CPU | 48 CPU | 96CPU

time = 30.0 ms

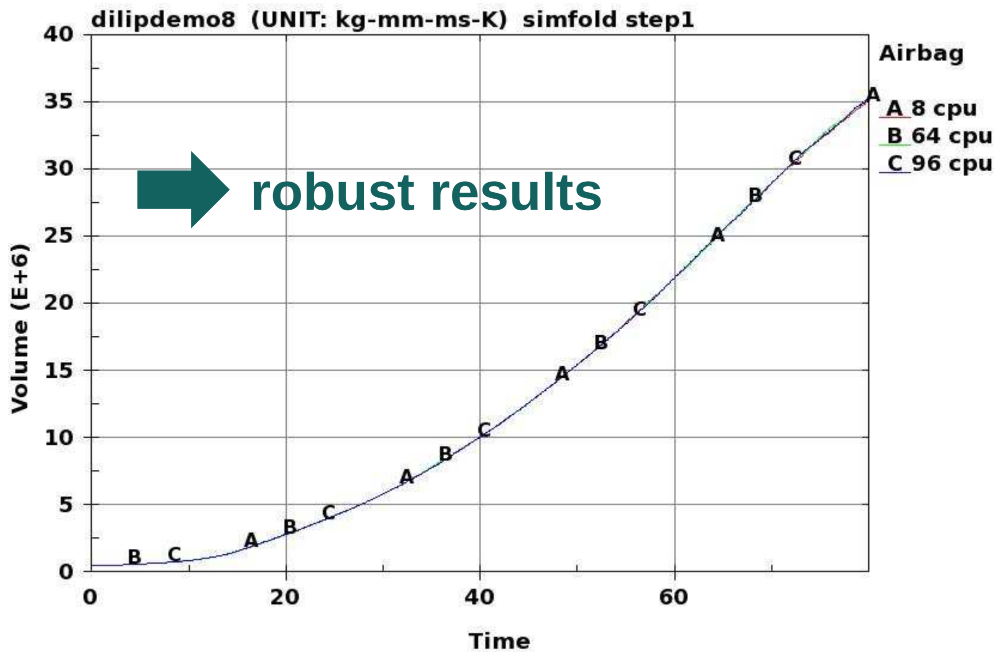


8 CPU | 48 CPU | 96CPU

time = 80.0 ms



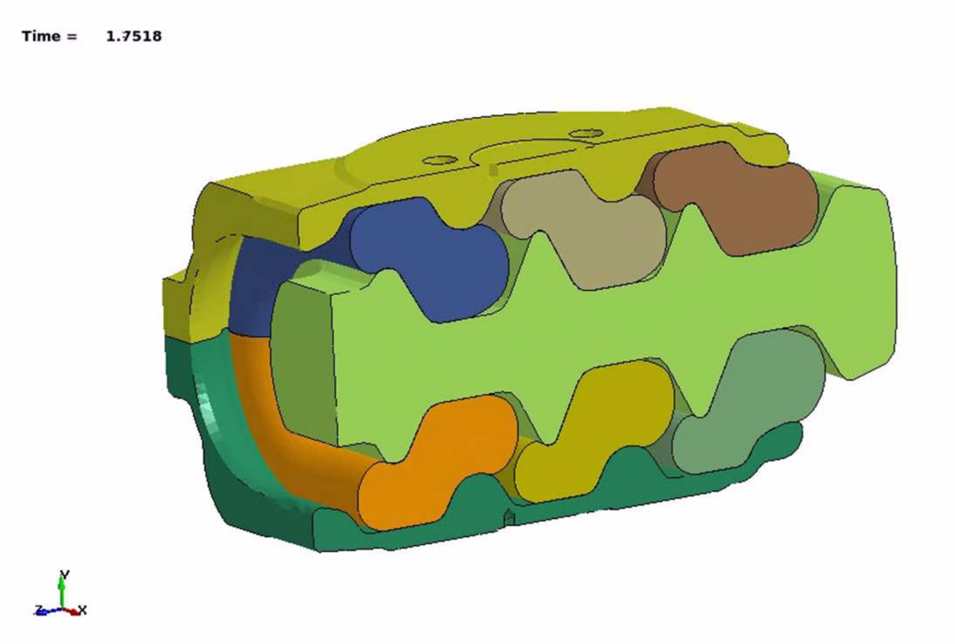
8 CPU | 48 CPU | 96CPU

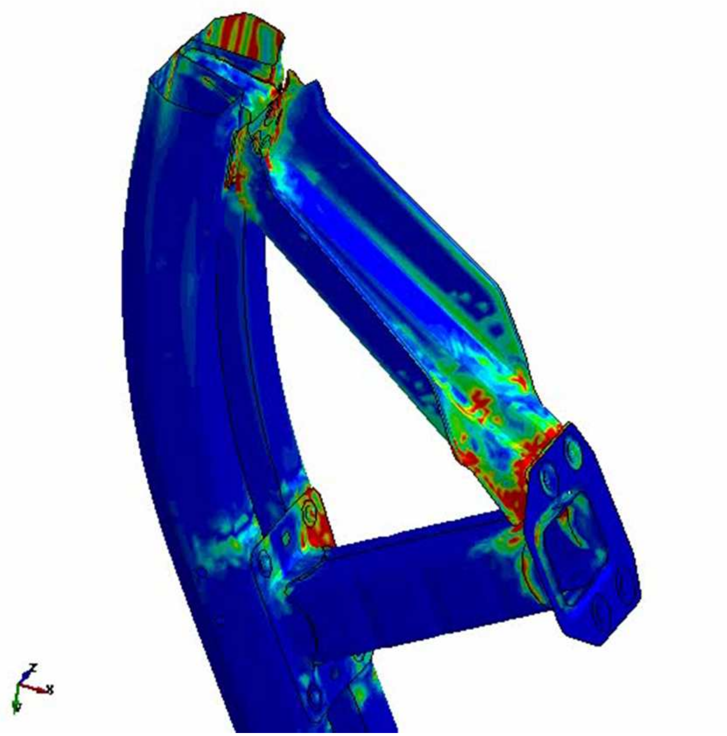


Implicit Analysis

Implicit Enhancements (1)

- Much work on improving robustness and convergence characteristics of solver
  - Convergence tolerances
  - Line search (LSMTD=5)
  - Contacts and smoothness
  - R7.1.1 promising
  - Debug informations: D3ITCTL on *CONTROL_IMPLICIT_SOLUTION + RESPLT on *DATABASE_EXTENT_BINARY
  - Easy detection of non-converged "spots"



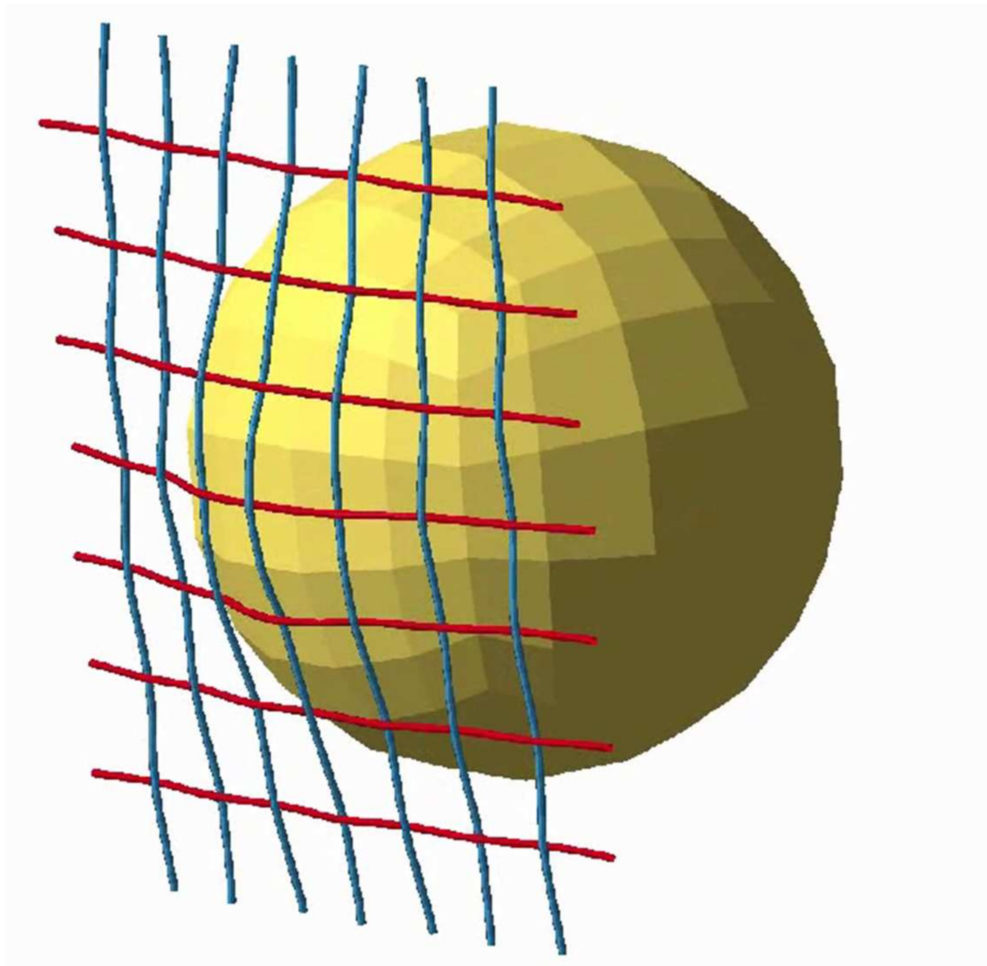


Implicit Enhancements (2)

- New option IAUTO=2 on *CONTROL_IMPLICIT_AUTO to limit the mechanical time step by the active thermal time step
- New option IRATE=2 on *CONTROL_IMPLICIT_DYNAMICS to turn off rate effects in material models for both implicit **and** explicit
- *CONTROL_IMPLICIT_BUCKLE
  - Extend implicit buckling feature to allow for implicit problems using inertia relief
  - Extend implicit buckling feature to allow for intermittent mode extraction: NMODE<0
- *CONTROL_DYNAMIC_RELAXATION
  - Extend implicit-explicit switching to allow explicit simulation for the dynamic relaxation phase and implicit for the transient phase
- New keyword *CONTROL_IMPLICIT_MODAL_DYNAMIC

Mortar Contact

- Improved global search algorithm
  - Significant speed-up especially for single surface contact
- Support contact with lateral surface of beams
  - Beam cross section approximated as circular



- IGAP.GT.1 incorporates progressive stiffening for large penetrations
- MINFO on *CONTROL_OUTPUT activates output for debugging
  - Maximum penetration is reported in message file together with elements

General New Features

- New keyword card *CONTROL_REQUIRE_REVISION to prevent the model from being run in old versions of LS-DYNA

- New command line option "ldir=" for setting a "local" working directory

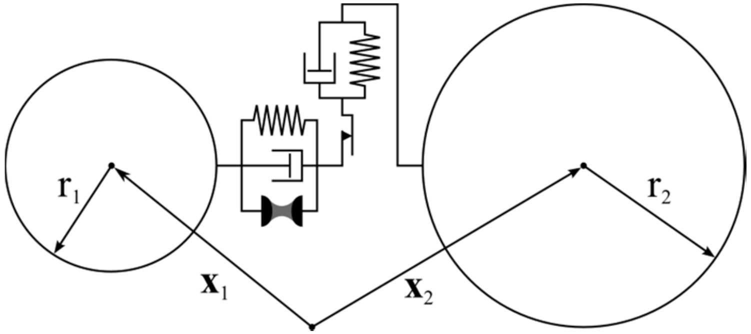
- *CONSTRAINED_BEARING to define a bearing between 2 nodes
  - This feature incorporates equations to simulate the effect of a ball bearing

- New keyword *DEFINE_TABLE_MATRIX
  - Alternative way of defining a table and the curves that the table references from a single unformatted text file, e.g., as saved from an Excel spreadsheet

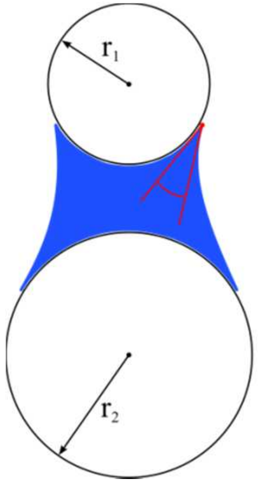
Discrete Element Method

Discrete-Element Method (DEM) in LS-DYNA

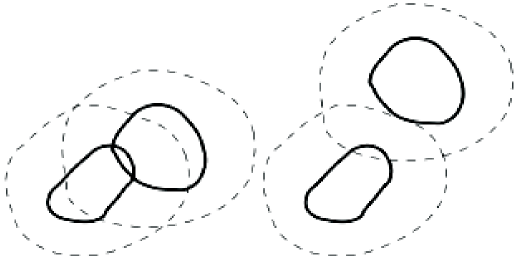
- Basic Ideas
  - Newtonian mechanics of a set of particles
  - Contact between particles
- Used to model
  - powders like toner, …
  - granular matter like sand, ore, …
  - large rocks, liquids
- Applications include
  - mining, mineral processing
  - agriculture and food handling and storage silos
  - chemical and civil Engineering



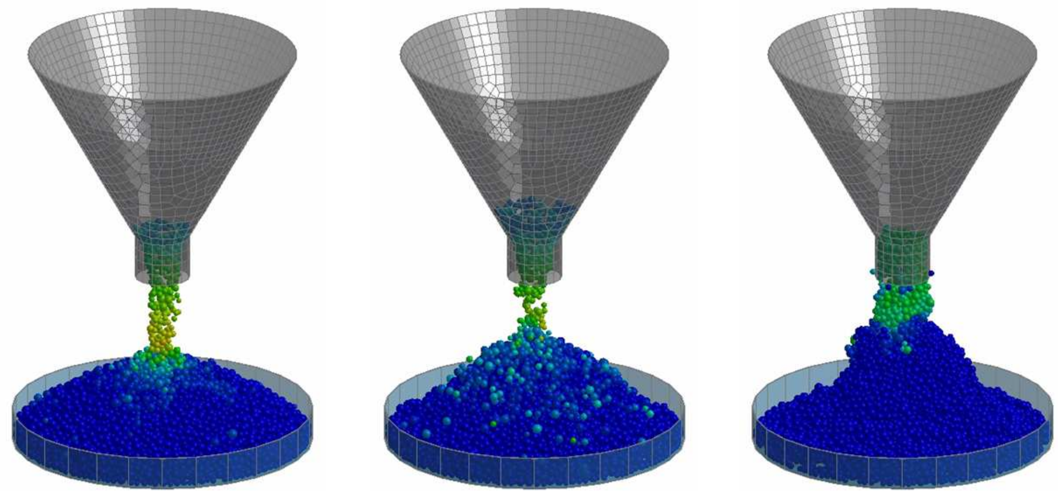
mechanical contact



liquid bridge

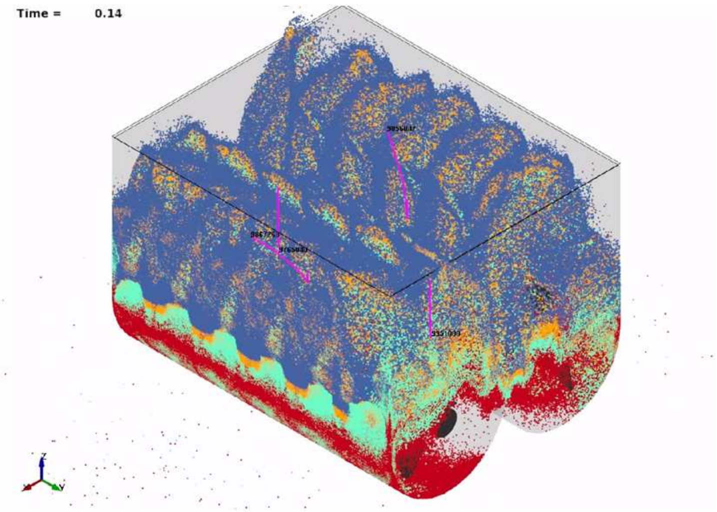


- Filling of dry / wet sand and mud
  - Stable interaction of particles with deformable / rigid structures



dry sand | wet sand | mud

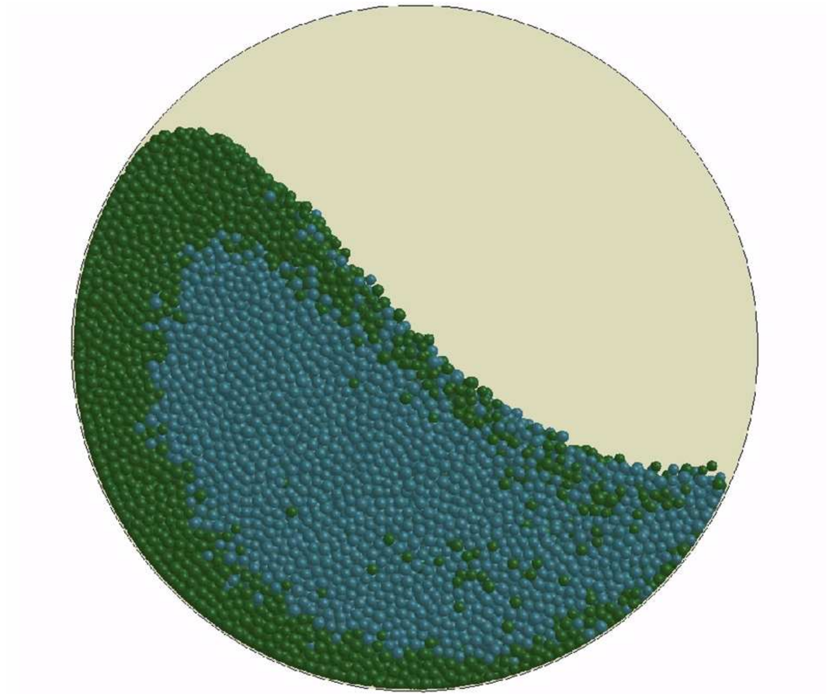
- Good parallel scalability



10 million particles

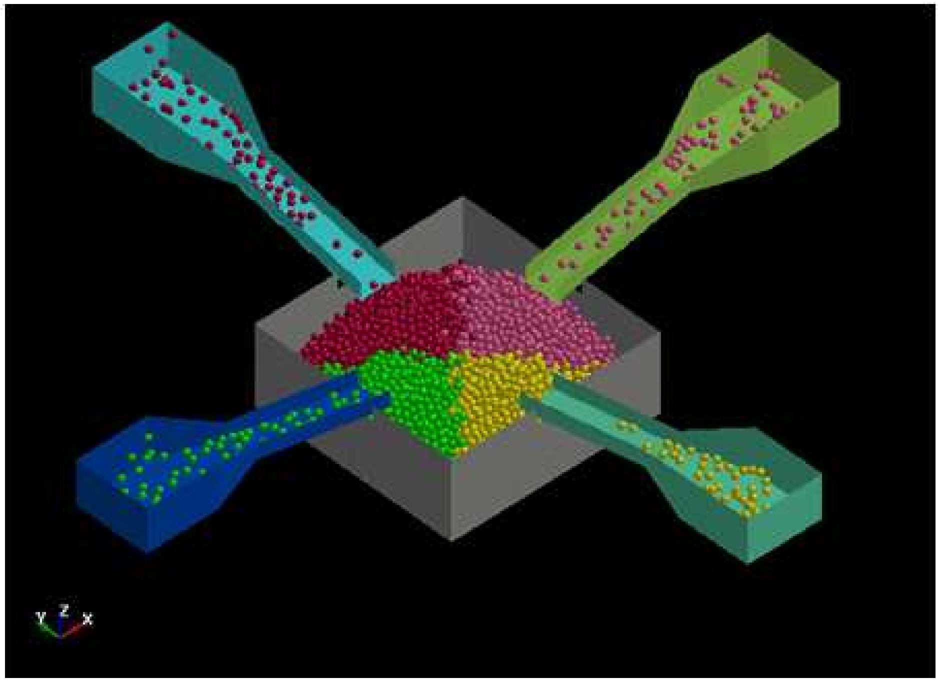
*DEFINE_DE_BY_PART

- Define control parameters for spheres by part-ID
- Overrides the values set in *CONTROL_DISCRETE_ELEMENT



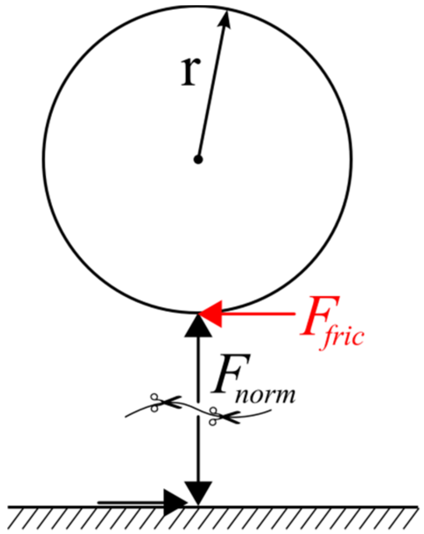
*DEFINE_DE_INJECTION

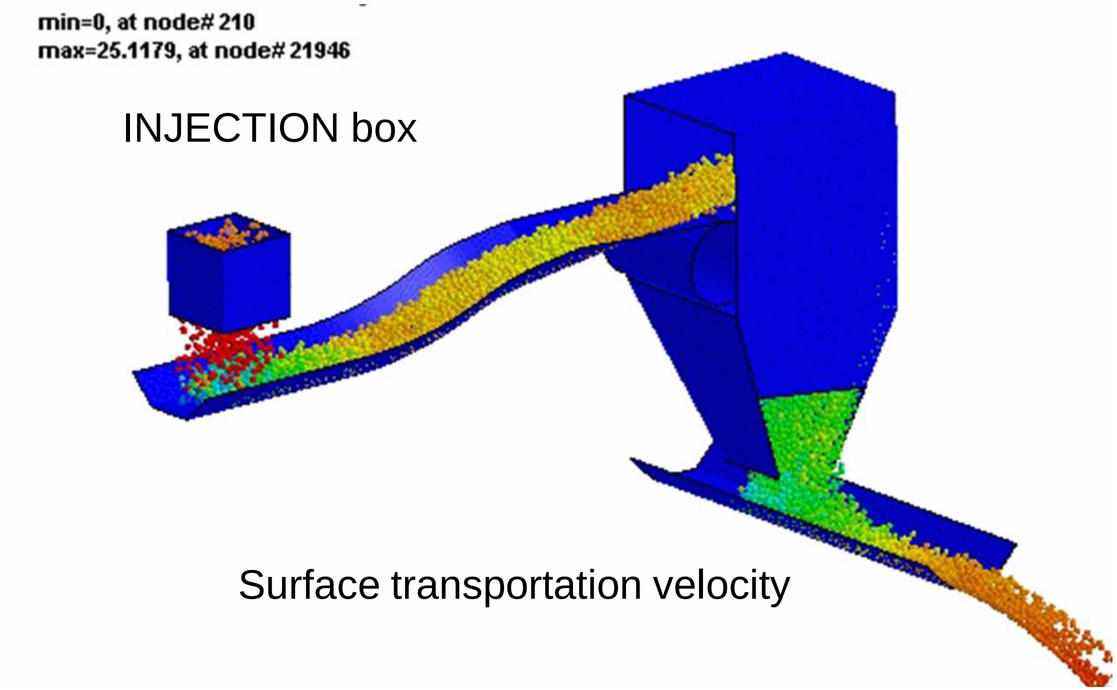
- Automatic sphere generation through rectangular plane

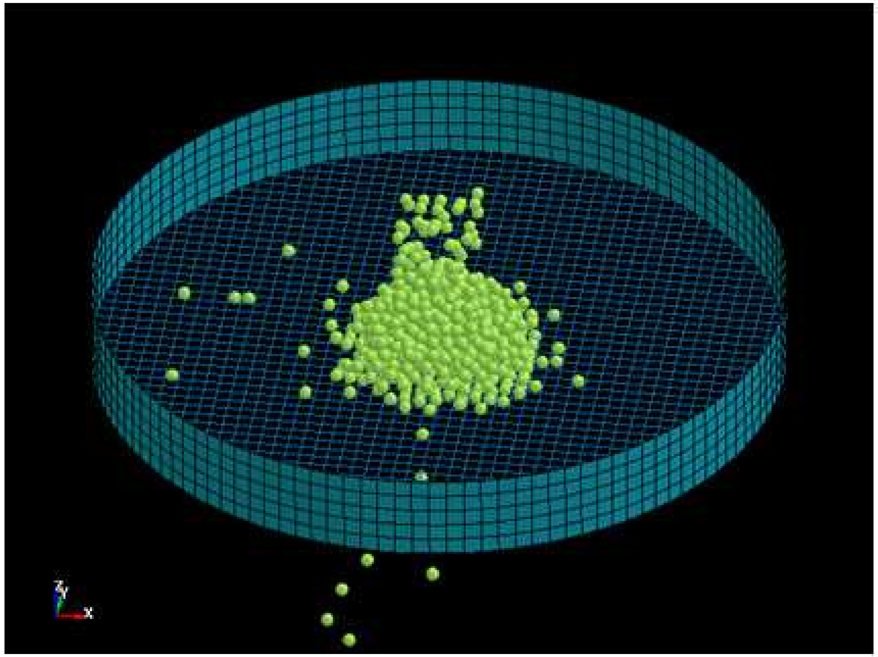


*DEFINE_DE_TO_BEAM_COUPLING
*DEFINE_DE_TO_SURFACE_COUPLING

- Application of traction forces at the perimeter of the spheres
- Surface velocity for transportation belts

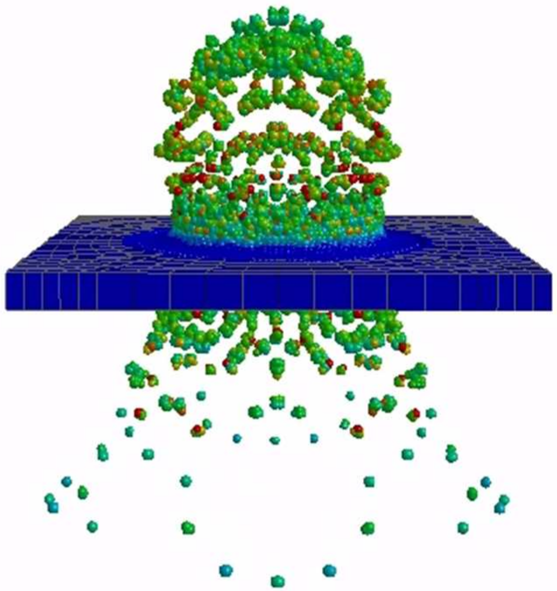






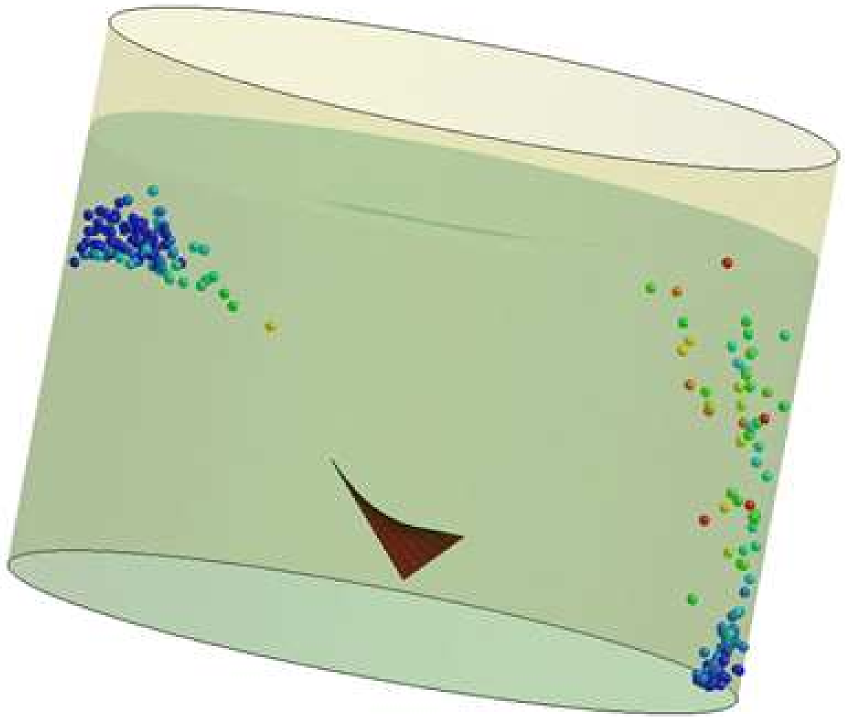
*DEFINE_SPH_DE_COUPLING

- Penalty based SPH to SPH/DE contact

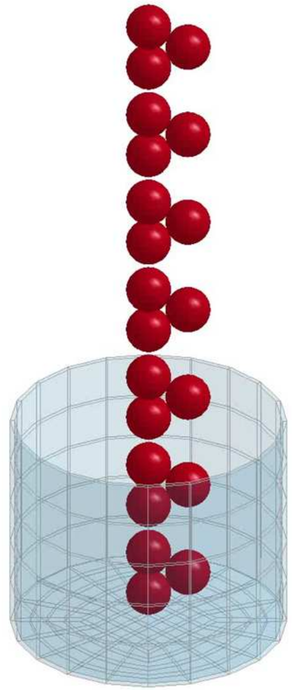


*ALE_COUPLING_NODAL_DRAG

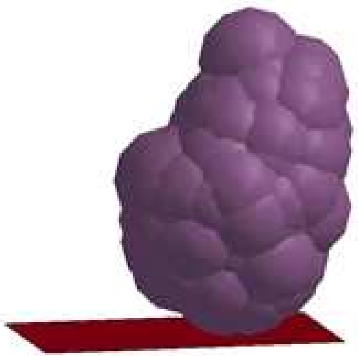
- Available soon (developer version)
- Penalty based ALE to DE contact

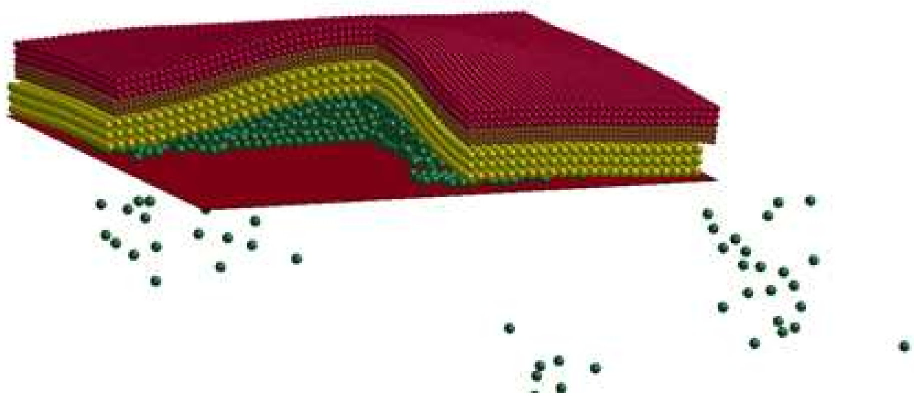


*DEFINE_DE_BOND



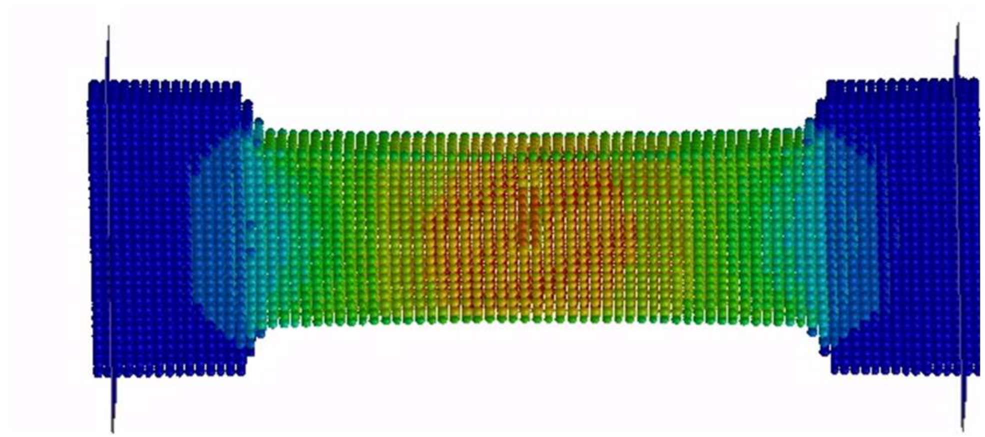
- DE Bond Type I
  - Simple links, truss or beam between spheres (extended Peridynamics)
  - Manual elastic bond definition between spheres
  - Bonds may be breakable or unbreakable
  - Define maximum gap for bondage for clustered particles

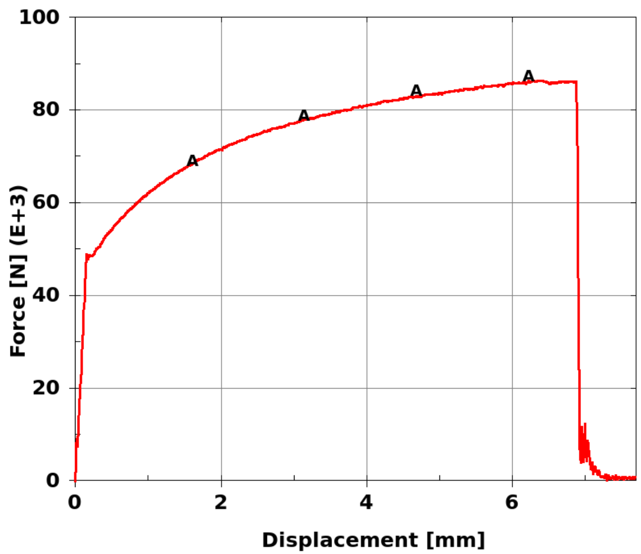




*DEFINE_DE_HBOND

- DE Bond Type II
  - Heterogeneous links to model continuum mechanics (Meshless Local Petrov-Galerkin)
  - Based on regular *MAT definitions
  - Extended features for brittle failure, micro cracks, etc.
- Benchmark test: Tension bar
  - Goal: Reproduce elasto-plastic material behavior

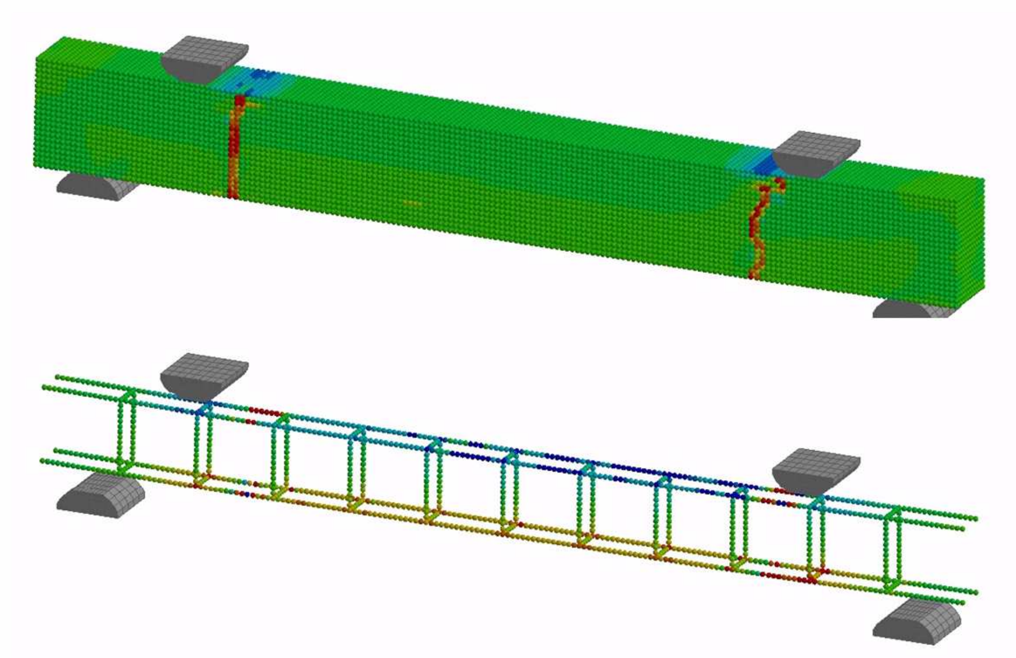




- More Information:
  - Talk by Z. Han (LSTC), International LS-DYNA Conference, 8-10 June, Detroit

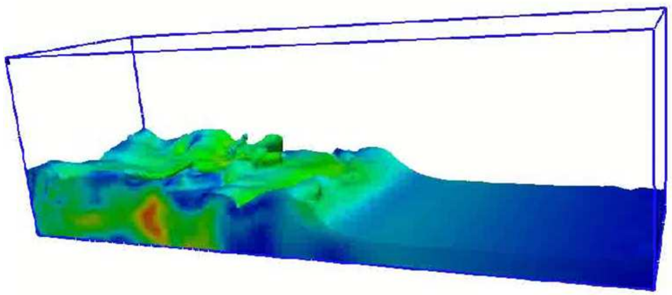
*INTERFACE_DE_HBOND

- Define different failure models for the heterogeneous bonds between particles
  - of the same material
  - of different materials
- Application for heterogeneous bond model with interface
  - Failure of a reinforced concrete beam under 4-point bending
    - Possibility to distinguish between reinforcement bars and concrete



Conclusion: LS-DYNA R7.1.1

- Many more developments and enhancements in other areas (ALE, EFG, SPH, Thermal, Frequency Domain, …) and the multiphysics solvers (ICFD, CESE, EM, Chemistry)



Presentations at Infoday Multiphysics (March 2014):
http://www.dynamore.de/en/news/news-en/2014/info-mp

- Comprehensive list of enhancements and corrections on www.dynasupport.com/release-notes
- R7.1 Keyword User's Manual can be downloaded from www.dynamore.de/en/downloads/manuals