Recent Developments of LS-DYNA® in Stamping Simulation

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Outline

- Implicit method
- Material work-hardening
- Some new keywords
- Surface low detections
- Conclusions

Improvements in Implicit Method

Implicit Method

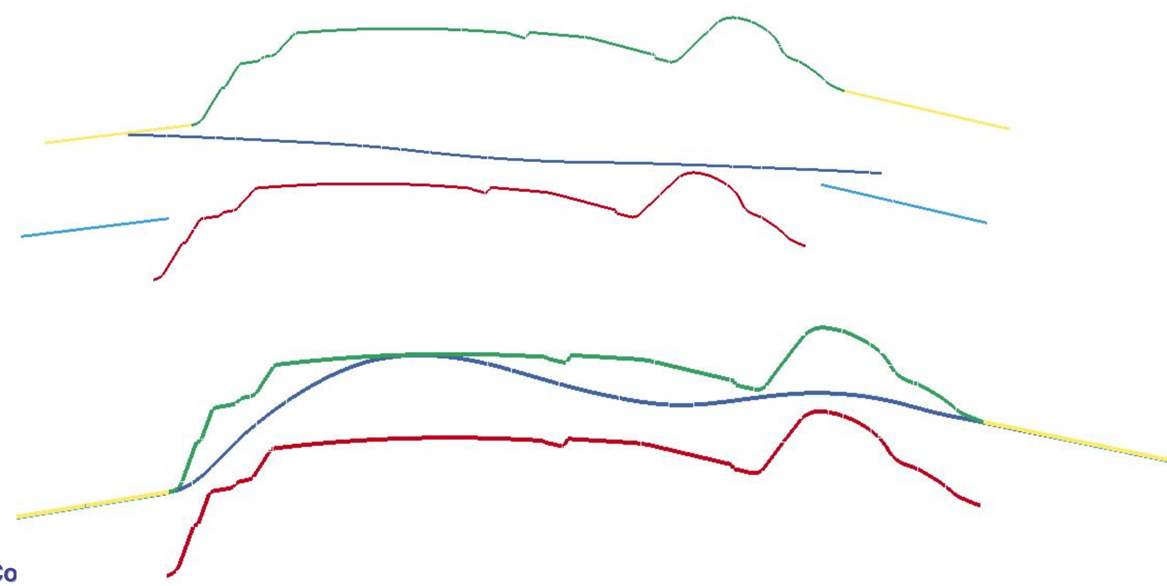
- Implicit method has been gaining more popularities in sheet stamping simulation
  - Initial application was mainly limited to springback predictions
  - Gravity loading simulation has been proven to be robust with implicit method
  - Implicit method has also shown great potentials in flanging simulation.

Implicit Method: Binder Wrapping

- Binder wrapping characteristics
  - Large blank movements, large dynamic effect
  - Small plastic deformation
  - Element is relatively coarse, and the number of element is small
  - Implicit method might be the preferred one
- Recent developments
  - New implicit contact
  - New features to help convergence
  - An extensive parameter studies
    - The default parameters are suitable for most of the binder wrapping process
    - It is easy to use
    - User in-dependent results can be obtained

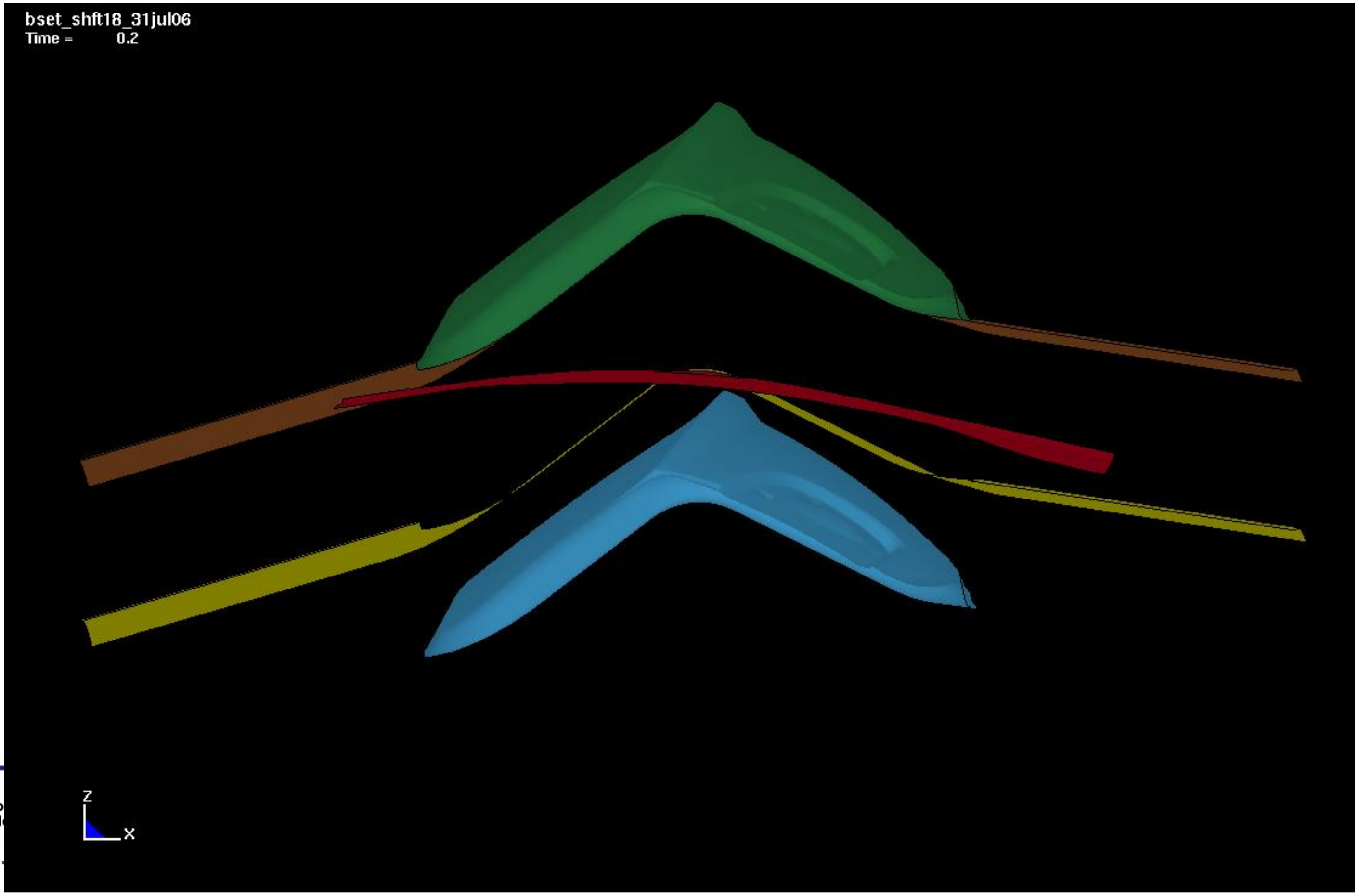
Implicit Method: Binder Wrapping

- The proper step size for a typical binder wrapping process
  - The new algorithm allow large time step. While the old time will limit the time step size
  - Too small time step will require many time steps
  - Too large time step will require more iterations, sometimes, the result is not good



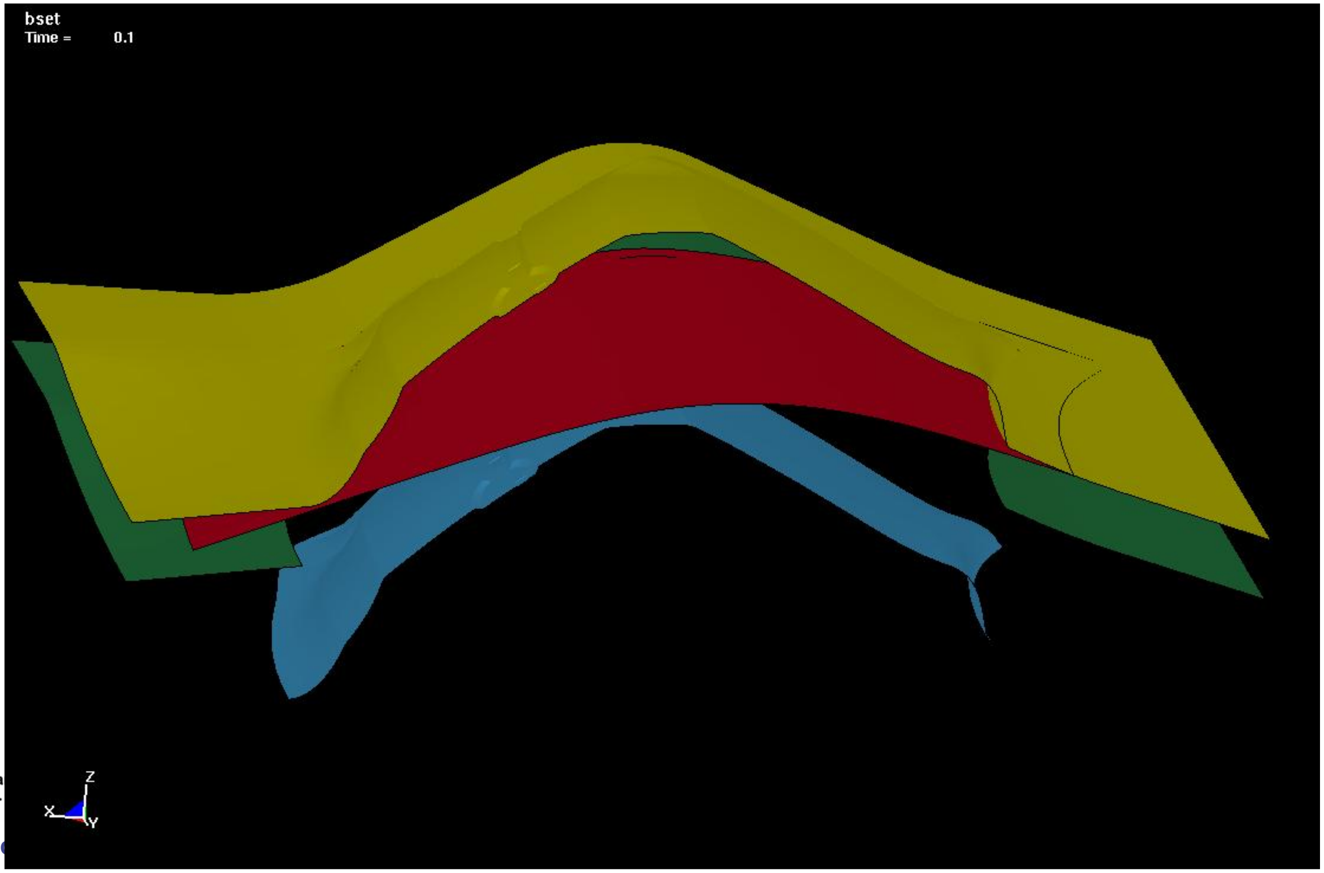
Implicit Method: Binder Wrapping

- Too small time step might have convergence problem



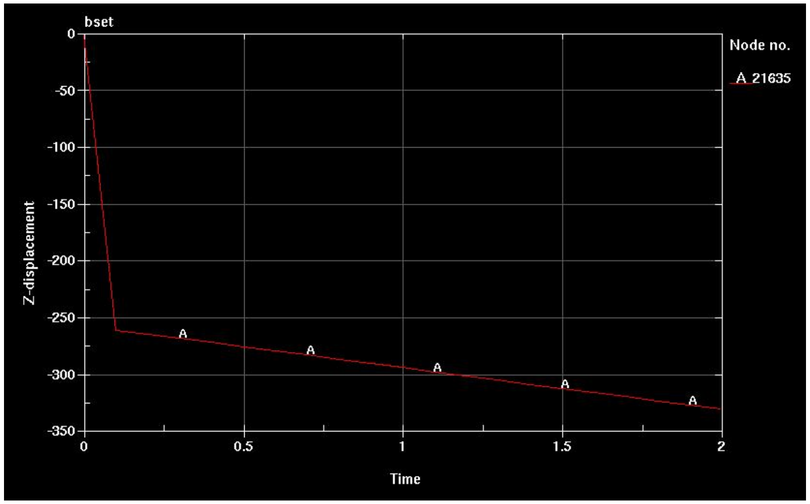
Implicit Method: Binder Wrapping

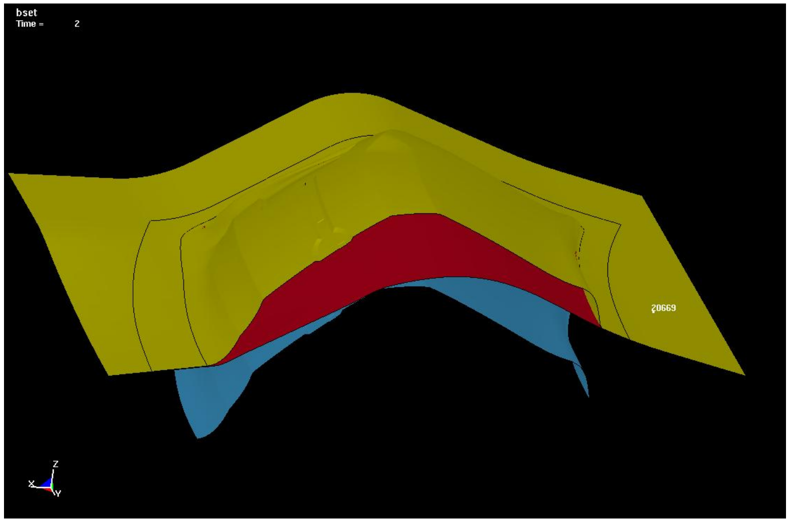
- Reasonable time step should make sure that most of the rigid body motions are constrained



Implicit Method: Binder Wrapping

- A typical time step selection
  - 10 time steps are used
  - It took 12 minutes to finish with ONE CPU





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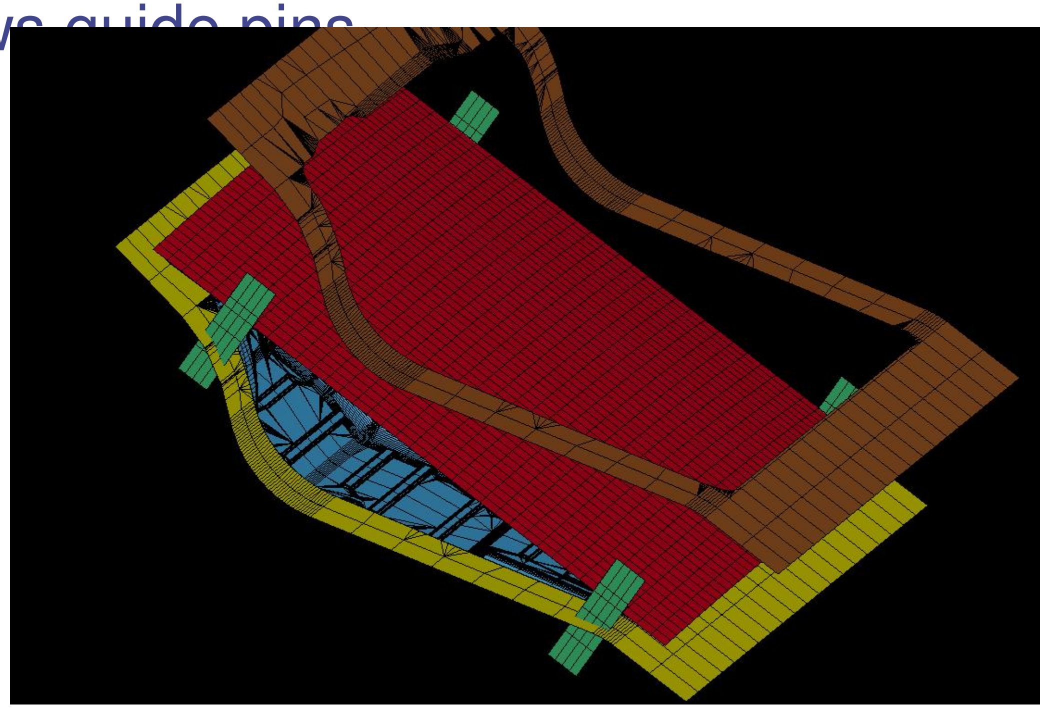
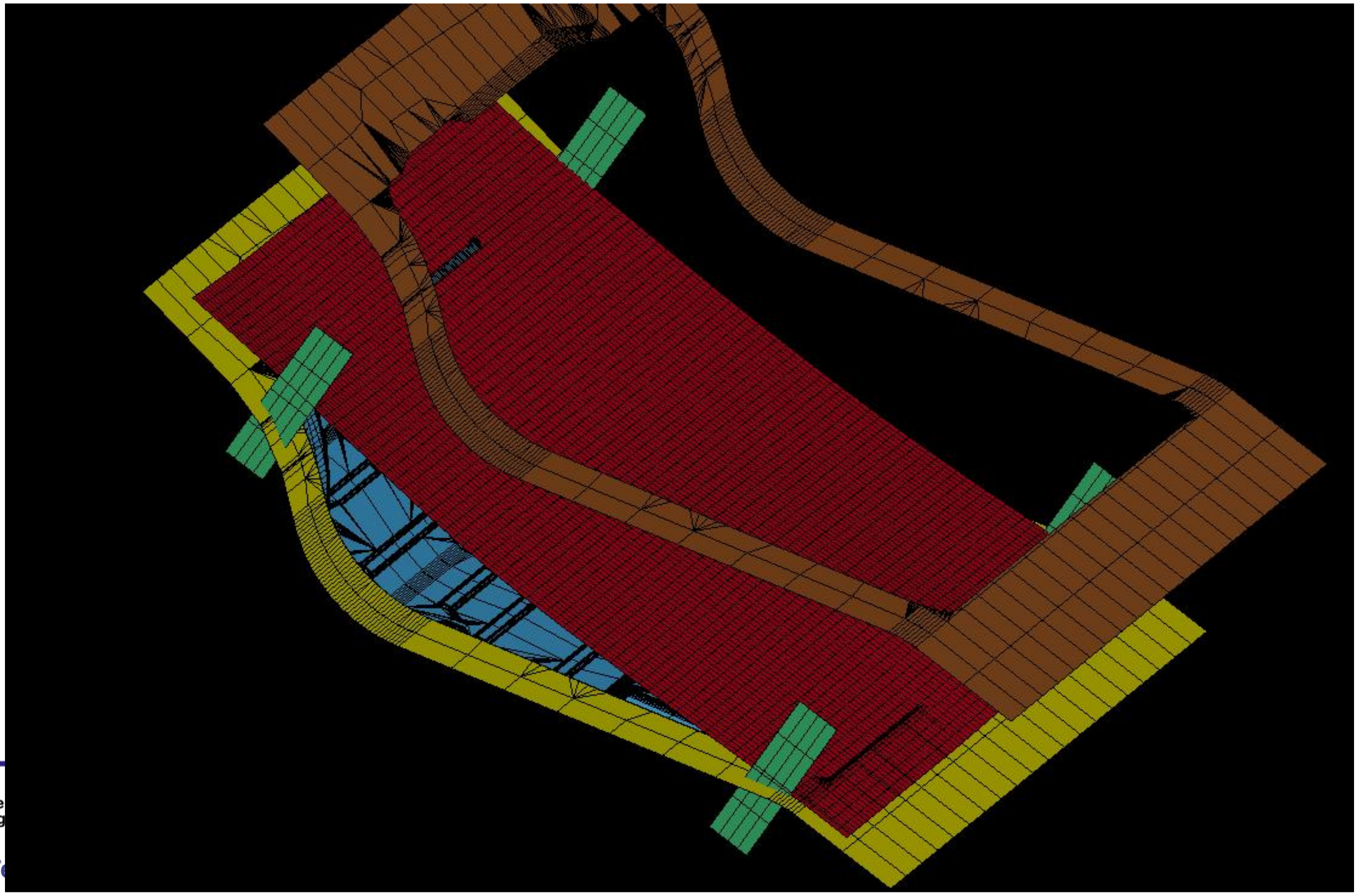
Implicit Method: Binder Wrapping

- Binder and Gravity Loading are combined into one simulation
  - In the old method, gravity loading has to be done separately
  - It allow mesh refinement during each step
  - It allows guide pins



Implicit Method: Binder Wrapping

- After Gravity Loading, blank elements are refined



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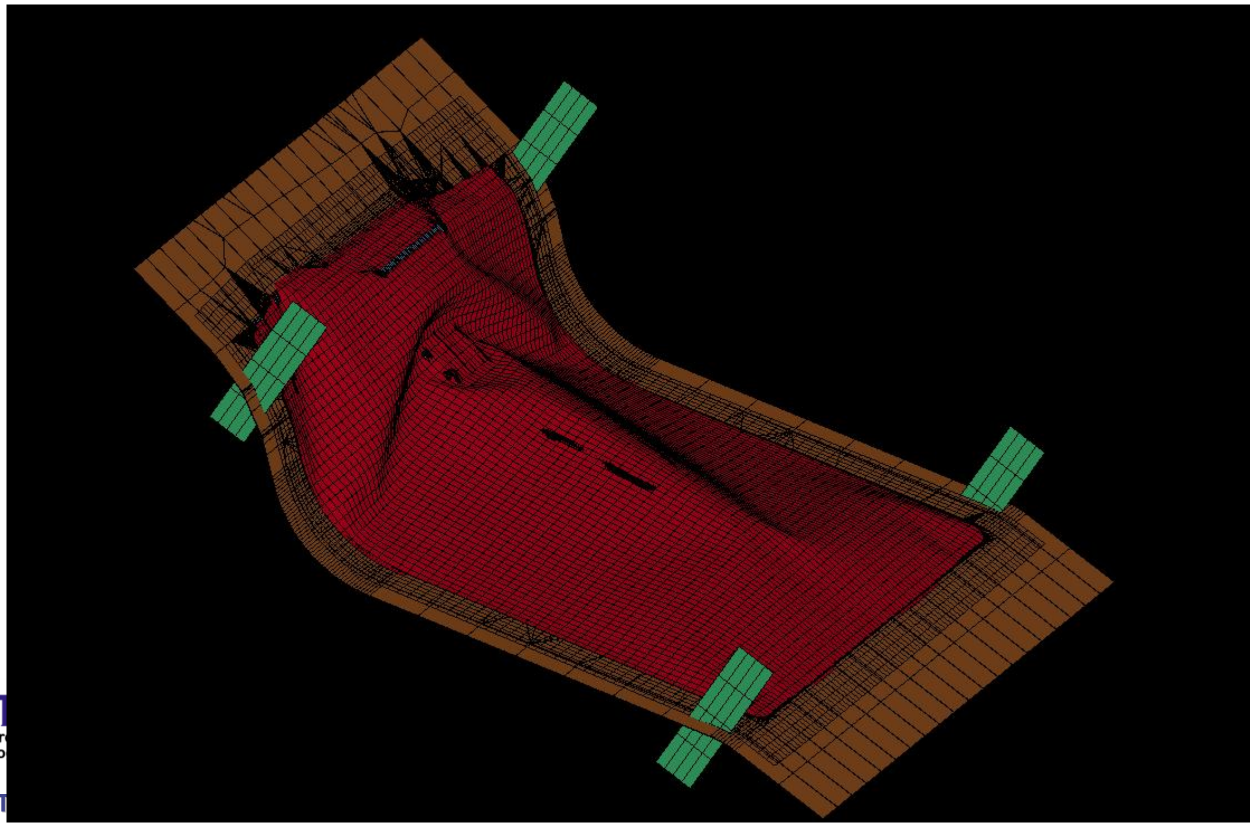
Implicit Method: Binder Wrapping

- Final geometry: all the buckling mode has been correctly simulated
  - It took 90 minutes to finish



Implicit Method: Other Applications

- Initially developed for metal stamping simulations that involve gravity loading of blanks on dies.
- Now extended as a general capability
  - Serial, SMP and MPP implementation
- Robust contact treatment
- Vehicle does not need to be supported to eliminate rigid body modes
- Elimination of loose parts not required
- Reduces model preparation time dramatically over traditional implicit method.

Implicit Method
Compensation Based on Scan Data

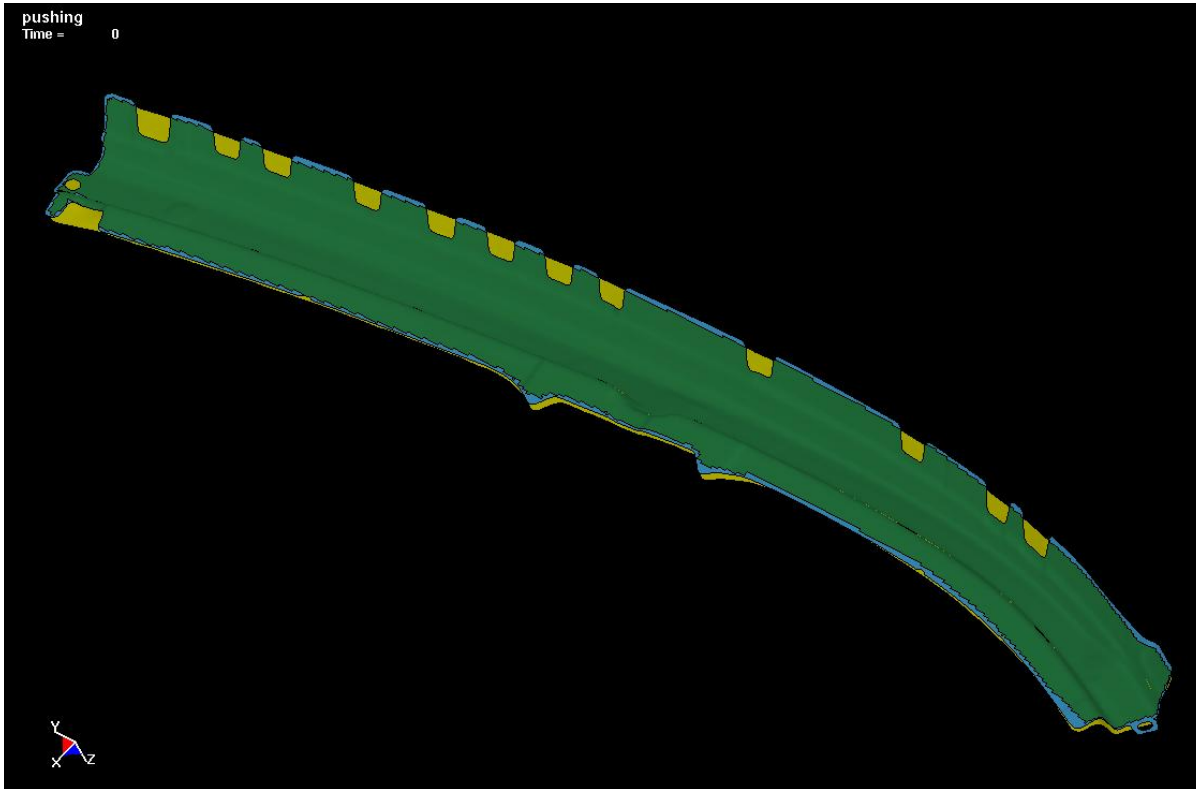
- Sometimes, springback predictions are not accurate
  - Scan data can be used to compensate the springback deviations
- Procedure in using scan data
  - Perform a forming simulation, and obtained the deformed part
  - Assume the scan data as rigid tools
  - Assume the deformed as a deformable
  - Apply internal pressure to the deformed part
  - After push, the blank geometry can be used as sprung shape
  - Use the same procedure as before and compensate the rigid tool

Implicit Method
Compensation Based on Scan Data

- How to push the deformed part to the scanned geometry?
  - The pressure is applied by using load mask
    - All the blank element will have a normal pressure
    - The pressure is applied to the opposite of element normal directions
      - Blank normal has to be checked
    - For most of the situation, the internal pressure can be in the range of 20 ~ 30 MPA
  - Use implicit method
    - Use the keyword: *CONTROL_IMPLICIT_FORMING
    - One step pushing is used
    - The CPU time is small (usually can be done within a few minutes)

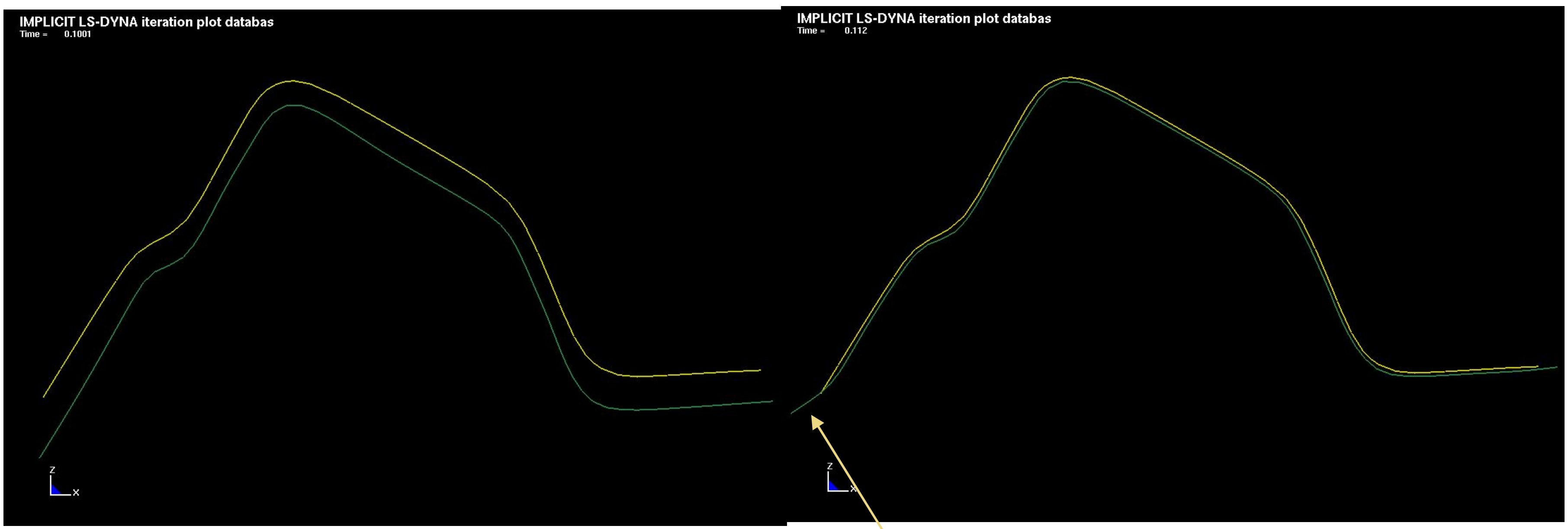
Implicit Method
Compensation Based on Scan Data

- Benchmark Study:
  - Number of element: 41,457
  - CPU cost: 7 minutes and 39 seconds



Implicit Method
Compensation Based on Scan Data

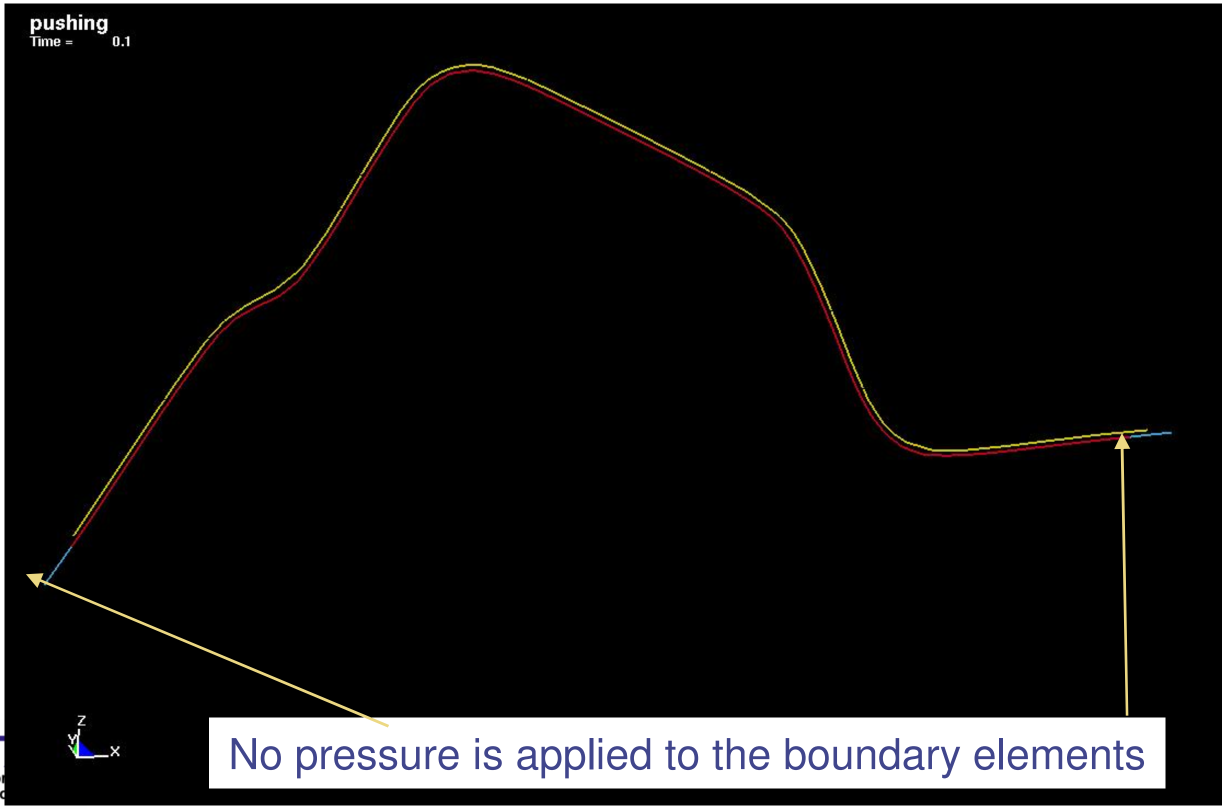
- Problems might happen during the pushing:
  - No support for the boundary elements



Over-bend in the boundary areas

Implicit Method
Compensation Based on Scan Data

- Change the boundary elements to a different part
  - Avoid applying pressure to the boundary element

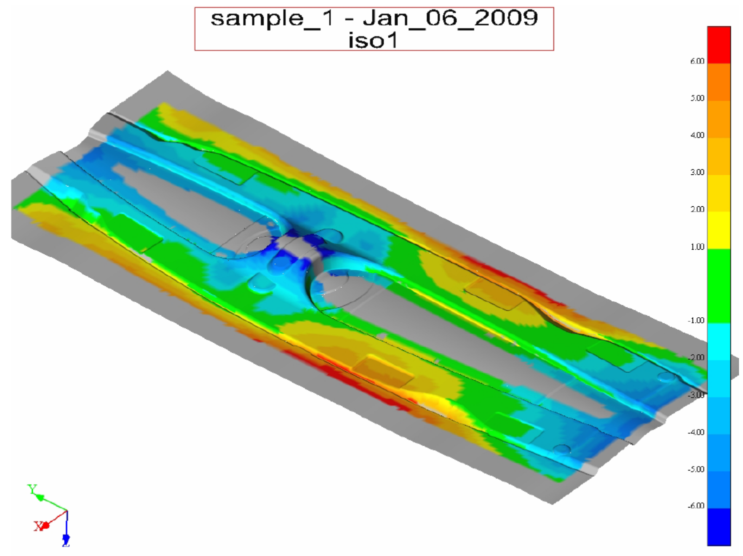


Implicit Method
Compensation Based on Scan Data

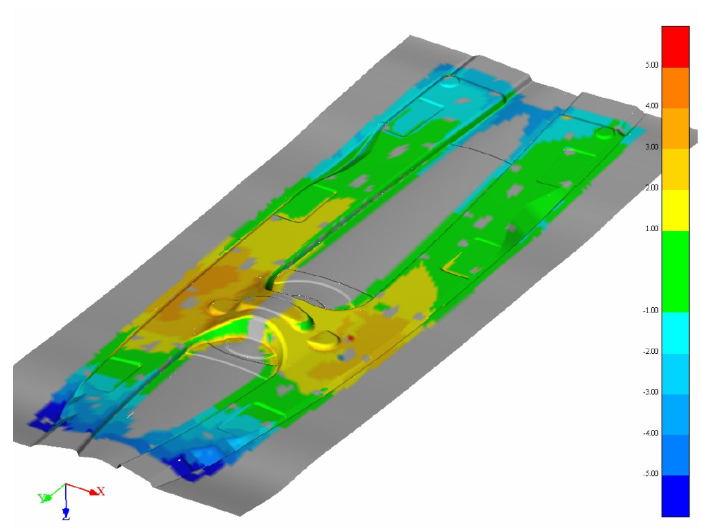
- After first tryout, the parts exhibited significant springback issues.
- Part could not even be placed on the checking fixture without extreme hand-working.
- Part was bowed throughout the length of the channel, twisted, there were bulges adjacent to the deeper areas of form, form depth in the deeper areas was incorrect, and the stepped flanges were crowning.
- Part showed that it was under-bent just about everywhere.

Implicit Method
Compensation Based on Scan Data

- Example:



- There is a dramatic change.
- A significant amount of springback has been removed
- With adjustments to magnification, an even more effective compensated shape could have been created.



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Courtesy of Matt Clarke (Continental Tool And Die)

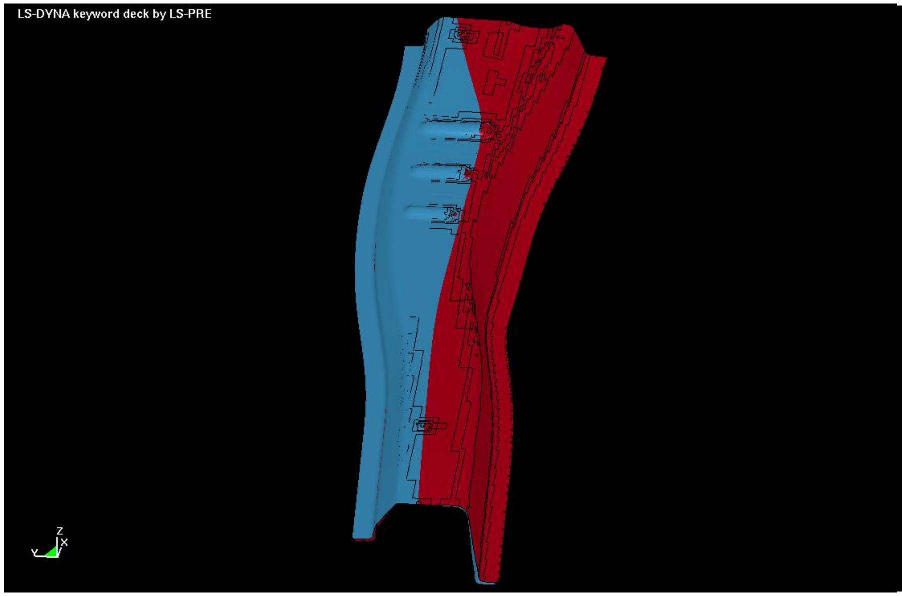
Material kinematic hardening

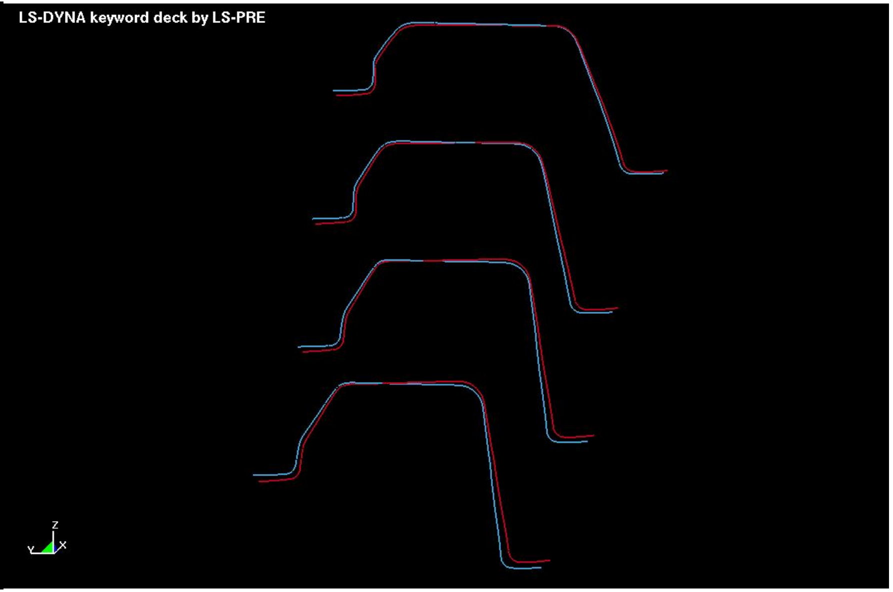
Yoshida model

Chaboche's model

Springback Prediction for HSS

- Some parts are sensitive to stress noise
  - More accurate stress calculation is important

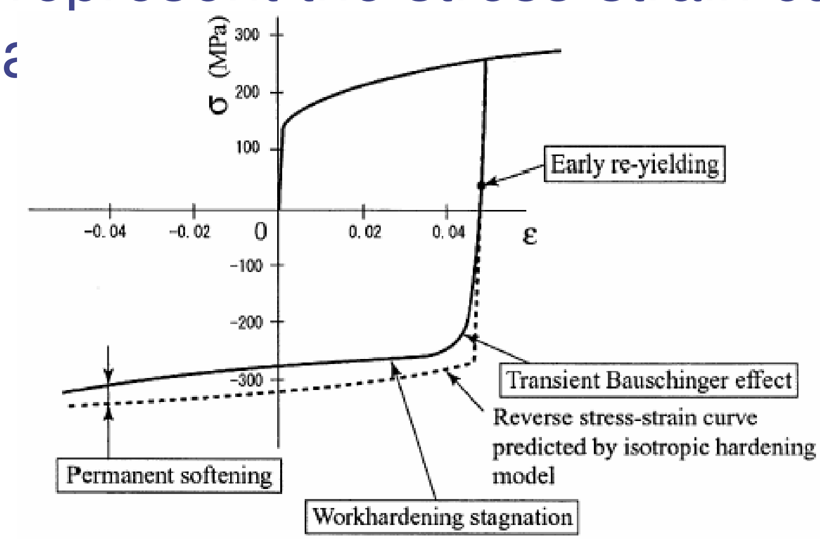




Twisting mode corresponding to the lowest frequency (17.97)
And is far smaller than the next one: 54.7
Accordingly, small stress noise might excite the wrong twisting mode

Yoshida Kinematic Hardening

- Recent researches found that Yoshida non-linear kinematic hardening is the preferred one.
  - It can describe the softening effect from reverse loading
  - It can accurately represent the stress-strain curve from the cyclic loa



Picture was cut from Yoshida's paper: J. of Mech. Sco. Vol. 45, p. 1687

Yoshida Kinematic Hardening

- Key points of Yoshida's theory:
  - Yield surface does not change in size
  - Center of yield surface moves with deformation
  - Bounding surface change both in size and location

$$\boldsymbol{\alpha}_* = \boldsymbol{\alpha} - \boldsymbol{\beta}.$$

$$\overset{\circ}{\boldsymbol{\alpha}}_* = C\left[\left(\frac{a}{Y}\right)(\boldsymbol{\sigma} - \boldsymbol{\alpha}) - \sqrt{\frac{a}{\bar{\alpha}_*}}\,\alpha_*\right]\dot{p},$$

$$\dot{p} = \sqrt{(2/3)\boldsymbol{D}^p : \boldsymbol{D}^p}, \quad \bar{\alpha}_* = \phi(\boldsymbol{\alpha}_*), \quad a = B + R - Y,$$

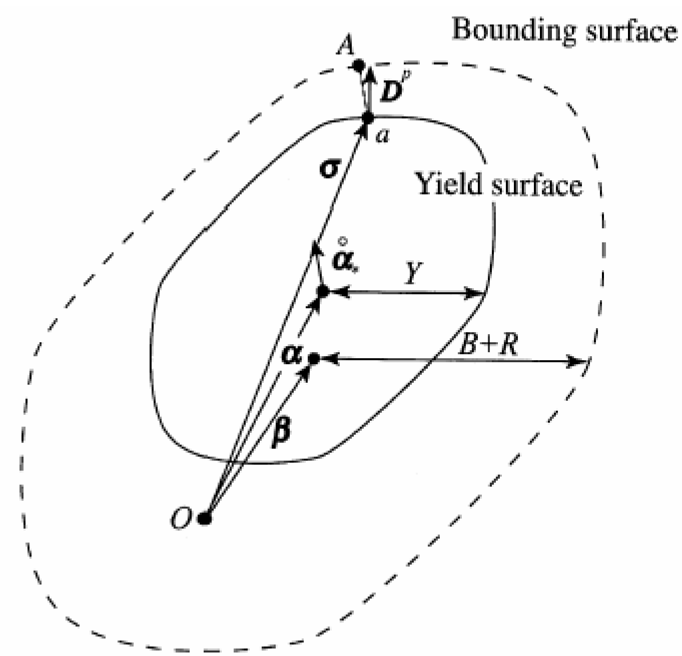


Fig. 2. Schematic illustration of the two-surface mode

Yoshida Kinematic Hardening

- Bounding surface changes in both its size and location:

$$\dot{R} = k(R_{sat} - R)\dot{p},$$

$$\overset{\circ}{\boldsymbol{\beta}}' = k\left(\tfrac{2}{3}\,b\mathbf{D}^{p} - \boldsymbol{\beta}'\,\dot{p}\right)$$

$$\sigma_{bound} = B + R + \beta = B + (R_{sat} + b)(1 - e^{-k\varepsilon^{p}}).$$

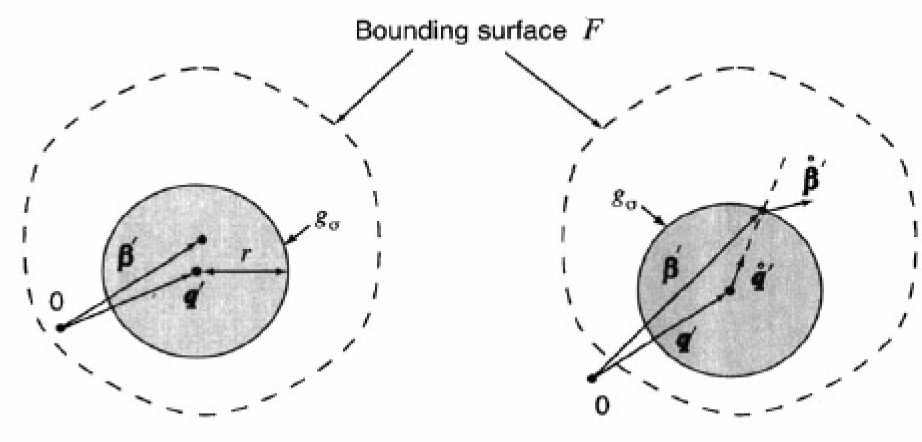
Yoshida Kinematic Hardening

- Work-hardening stagnation

$$g_\sigma(\boldsymbol{\sigma}', \boldsymbol{q}', r') = \tfrac{3}{2}(\boldsymbol{\sigma}' - \boldsymbol{q}') : (\boldsymbol{\sigma}' - \boldsymbol{q}') - r^2 = 0,$$

$$\overset{\circ}{\boldsymbol{q}}' = \mu(\boldsymbol{\beta}' - \boldsymbol{q}').$$

$$\dot{r} = h\Gamma, \qquad \Gamma = \frac{3(\boldsymbol{\beta}' - \boldsymbol{q}') : \overset{\circ}{\boldsymbol{\beta}}'}{2r}$$

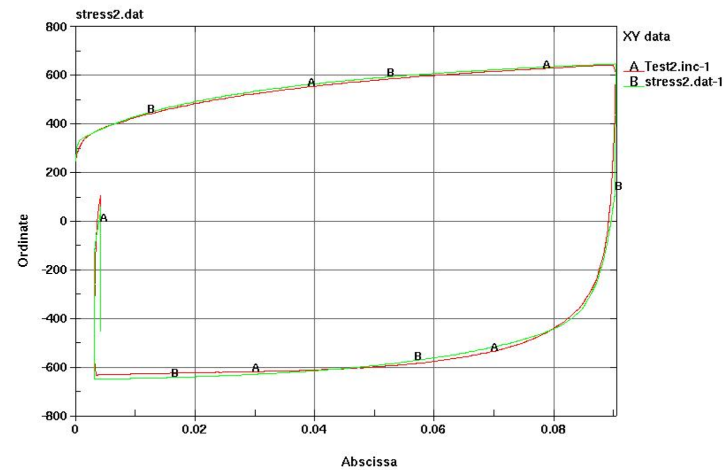


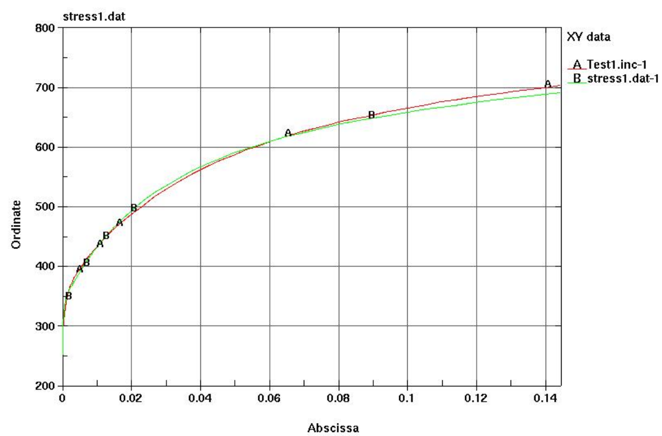
(a) when $\dot{R} = 0$ (b) when $\dot{R} > 0$

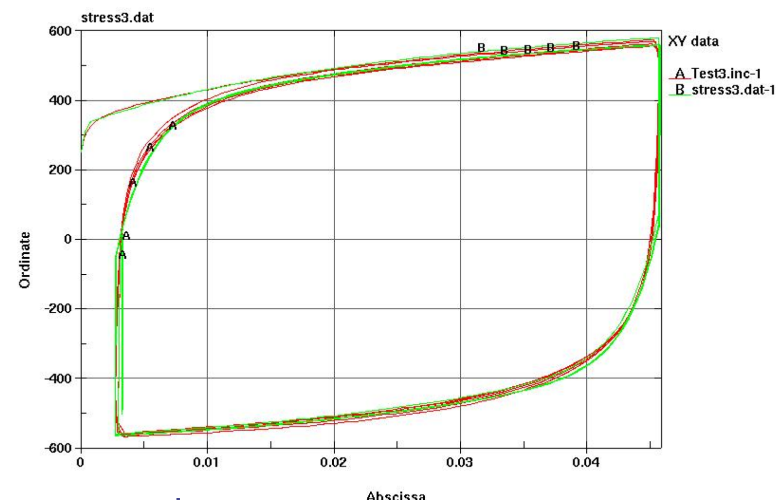
Material Data Fitting Comparisons (DP600)

Material Parameters

Y = 0.253E+03
m = 0.405E+02
B = 0.342E+03
h = 0.100E+01
c = 0.430E+03
b = 0.155E+03
rsat = 0.543E+03



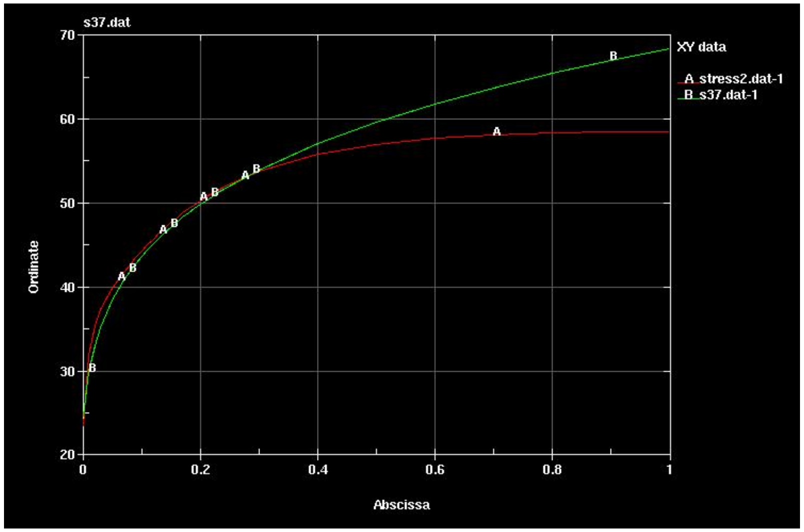




The obtained parameters can nicely represent the stress-strain curves with different loading paths.

Yoshida's Model Characteristics

- Yoshida's Model can give good fit of the test
  - The effective strain usually small (<0.16)
- Yoshida Model shows saturation of stress

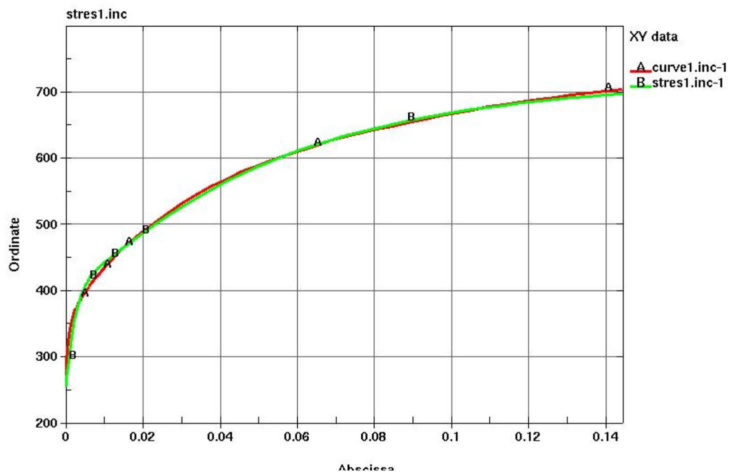


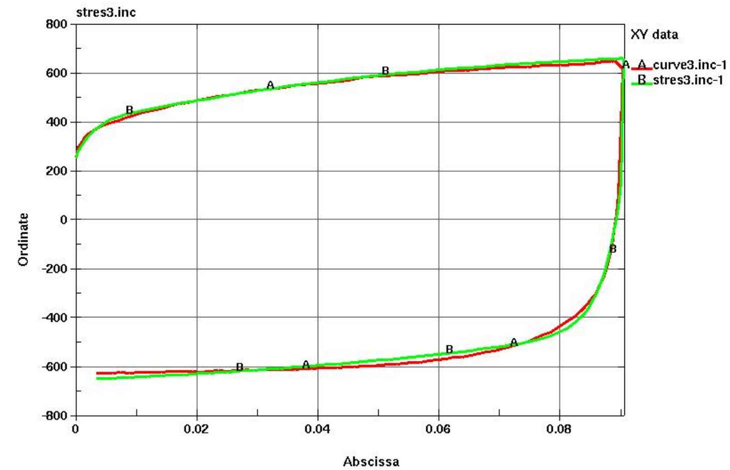
Chaboche's Model (M103)

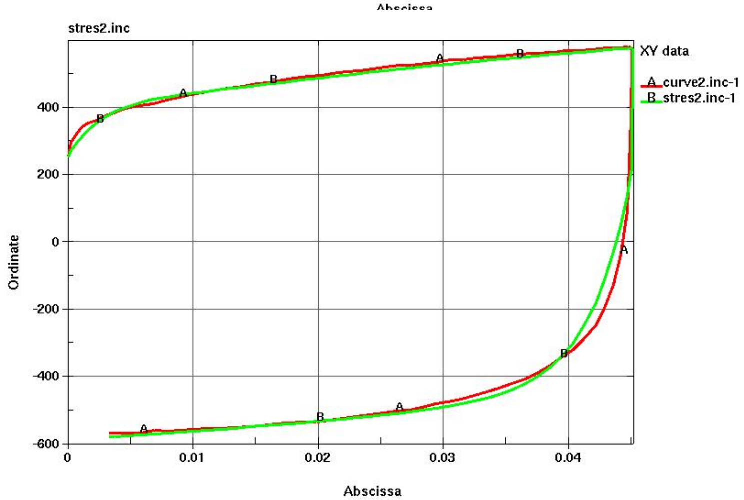
- Difficulty in using it
  - There are eight user-defined material variables, make it difficult for ordinary user to use it
  - The build-in curve fitting only works for one stress-strain curve
    - Uniaxial-tension curve has to be used
    - It is impossible to get an reasonable material parameters
- An optimization algorithm has been developed
  - It is a stand-along code
  - Up to eight stress-strain curves can be used as input
    - The file names should begin from curve1.inc, curve2.inc…
  - Many iterations will be needed

$$\overline{\sigma} = \sigma_0 + Q_{r1}(1.-\exp(-C_{r1}\overline{\varepsilon})) + Q_{r2}(1.-\exp(-C_{r2}\overline{\varepsilon})) + Q_{x1}(1.-\exp(-C_{x1}\overline{\varepsilon})) + Q_{x2}(1.-\exp(-C_{x2}\overline{\varepsilon}))$$

Chaboche' Mixed-Hardening Model DP600

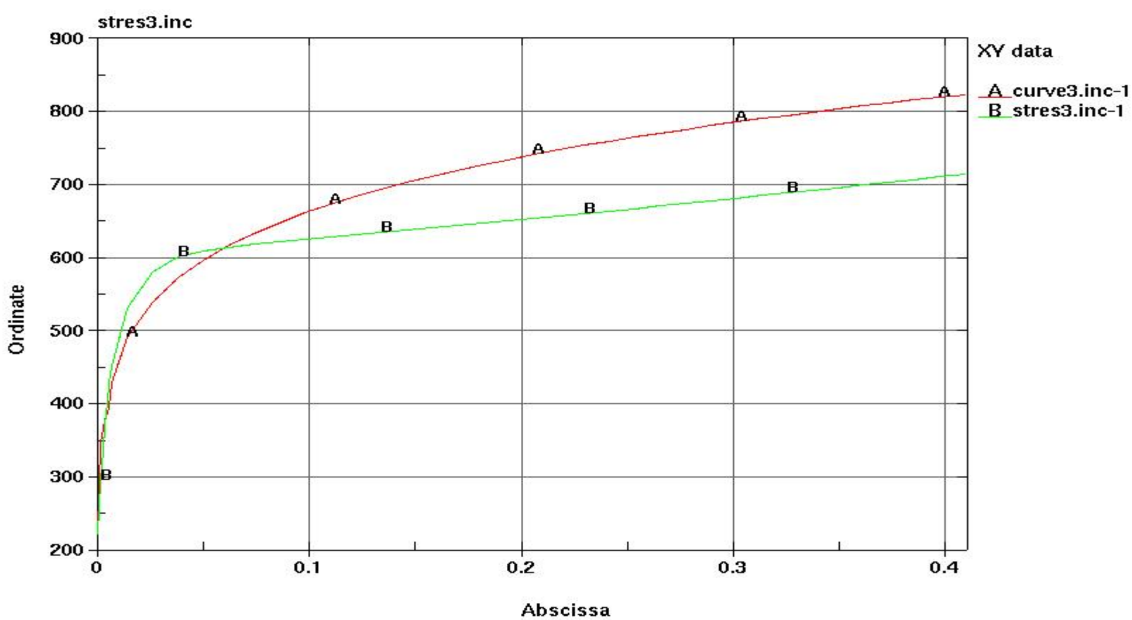






Chaboche' Mixed-Hardening Model Saturation problem

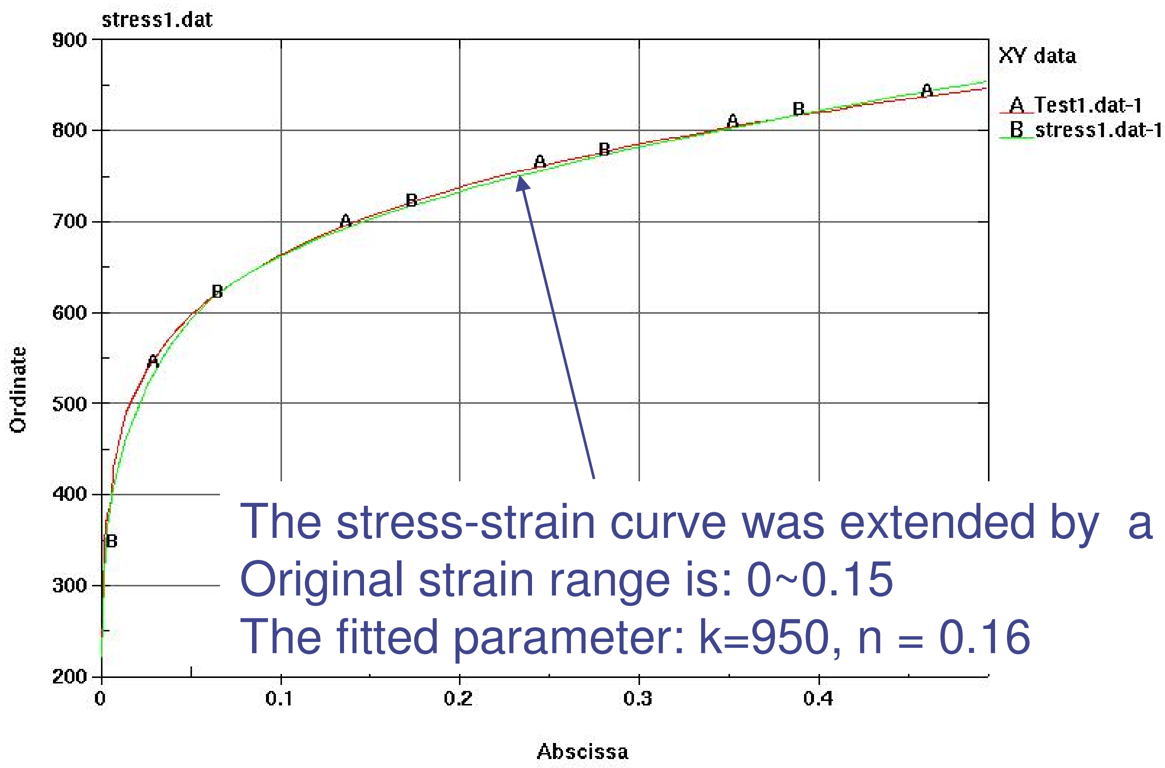
- Chaboche's Model has saturation problem
  - The stress strain curve is extended by power law
  - Then fit the curve and obtain the parameters
  - The fitted curve does not match the experimental data



Modifications of Yoshida's Model
New Proposal

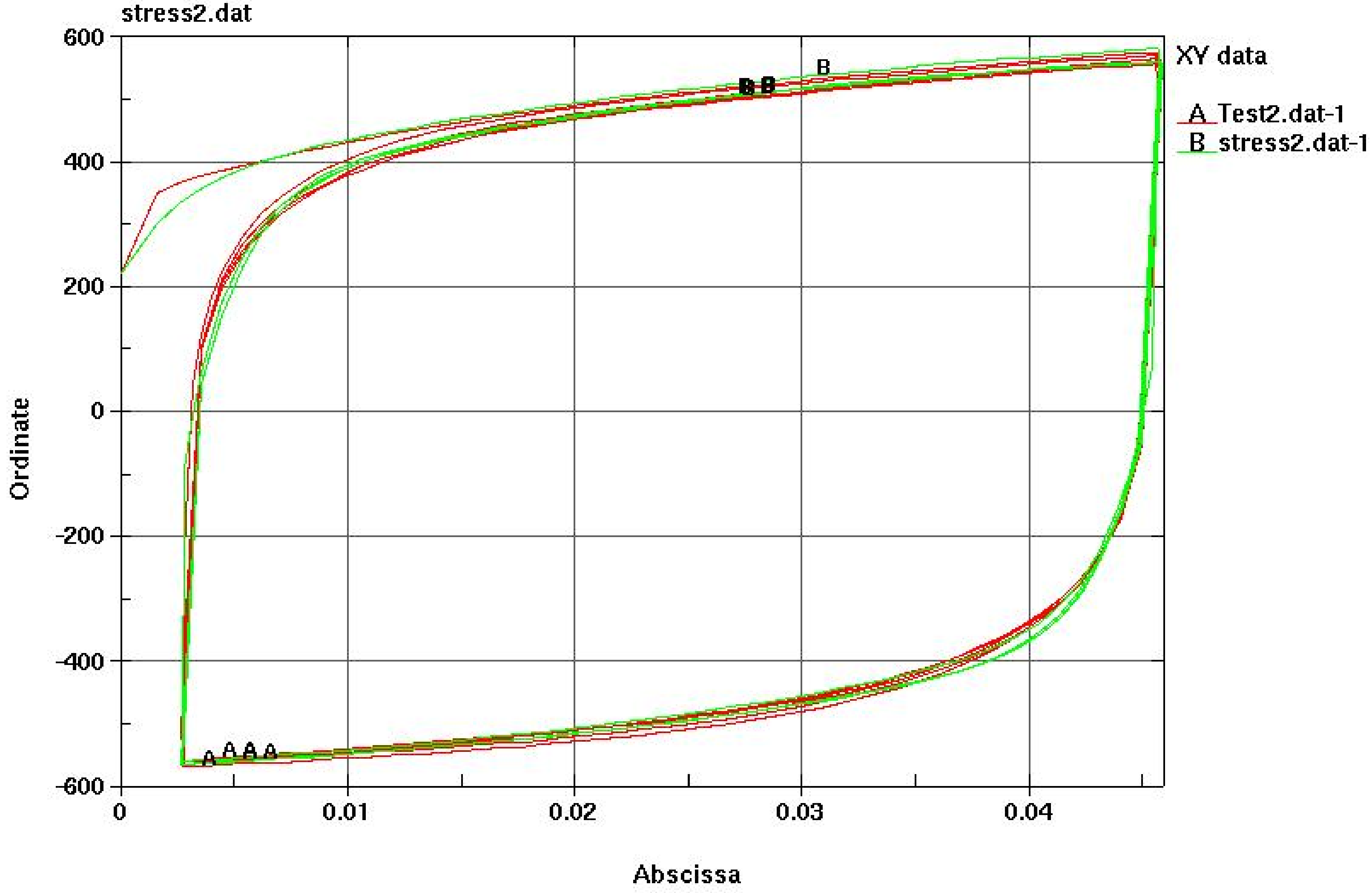
- A new algorithm has been proposed and tested
  - Use a power-law to replace the R calculation in Yoshida's model
  - The old function: $\dot{R} = k(R_{sat} - R)\dot{p},$
  - The new function: $R=Rsat(e+e0)^{n}-Rsat(e0)^{n}$
  - This new function will not have saturation problem
  - There are two more parameters need to be fit: e0 and n

Modifications of Yoshida's Model Example: DP600



The stress-strain curve was extended by a power law
Original strain range is: 0~0.15
The fitted parameter: k=950, n = 0.16

Modifications of Yoshida's Model
Example: DP600



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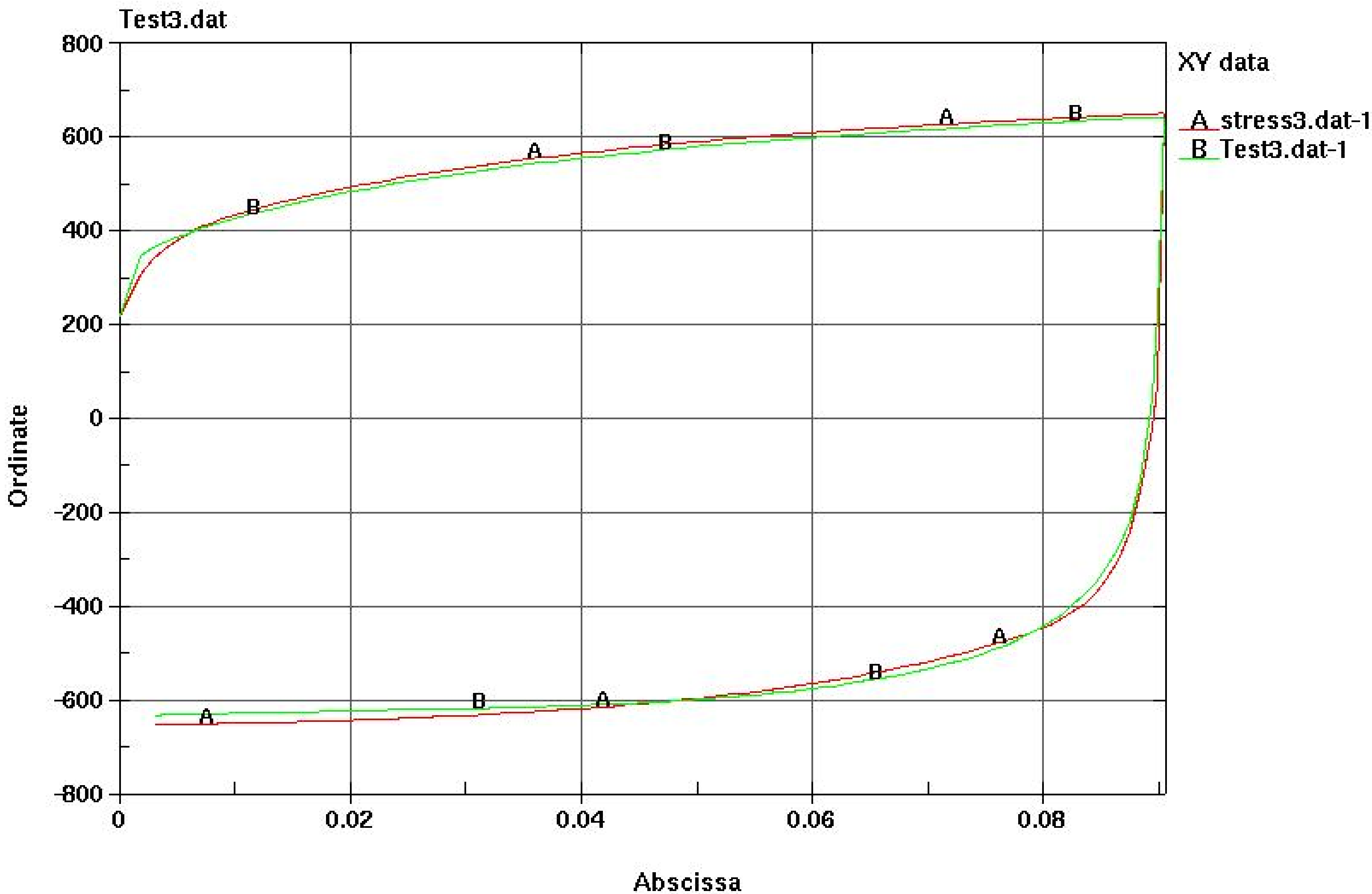
Modifications of Yoshida's Model
Example: DP600



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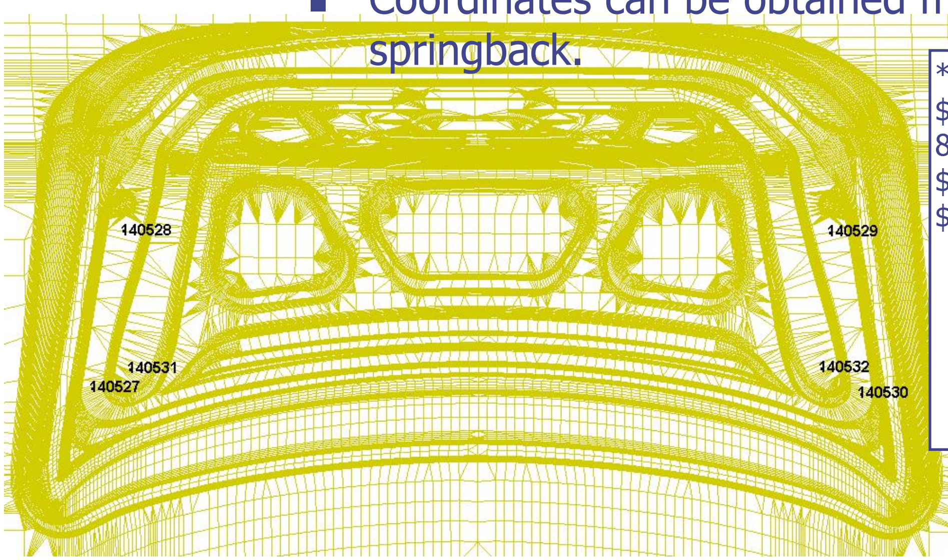
Some New Keywords

important for line-die simulation

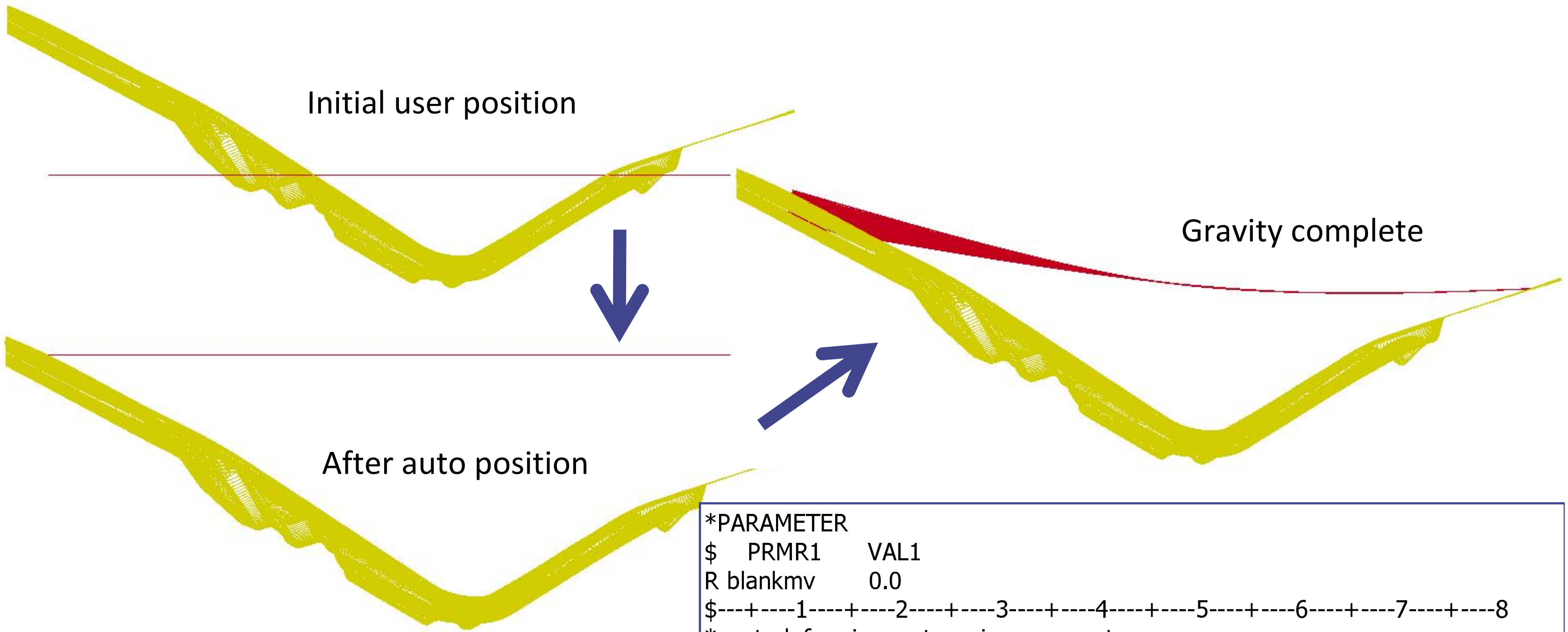
Coordinate-based constraint

- Why we need to put constraints on coordinates
  - It can be more accurate to constraint the model in a fixture
  - It can automate line-die simulation
- The keyword is
  - *CONSTRAINED_COORDINATE
  - It can also be applied to local coordinate system
  - Coordinates can be obtained from stationary tool in the CASE before springback.




```
*constrained_coordinate
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----
8
$       ID      IDPT IDIR(DOF)        x         y         z       CID
$ unique ID, PartID, DOF (one at a time)
         1         1         3   1326.28  -100.236   156.434
         2         1         3   1276.21   159.983   138.517
         3         1         3   2466.03  -100.241   156.464
         4         1         3   2516.35   151.889    138.81
         5         1         1   2454.17   121.142   135.007
         6         1         2   2454.17   121.142   135.007
         7         1         2   1339.84   118.347   135.237
```

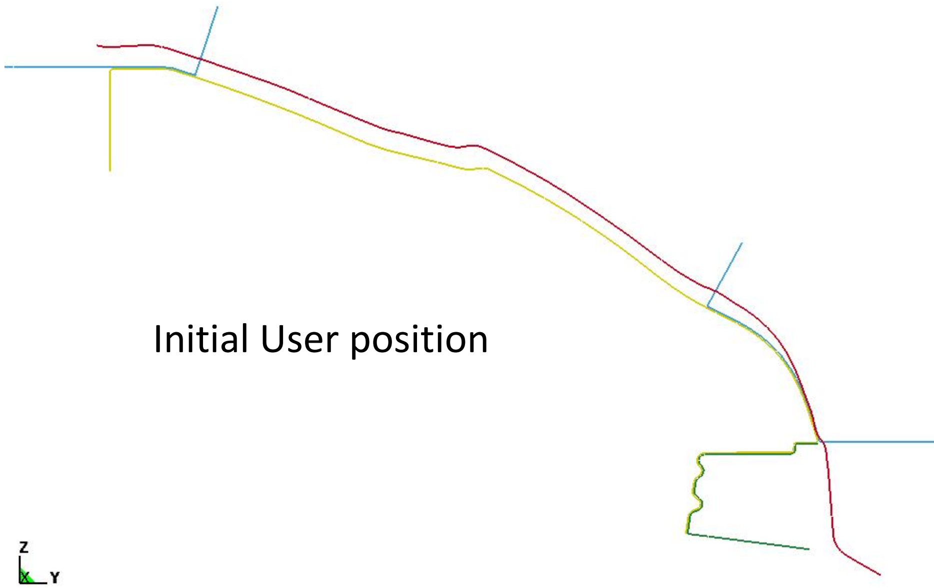
*CONTROL_FORMING_AUTOPOSITION_PARAMETER



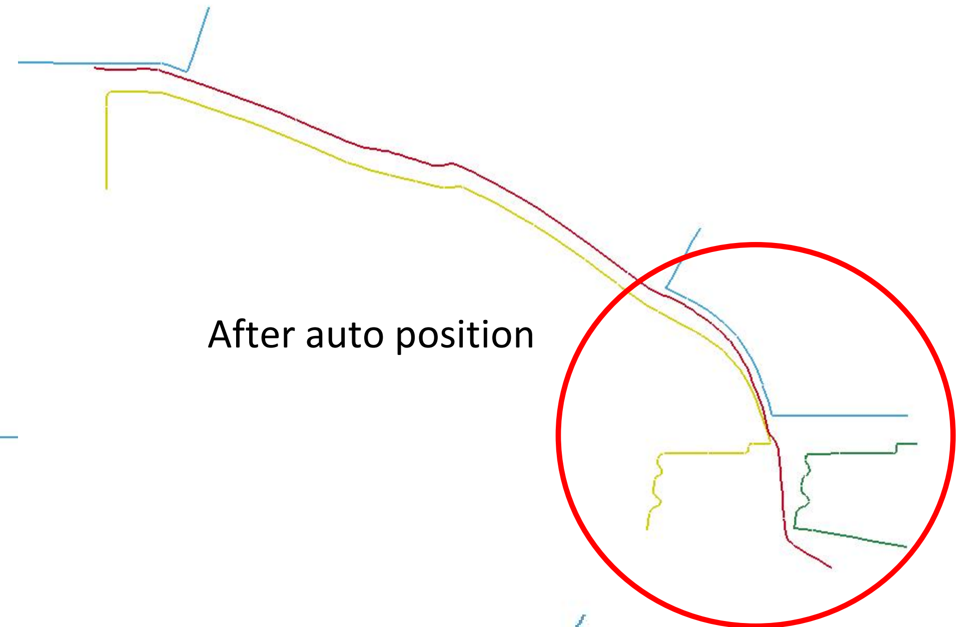

```
*PARAMETER
$    PRMR1       VAL1
R blankmv        0.0
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
*control_forming_autoposion_parameter
$       PID       CID       DIR       MPID  position   premove     THICK  PARORDER
$  blankmv
         1                    3         4          1                    0.9     blankmv
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
*PART_MOVE
$    PID           XMOV           YMOV           ZMOV     CID
        1              0.0              0.0      &blankmv
$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
*CONTROL_TERMINATION
$   ENDTIM    ENDCYC     DTMIN    ENDNEG    ENDMAS
   1.0000
*CONTROL_IMPLICIT_forming
1
```

Line Die Simulation

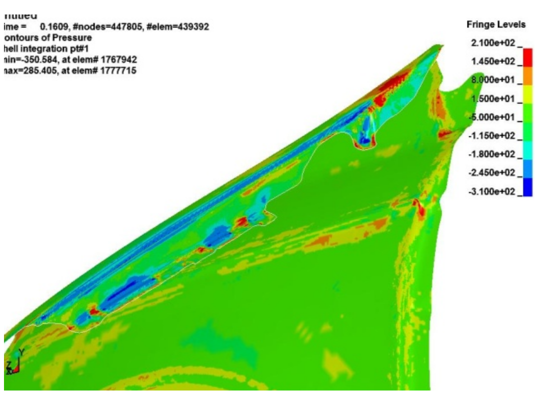
NUMISHEET Fender on Air with Flanging - Flanging

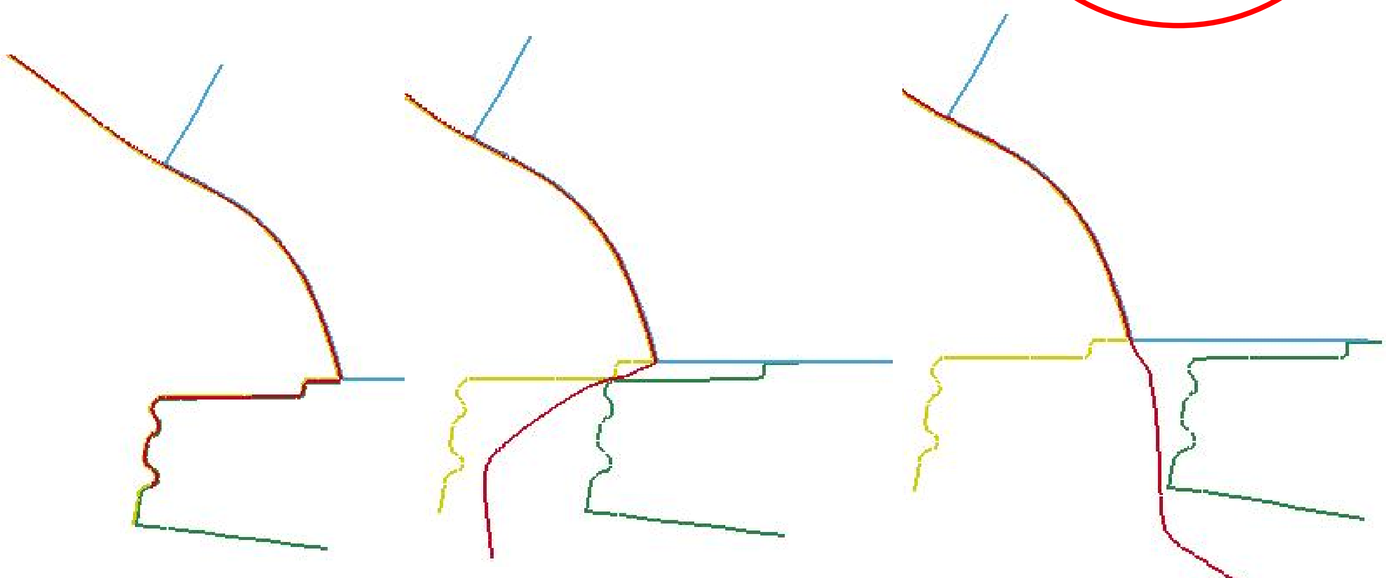


Initial User position



After auto position





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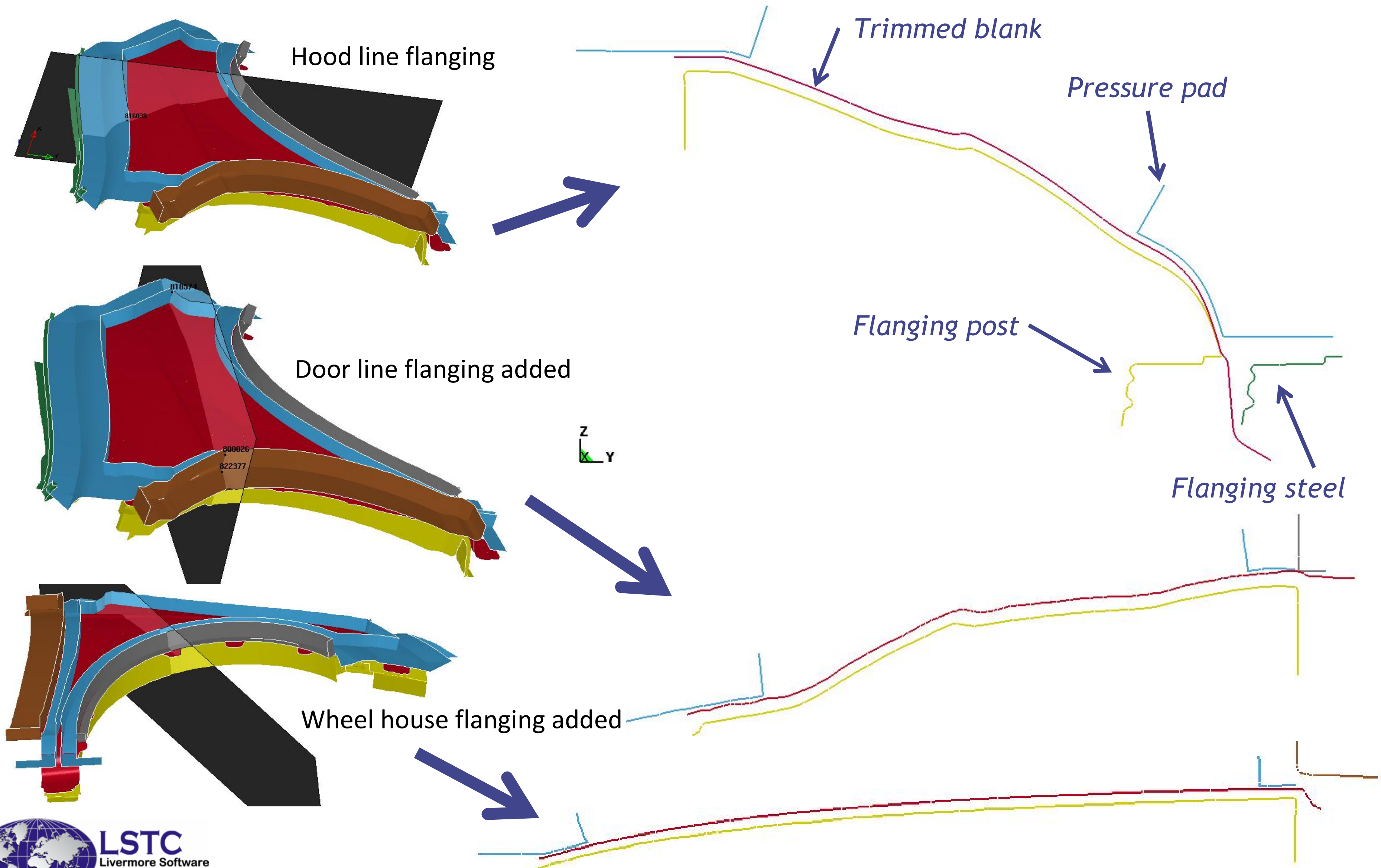
Flanging simulation progression

Line Die Simulation

NUMISHEET Fender on Air with Multi-flanging – Flanging in Three Areas



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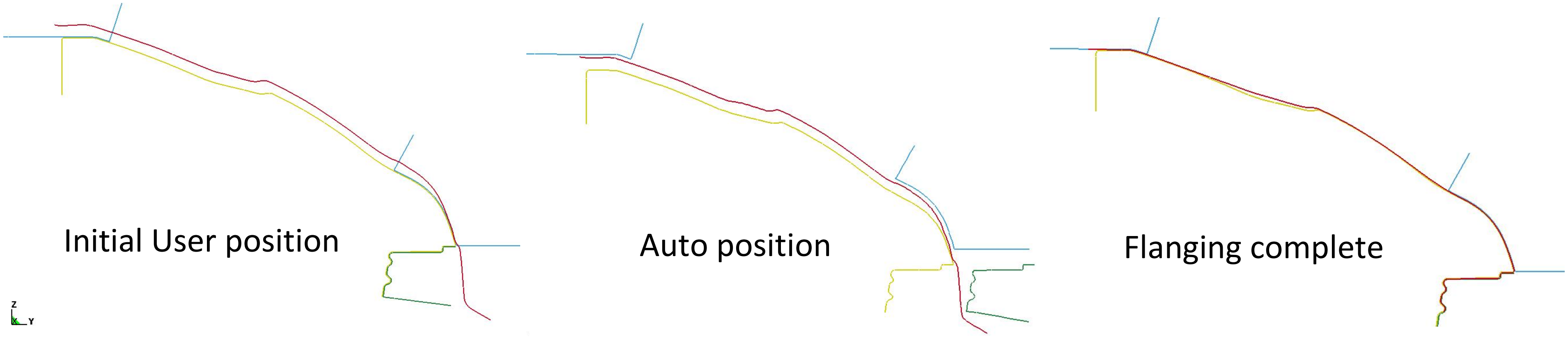
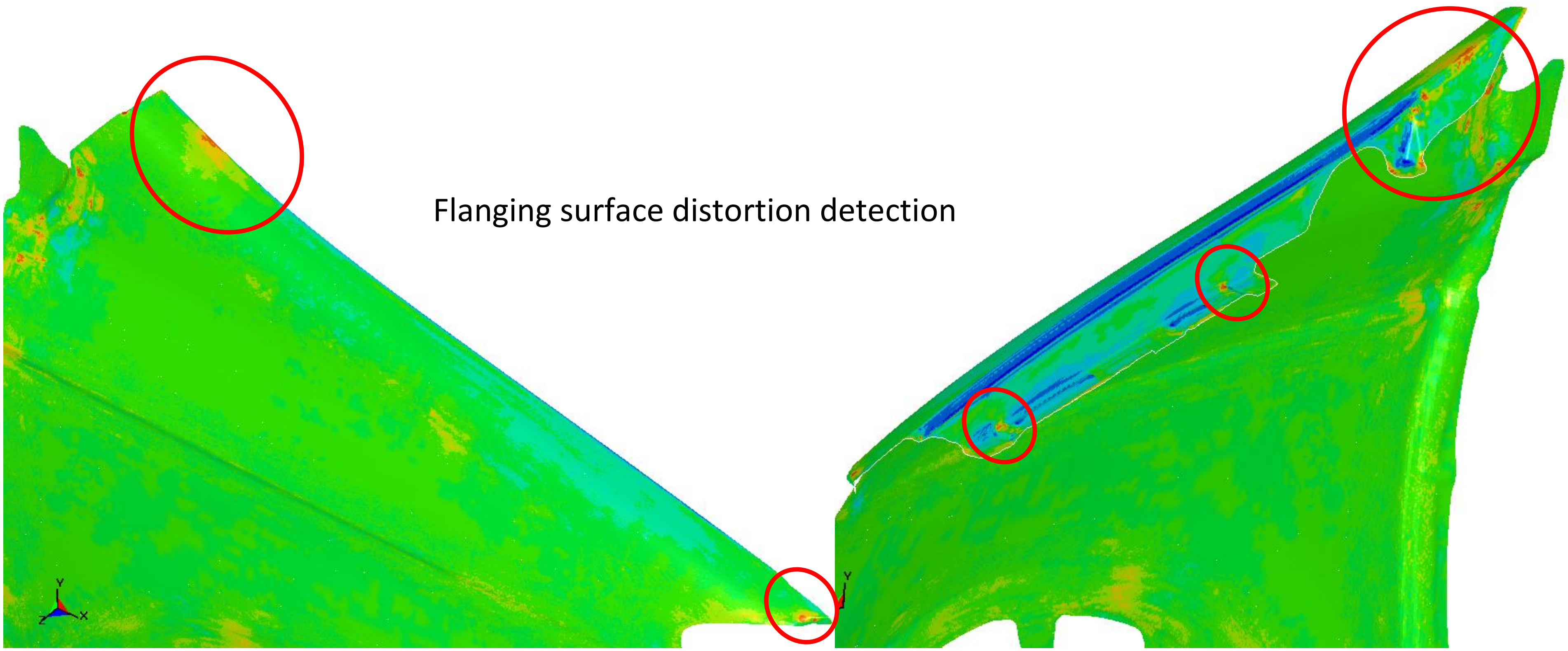
Line Die Simulation

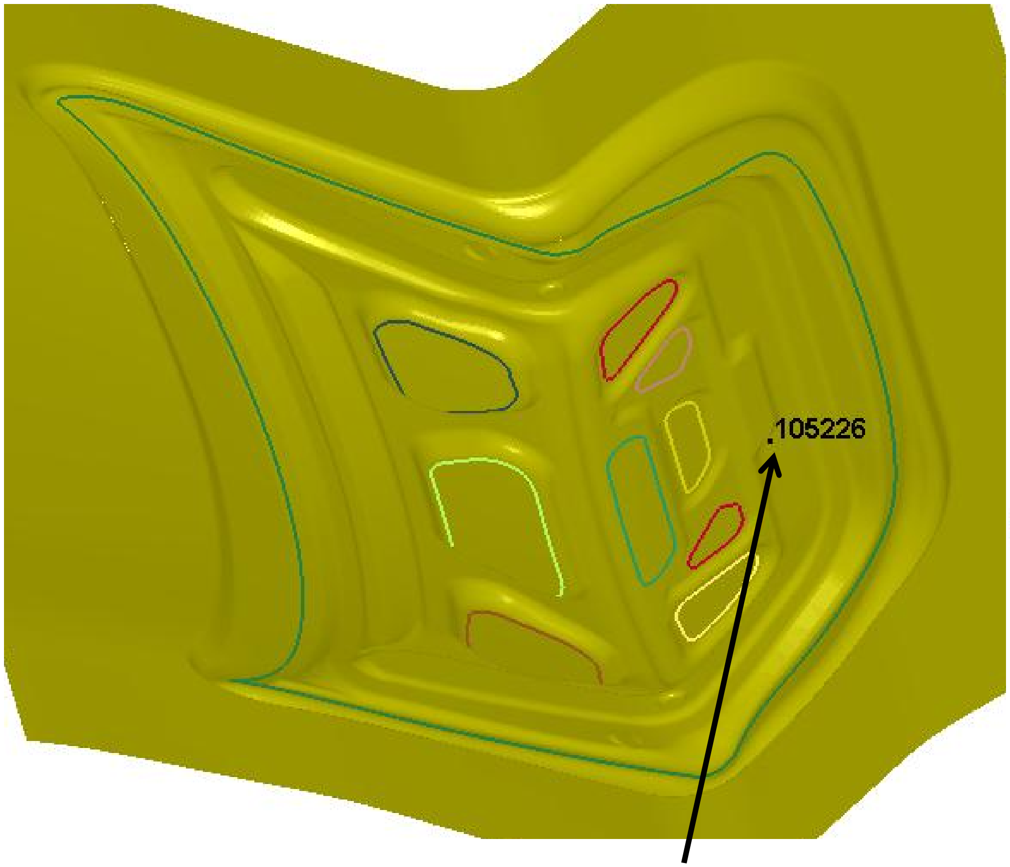
NUMISHEET Fender on Air with Multi-flanging – Details

Hood line flanging





New Option for Trimming

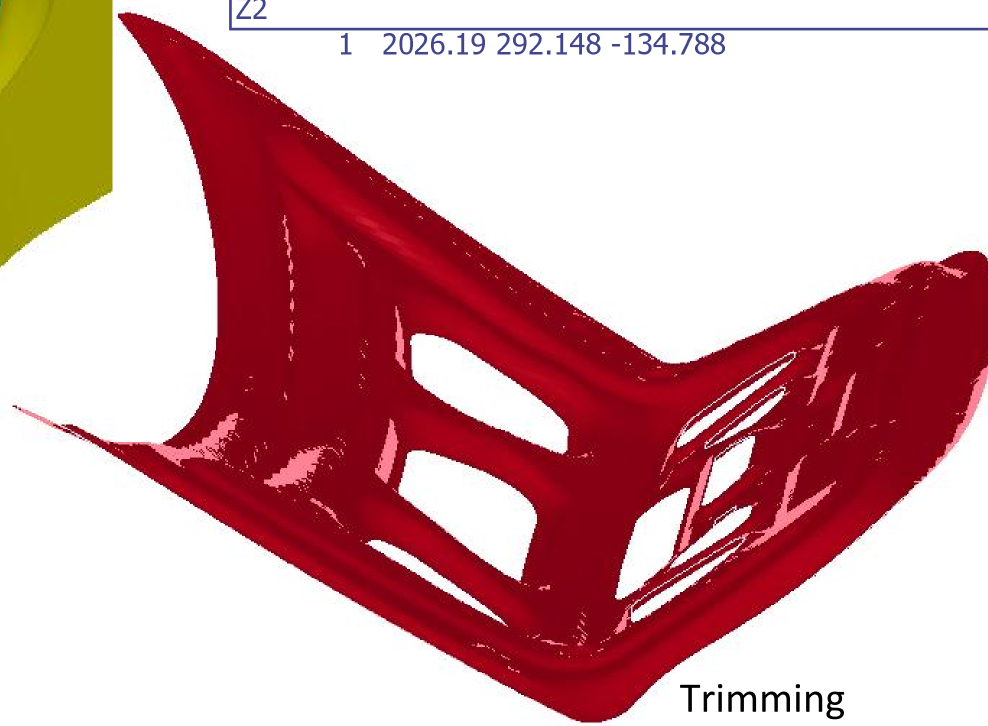


Define a seed node on stationary tool (not blank) for trimming; use negative option

```
*node
105226,2026.19,292.148,-134.788
*DEFINE_CURVE_TRIM_NEW
$#    tcid    tctype     tflg     tdir     tctol     toln     nseed
         1         2        0        0     0.250             -105226
deck_trimline.iges
```

Or,

```
*DEFINE_CURVE_TRIM_NEW
$#    tcid    tctype     tflg     tdir     tctol     toln     nseed
         1         2                 0     0.250
deck_trimline.iges
*define_trim_seed_point_coordinates
$    NSEED        X1        Y1        Z1        X2        Y2
Z2
         1    2026.19 292.148 -134.788
```



Trimming

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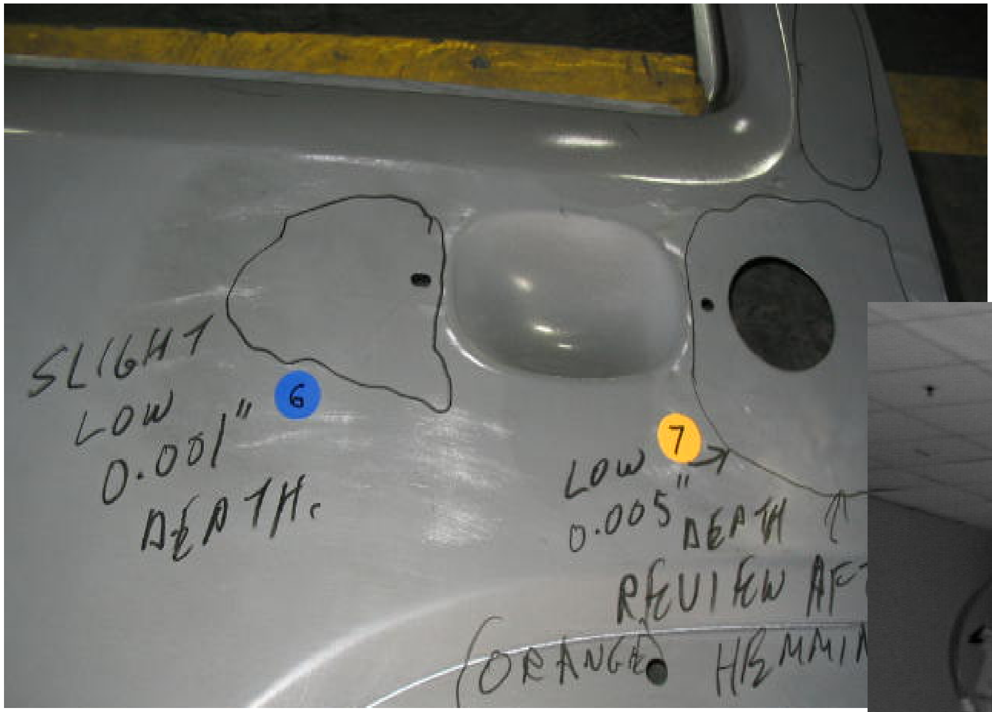
Surface Defect (Surface Low) Prediction



Reflect light on a stamped panel

Surface Defect (Surface Low) Prediction

```
*CONTROL_FORMING_STONING
$    ISTONE     LENGTH      WIDTH      STEP   DIRECT   REVERSE    METHOD
          1      300.0        4.0      0.10        8         0         1
$     NODE1      NODE2        SID     ITYPE
$ stone orientation in all direction
,,1,2
```

Stone length

Stone width

Stone step size

Stoning direction

Mesh normal reverse option

Node 1 and 2 defining stoning direction; Leave blank if “DIRECT” is defined.

ELSET defining stoning region.

Method=0: stoning

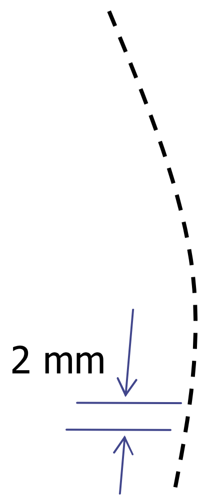
Method=1: curvature

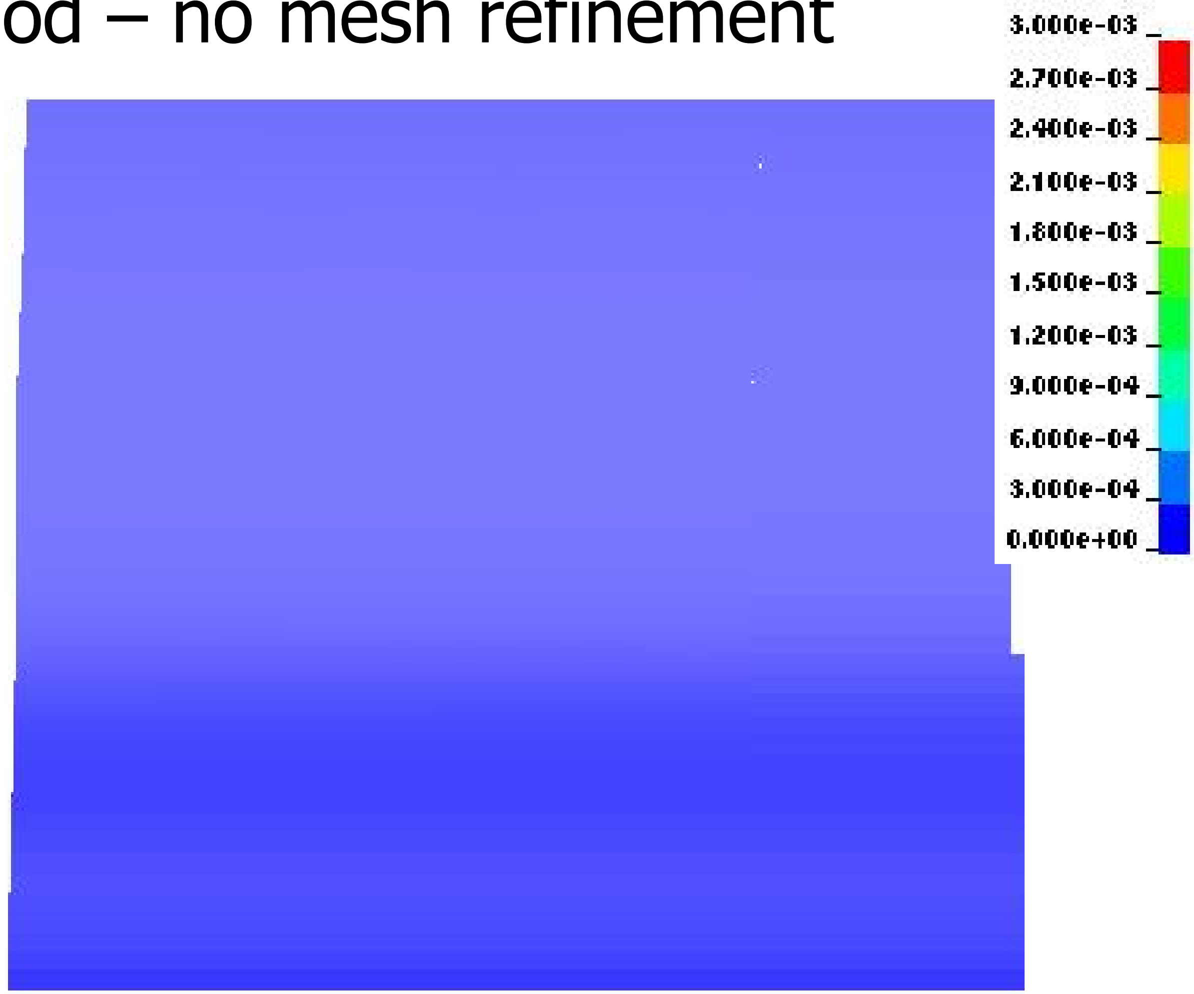
- Smoothed surface for stoning and curvature calculation
- Stoning direction can be manually defined by two nodes, or input # of directions without Node1 and Node2 definition

Surface Defect (Surface Low) Prediction

◆ Stoning method – no mesh refinement

- 2.0mm element size around door handle untrimmed – one way curvature.
- Mesh built with surface (not splitting from a coarser mesh)
- Results are in the order of 1.0E-04 to 1.0E-05.





Summary:

Basically no differentiation in surface lows.

```
*CONTROL_FORMING_STONING
$    ISTONE     LENGTH      WIDTH       STEP     DIRECT    REVERSE     METHOD
          1      150.0        4.0       1.00          2          0          0
$     NODE1      NODE2        SID      ITYPE
,,1,2
```

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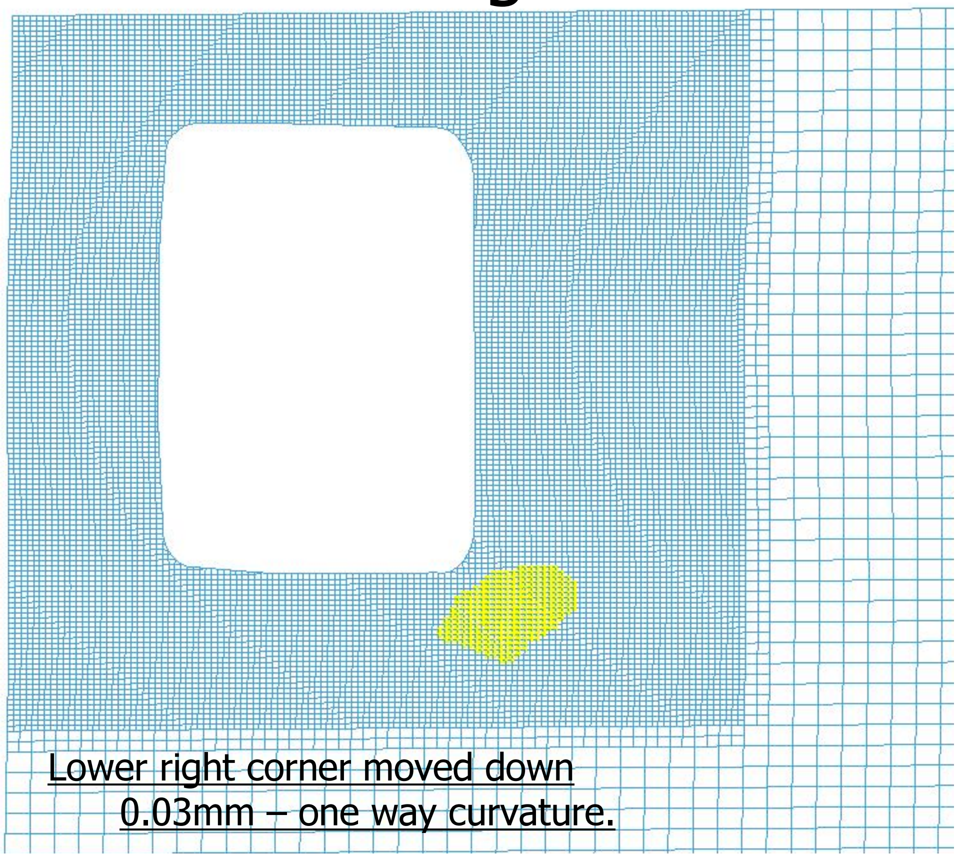
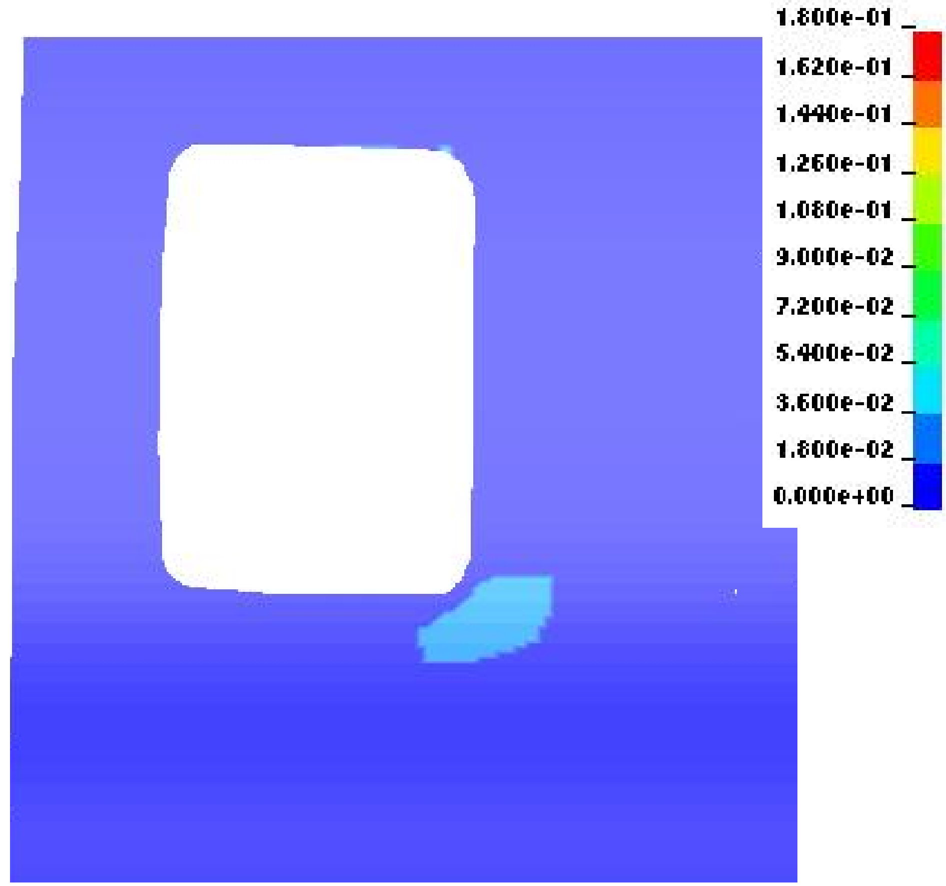
Surface Defect (Surface Low) Prediction

- Stoning method





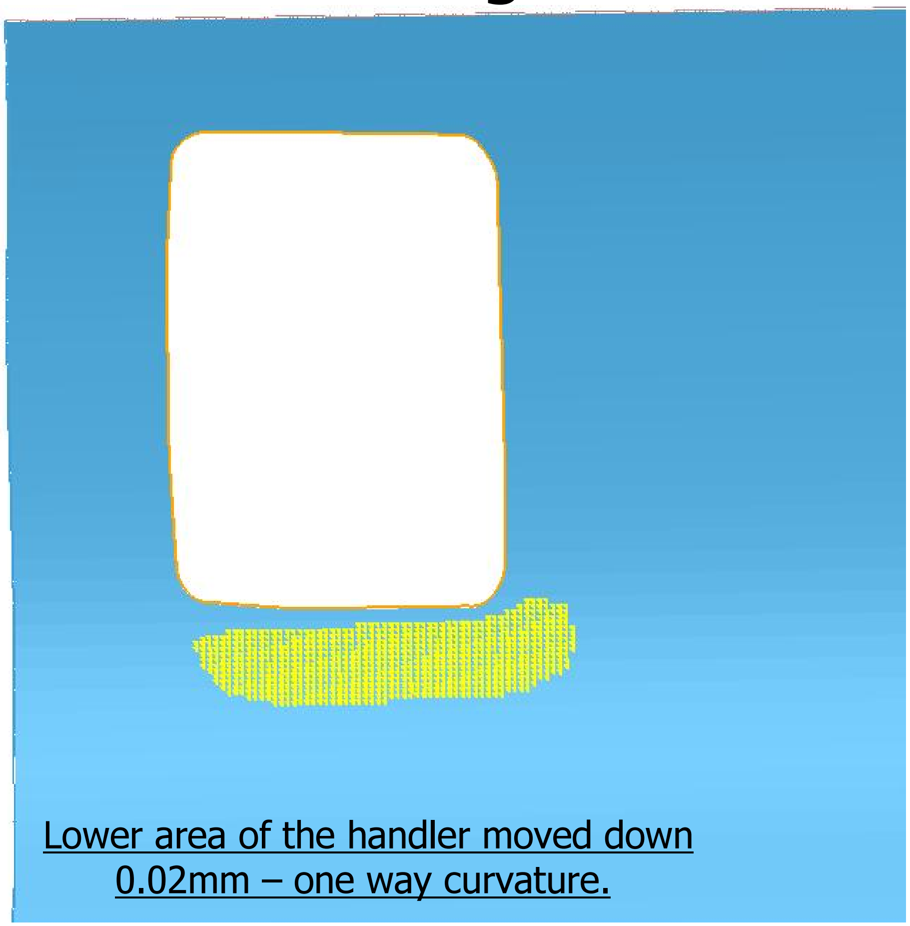
Summary:

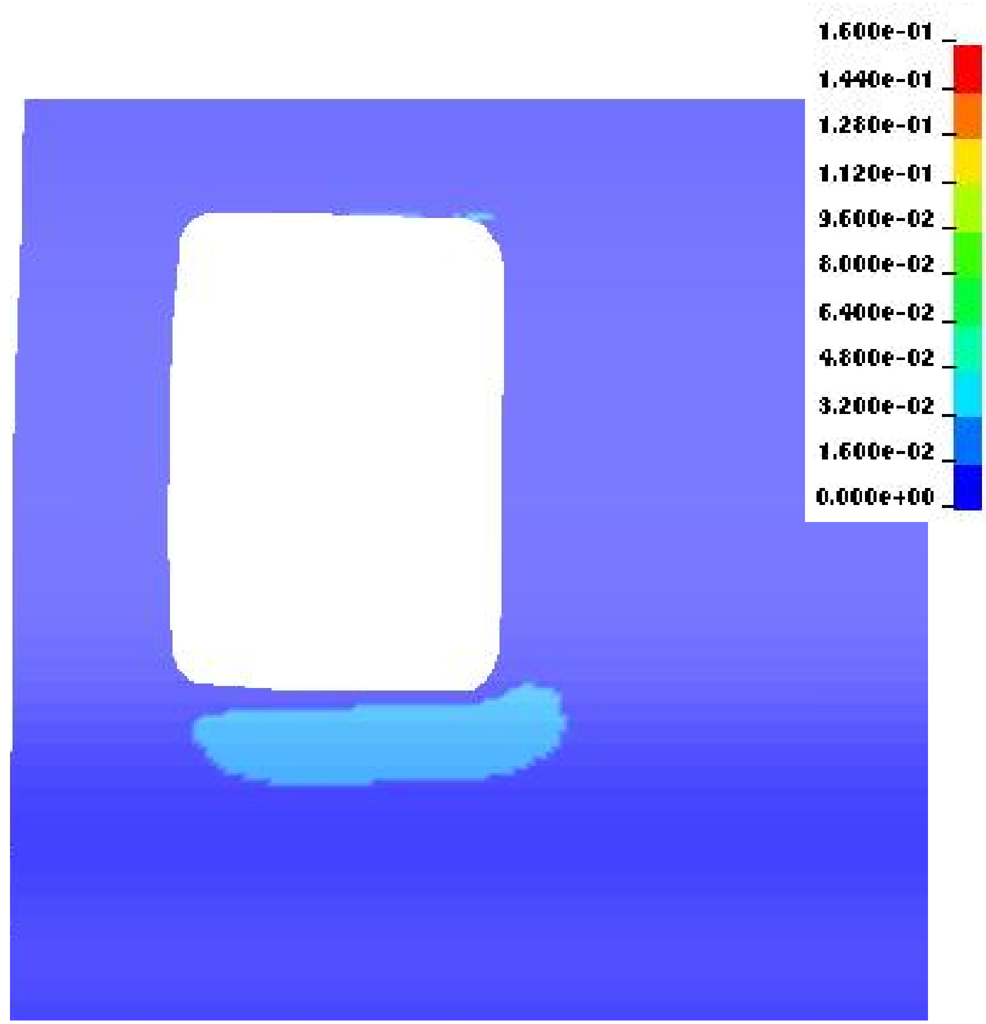
Expected.

```
*CONTROL_FORMING_STONING
$    ISTONE     LENGTH      WIDTH       STEP     DIRECT    REVERSE     METHOD
          1      300.0        4.0       0.10          8          0          0
$     NODE1      NODE2        SID      ITYPE
$ stone orientation in all direction
,,1,2
```

Surface Defect (Surface Low) Prediction

- Stoning method





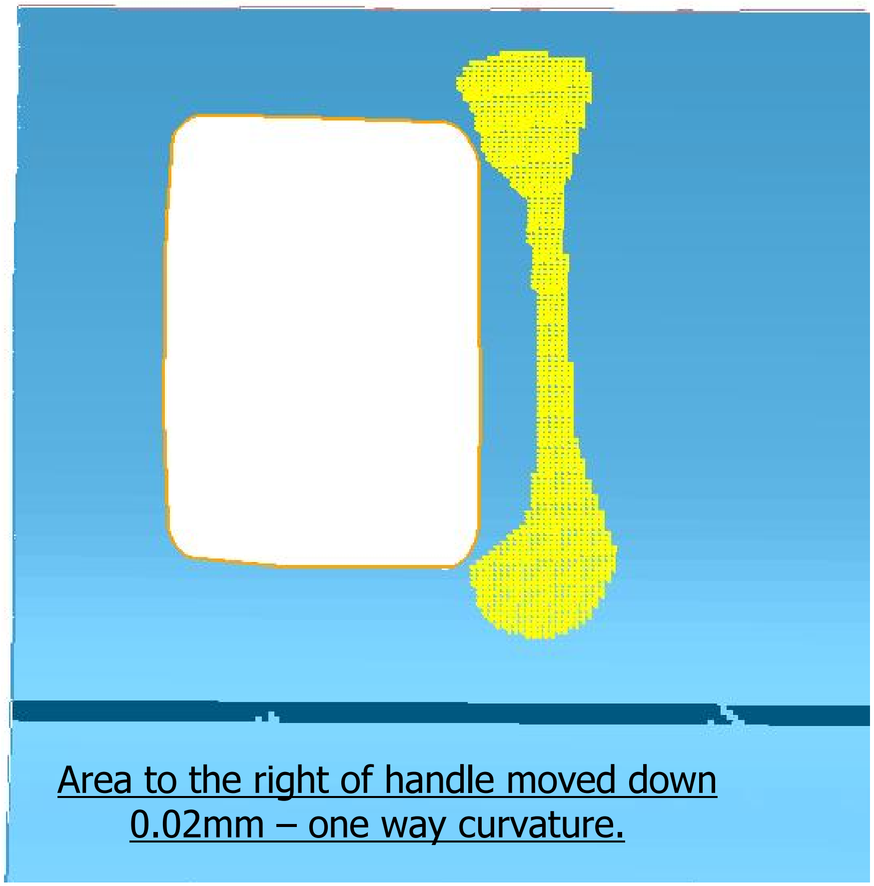
Summary:

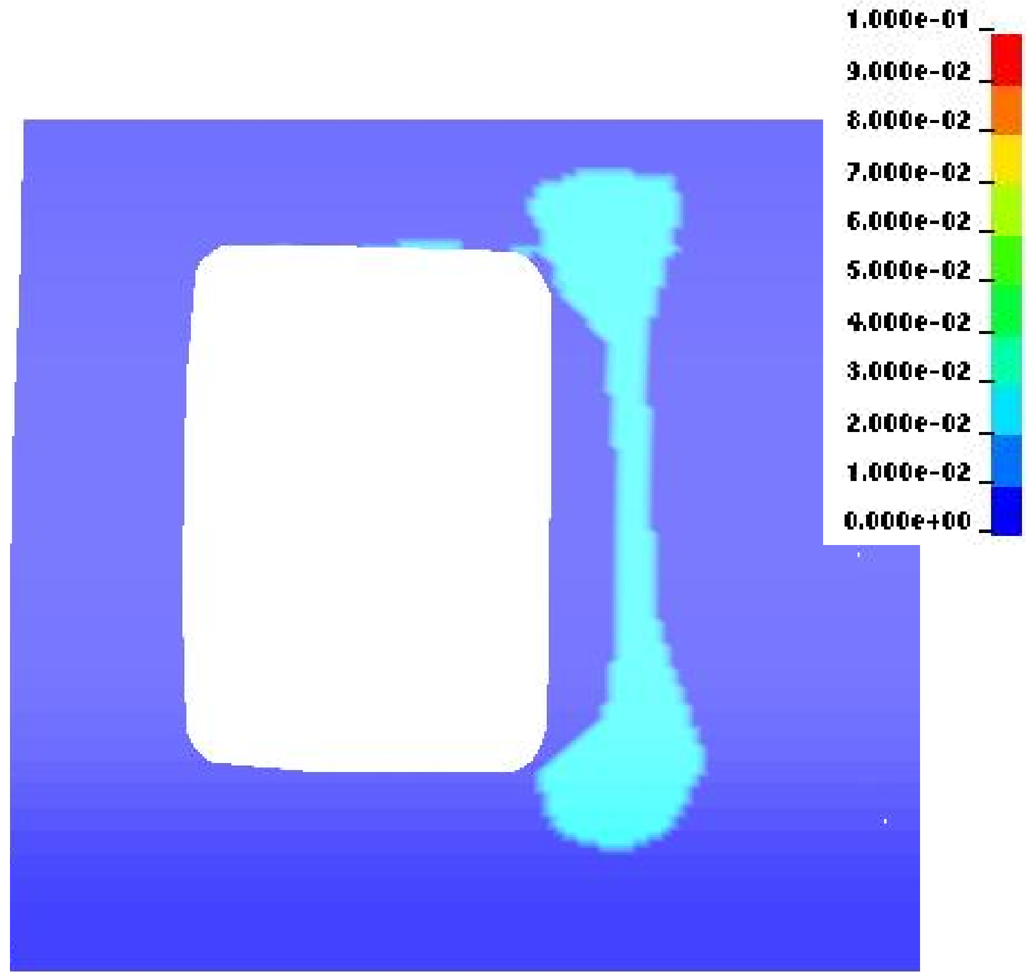
Expected.

```
*CONTROL_FORMING_STONING
$   ISTONE     LENGTH      WIDTH       STEP     DIRECT    REVERSE     METHOD
         1      300.0        4.0       0.10          8          0          0
$    NODE1      NODE2        SID      ITYPE
$ stone orientation in all direction
,,1,2
```

Surface Defect (Surface Low) Prediction

- Stoning method





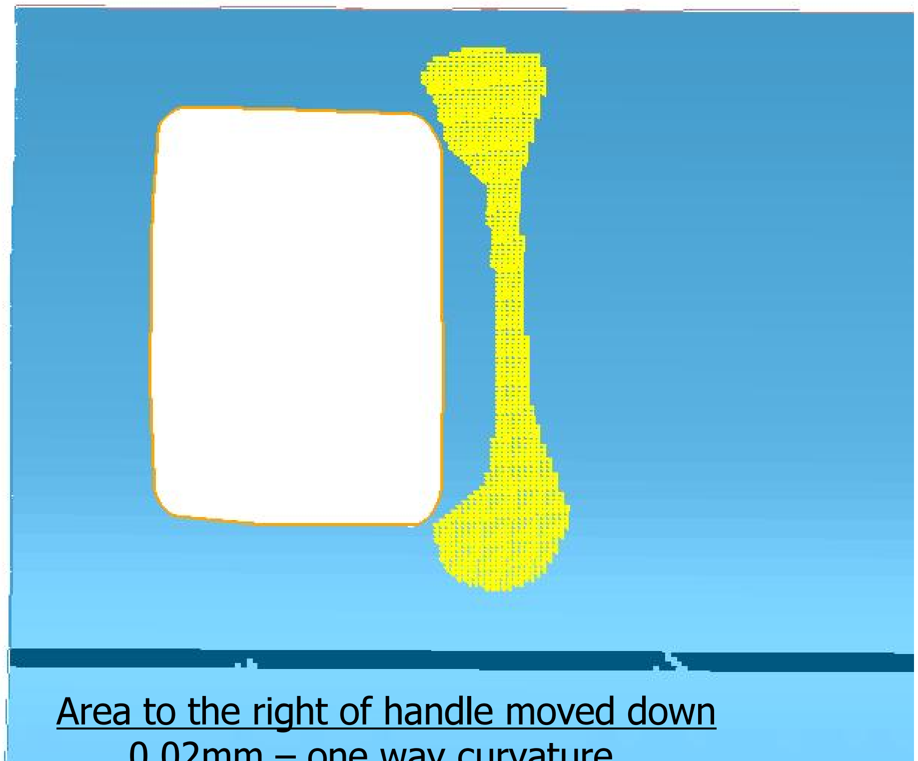
Summary:

Expected.

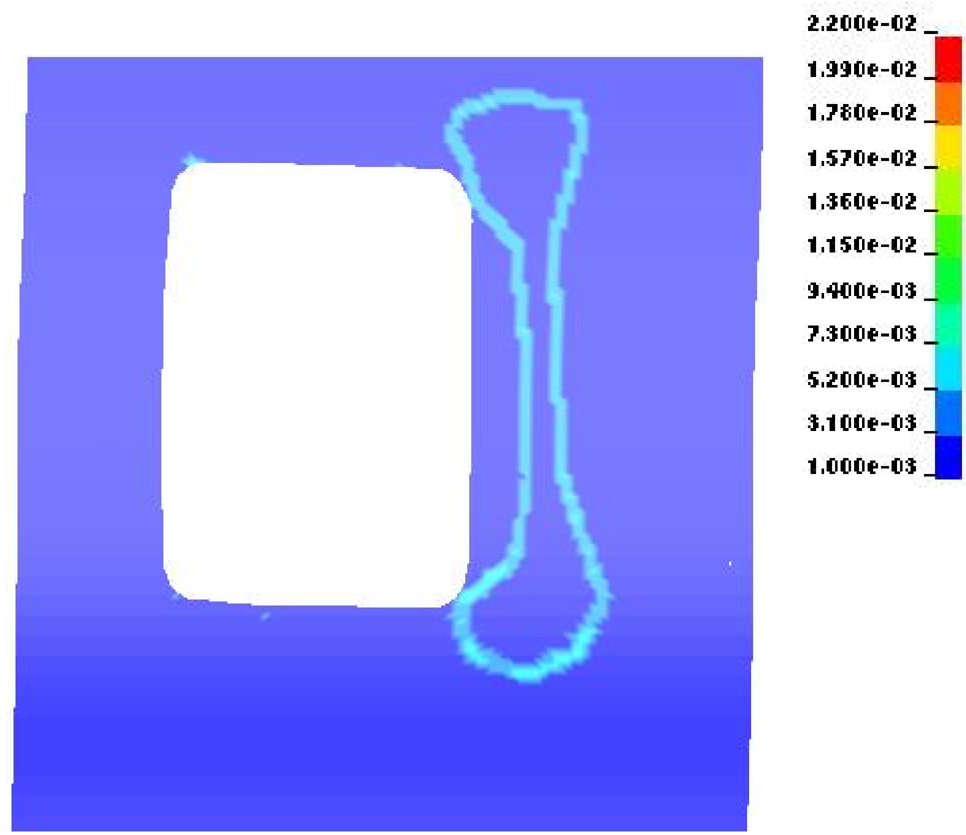
```
*CONTROL_FORMING_STONING
$    ISTONE    LENGTH     WIDTH      STEP    DIRECT   REVERSE    METHOD
          1     150.0       4.0      1.00         2         0         0
$     NODE1     NODE2       SID     ITYPE
,,1,2
```

Surface Defect (Surface Low) Prediction

- Curvature method



Area to the right of handle moved down 0.02mm – one way curvature.



Summary:

Captures the boundary of the surface low area. Inside of the boundary no curvature change. Expected.

```
*CONTROL_FORMING_STONING
$    ISTONE     LENGTH      WIDTH       STEP     DIRECT    REVERSE     METHOD
          1      150.0        4.0       1.00          2          0          1
$     NODE1      NODE2        SID      ITYPE
$ stone orientation in all direction
,,1,2
```

Conclusions

- LSDYNA's Implicit capability becomes even more robust and efficient
- LSDYNA can continue maintains technical leader in sheet stamping simulation