Advances in LS-DYNA® Metal Forming (I)

Xinhai Zhu & Li Zhang

Livermore Software Technology Corporation

Abstract

Some of the new features developed since the last conference will be discussed.

1) *Gaging pin contact improvement*
   New contact treatment for edge contact between gaging pin and sheet blank edge during gravity loading.
2) *Output control for parameterized input*
   Specifying D3PLOT and INTFORC outputs made easy for parameterized input.
3) *Gravity loading – switching between implicit dynamic and implicit static*
   Taking advantage of the best of both dynamic and static methods.
4) *Polygon adaptive box*
   A more flexible adaptive remeshing control.
5) *Maximum ID specification for blank adaptive remeshing*
   Setting starting element and node ID for an adaptive blank in a line-die simulation.
6) *Flange unfolding*
   Unfolding of deformable flanges onto addendum for trim line development.

Gage pin contact improvement

During implicit gravity loading using *CONTROL_IMPLICIT_FORMING with IOPTION 1, the edge-length of the blank mesh, which is typically non-adaptive, is usually in a range between 0.5" to 1.0". The gage pins are usually smaller in size compared with element edge-length of the blank mesh, see Figure 1. In a simplified model, a blank with a notch is loaded with gravity in +Y direction, and sitting above the post and binder, Figure 2. With the gaging pin positioned in the notch, whose three edges consist only one element each, the blank edge completely misses the gaging pins (Figure 2, right, red circle area). In order to remedy the problem, a new contact algorithm in *CONTACT_FORMING_NODES_TO_SURFACE, defined with parameter SOFT=6, was developed to address the issue, as shown in the keyword card below.

```
*CONTACT_FORMING_NODES_TO_SURFACE
$     SSID      MSID     SSTYP     MSTYP    SBOXID    MBOXID       SPR       MPR
        21        20         4         3
$       FS        FD        DC         V       VDC    PENCHK        BT        DT
 0.125E+00                               0.200E+02         4
$      SFS       SFM       SST       MST      SFST      SFMT       FSF       VSF

$     SOFT
         6
```

The slave side of the contact segment is defined by a node set (#21), while the master segment is defined as usual by the blank part set ID (#20), Figure 3. The node set should consist of any blank edge nodes where the pins are expected to be contacted during the gravity loading, and must be defined in a sequential order by using the '*By Path*' feature in LS-PrePost®4.0, Figure 4.

The result of using the new contact algorithm is shown in Figure 5, where contact between blank edge and gage pin is maintained after the gravity loading is completed. This new feature supports gaging devices of various shapes, including those shown in Figure 6.

In Figure 7, a blank is gravity loaded into 8 curved gage pins from the 2002 NUMISHEET fender model. Without the new contact, the blank edge went through the pins; with the new algorithm, the blank is completely supported by the pins.

It should be noted that the blank edge in SOFT=6 is ‘square’, not ‘rounded’ (no thickness); also, the gage pin has no thickness, either. No adaptive remeshing is supported. The parameter ORIEN in *CONTROL_CONTACT must be set to ‘4’. This feature is available in implicit static, SMP, double precision version starting in Revision 81297.

Output control for parameterized input

Often times engineers are more interested in formability conditions such as wrinkles and necking at the specific punch travel distance. These forming results are critical in determining whether the dies need to be modified for formability or quality improvement. For example, if wrinkles persist at less than 2 mm from punch home, then it is likely the wrinkles will remain in the final stamped parts. Similarly, engineers use severity of necking/split from punch distance to home to estimate how much product change is needed to bring the part to a safe forming condition. Typically, punch distances to home specified in millimeter, such as 1, 2, 4, 6 are input in the simulation input deck so corresponding D3PLOT files can be generated for formability assessment at these specified distances. In addition to formability information, sliding contact interface force and pressure (INTFOR) are also of interest. With the prevalent use of *CONTROL_FORMING_AUTOPOSITION_PARAMETER keyword, D3PLOT outputs based on tooling distances to home can become quite challenging. To make it easy to output D3PLOT and INTFOR files when using the auto-positioning feature, a new keyword *CONTROL_FORMING_OUTPUT was developed.

The inputs to the keyword are:

1) CID – tooling kinematic curve ID. As forming simulation is typically divided into binder closing phase and punch drawing phase, tooling kinematics of each phase is usually controlled by a load curve (*DEFINE_CURVE). These curve IDs are used as inputs here.
2) NOUT – total number of D3PLOT or INTFOR files needed for the phase that the curve ID represents. The number does not include the start and end states of the phase.
3) TBEG – start time of the phase.
4) TEND – end time of the phase.
5) Y1, Y2, Y3, Y4 – distances to punch home, where D3PLOT or INTFOR files needed, see Figures 1 and 2. A maximum of four distances can be input. In addition, when Y1 is a negative value, the absolute value is a curve ID, defined by *DEFINE_CURVE, with only the abscissa values indicating the punch distance to home, where plots are needed. The negative Y1 option gives users unlimited number of plots based on distance to home. Note that the parameter NOUT has priority over the number of abscissa values in the curve.

As shown in a keyword example representing a flanging process simulation involving four flanging steels (Figures 8 and 9), a total of 40 D3PLOTs and 40 INTFORs will be generated. D3PLOTs will be controlled by *CONTROL_FORMING_OUTPUT according to curve #980 and INTFORs by *CONTROL_FORMING_OUTPUT_INTFOR according to curve #981. The two curves can be exactly the same (most time they are) and generate the needed plots according to the punch to home distance values defined as the abscissa values. It should be noted that the total number of state plots is the sum of all NOUT values, and care should be taken for flanging processes of a large number of flanging steels to limit the output file size.

When these two keywords are used, the usual *DATABASE_BINARY_D3PLOT and _INTFOR are not needed, and ignored when present. If Y1 through Y4 are left blank, NOUT will be evenly divided throughout the punch travel. Distance inputs in LCID do not need to be in either descending or ascending order, and any values that are greater than the actual tool travel will be ignored.

This feature is available in LS-DYNA Revision 83757 and later releases.

Gravity loading – switching between implicit dynamic and static

Gravity loading simulation using implicit dynamics (Newmark time integration) gives a more detailed progression of how the blank comes into contact with the tools and eventually settles down in the tool. It is also useful in cases where two possible modes of final gravity loaded shapes exist, and is an alternative to using the pre-bending (*CONTROL_FORMING_PRE_BENDING) feature for gravity simulation. However, the termination time is hard to define, since users do not know ahead of time when the potential energy in the panel will eventually damp out. For users who prefer to use implicit dynamics for gravity loading simulation, the death time TDYDTH in *CONTROL_IMPLICIT_DYNAMICS is now activated for use with *CONTROL_IMPLICIT_FORMING.

In a partial keyword example below, with total termination time is set to 1.0, implicit dynamic will be conducted until 0.55 seconds, after which the implicit static will take over. The example using the keyword is shown in Figure 10 (left), where an initial totally flat blank is positioned on a curved binder. Kinetic energy starts to damp out at TDYDTH with a small transition step (Figure 11) to arrive at the final gravity loaded shape in Figure 10 (right).

```
*CONTROL_TERMINATION
1.0
*CONTROL_IMPLICIT_FORMING
$  IOPTION
         1
*CONTROL_IMPLICIT_DYNAMICS
$    IMASS     GAMMA      BETA    TDYBIR    TDYDTH
         1       0.6      0.38                0.55
```

The feature is available in double precision version, starting in Revision 81400.

Polygon adaptive box

In situations where only local mesh refinement is desired, the keyword *DEFINE_BOX_ADAPTIVE is used. However, this keyword allows only rectangular boxes, and for an area of interest that is not aligned with the global XYZ axes, many boxes are needed to enclose the area. The keyword *DEFINE_CURVE_BOX_ADAPTIVITY is therefore created to address the issue. With this keyword, only one polygon box needs to be defined to include areas of any panel shape.

Shown in Figure 12, polygon curves that make the box are input as XYZ data pairs (3E20.0), which can be converted from IGES format to the same format as *DEFINE_CURVE_TRIM_3D in LS-PrePost4.0. The parameter LEVEL defines the adaptive level within the polygon box. When DIST1 is a negative real number, it indicates the defined curve is a closed one (meaning the first data pair is the same as the last data pair), and the absolute value defines the depth of the polygon box in Z-direction. The minimum Z-coordinate of the box is Z_{min}-abs(DIST1) and the maximum Z-coordinate is Z_{max}+abs(DIST1). The Z-depth of the box is useful in line-die simulation where the area of interest maybe above or below another unconcerned area.

There are two scenarios in using the keyword. As shown in Figure 13, when local mesh refinement level of “2” within the polygon (defined by LEVEL) is smaller than the MAXLVL of “3” defined in *CONTROL_ADAPTIVE, mesh refinement in the polygon boxes goes beyond what is specified at 3 levels. When LEVEL=1, MAXLVL=3, and the polygon box excludes the area of interest, overall mesh refinements come to what is expected, see Figure 14. The later scenario of using the polygon box to exclude the area of interest, and using the MAXLVL to control the refinement in the local area is recommended when MAXLVL≠1. It is further noted that ADPSIZE in *CONTROL_ADAPTIVE is a “global” parameter, and has priority in controlling the final element size regardless what values are set for MAXLVL or LEVEL.

Lastly, the 3-D polygon curve should be near the sheet blank in Z-direction after the blank is auto-positioned in the start of a simulation. Similar to *DEFINE_BOX_ADAPTIVE, only the elements on the sheet blank that initially lie within the box will be considered for use with this keyword. Local coordinate system for defining the curve is not supported at this time. This feature is available in SMP starting in Revision 81918.

Starting ID specification for blank adaptive remeshing

When a line-die simulation job consists of draw, trimming (adaptive) and flanging is submitted as one single run (as is in LS-PrePost4.0 eZ-Setup), IDs of the newly created mesh from trimming may overlap those of the tooling mesh defined for flanging. Since the entire process simulation is set up as one sequential job and IDs of the flanging tooling mesh are known, the new mesh IDs from the trim simulation can be set larger than those from the existing IDs of the flanging tooling mesh, avoiding the overlapping problem in the flanging simulation. A new keyword, *CONTROL_FORMING_MAXID, was developed for this purpose. In a trimming example input deck shown in Figure 15, if the maximum element and node IDs of a flanging tooling mesh are 8700000 and 5000000, respectively, the starting ID of the new element and node can be set at 8790292 and 5921980, respectively to avoid the ID overlapping and error termination during the flanging simulation. The feature is available starting in Revision 84159.

Flange unfolding

Unfolding of flanges is one of the first steps in a stamping die development process. Immediately after tipping, binder and addendum are built for unfolding of flanges. According to process considerations (trim, draw depth, and material utilization, etc.), these addendum are built either in parallel or perpendicular to the draw die axis, tangentially off the main surface, or any combinations of the three scenarios. Trim lines are developed by unfolding the flanges in finished (hemmed or flanged) position onto the addendum. Addendum length in some areas may have to be adjusted to accommodate the unfolded trim lines.

Trim line development is very critical in hard tool development. Inaccurate trim lines lead to trim die rework, amount to hours and hours of welding, re-machining and spotting of trim die components. Up until recently, no flange unfolding capability existed in LS-DYNA. A major development effort produced a new keyword *CONTROL_IMPLICIT_UNFLANGING, enabling LS-DYNA users to conduct an 'unflanging' simulation within the software. This is a multi-step implicit static method with recent improvement employing a linear unfolding followed by a nonlinear unfolding. Detailed descriptions of the keyword can be found in the draft version of the keyword manual link: ftp://user:computer@ftp.lstc.com/manuals/DRAFT.

The inputs to the keyword are:

1) Flanges in flanged or hemmed position – small portions of the flanges may overlap the addendum or main part surface.
2) Addendum surface meshes – the addendum surfaces must be large enough to contain the flanges in unfolded state.
3) Boundary condition – the flange root nodes are fixed automatically. Users are required to define 3 nodes in sequential order using parameters NB1, NB2 and NB3 (Figure 16). For a flange of a closed loop, NB1 and NB3 will be next to each other, with NB3 somewhere in the middle of the loop.
4) Solution control variables – estimated number of unbendings, ranging from 10-100; unflanging and normal stiffness, ranging from 0.1-10.0; iteration limit for the first phase of unflanging, typically at 400.
5) Additional implicit control cards – this keyword is used in conjunction with option 1 of the *CONTROL_IMPLICIT_FORMING. Termination is determined by DELTAU in *CONTROL_IMPLICIT_TERMINATION, typically between 0.0005 and 0.001. An initial step size is typically 0.1 and can be specified using *CONTROL_IMPLICIT_GENERAL. Termination "time" is usually given as 10.0 in *CONTROL_TERMINATION, and should be sufficient in most cases.

The outputs of the simulation are:

1) Thickness and plastic strain information based on the unfolding are also output into an ASCII file of the dynain format to be viewed in LS-PrePost4.0.
2) Modified unfolding curve based on minimum/maximum thickness (THMN and THMX) and maximum plastic strain (EPSMX) specified can be output by activating the option

OUTPUT. This is useful to recommend a feasible trim line in a difficult unfold situation such as a severely stretched corner.

3) Flange unfolding progression animation in D3PLOT files.

Figure 16 shows an unfold of a complex flange, where the THMX is set at 1.2mm. Elements with thickness in the shrink flange area that exceeded 1.2mm were deleted, and a new trim curve is created indicating that a 'notch' in the area may be needed to avoid excessive wrinkles.

Summary

Various features related to metal forming have been developed to meet the requirements of our stamping users. LSTC has benefited from working with the best and brightest researchers and engineers, and will continue to improve to stay ahead.

References

LS-DYNA User's Manual R7.0 (Volume I), ftp://user:computer@ftp.lstc.com/manuals.

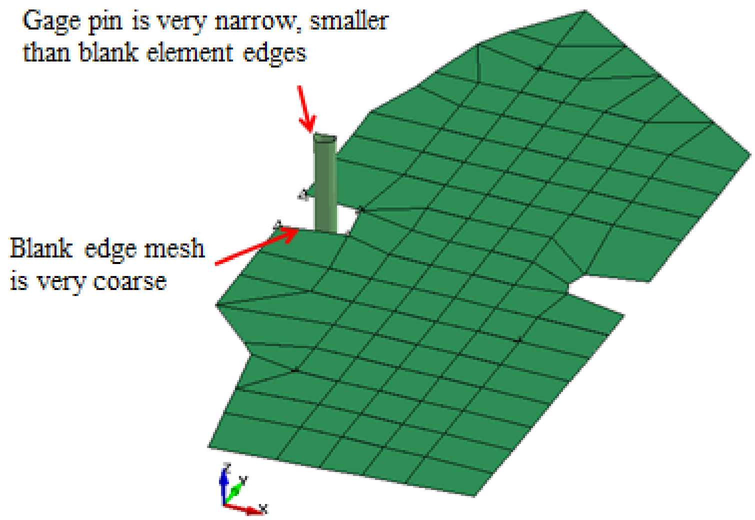

Figure 1. Gaging pin and blank mesh

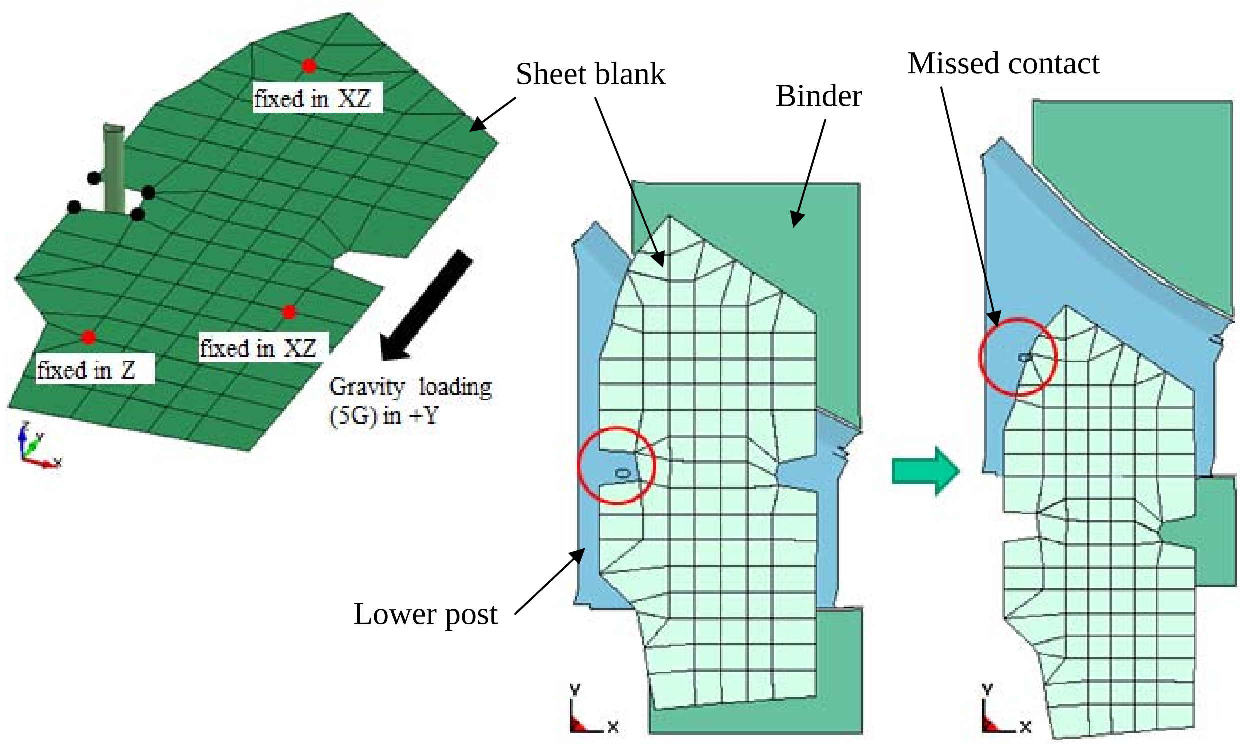

Figure 2. Missed contact between gaging pin and blank edge.

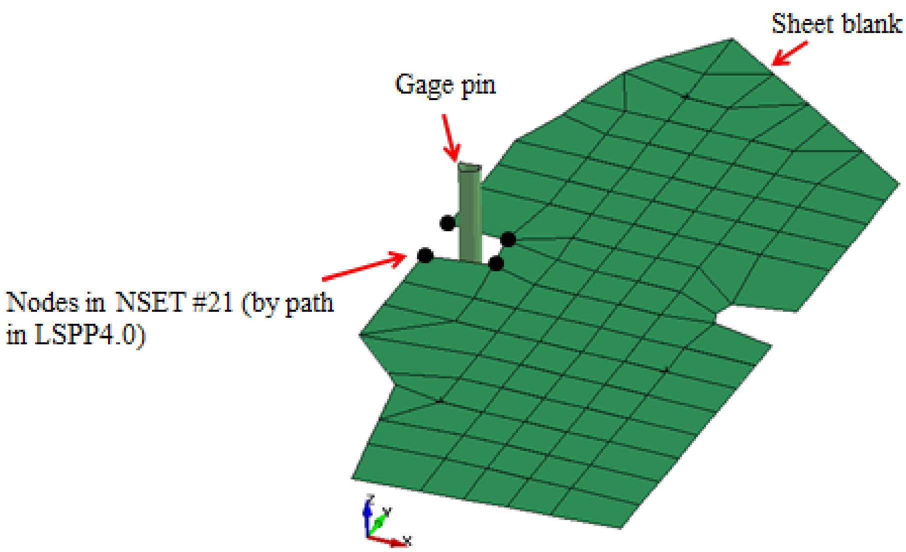

Figure 3. Define the node set.

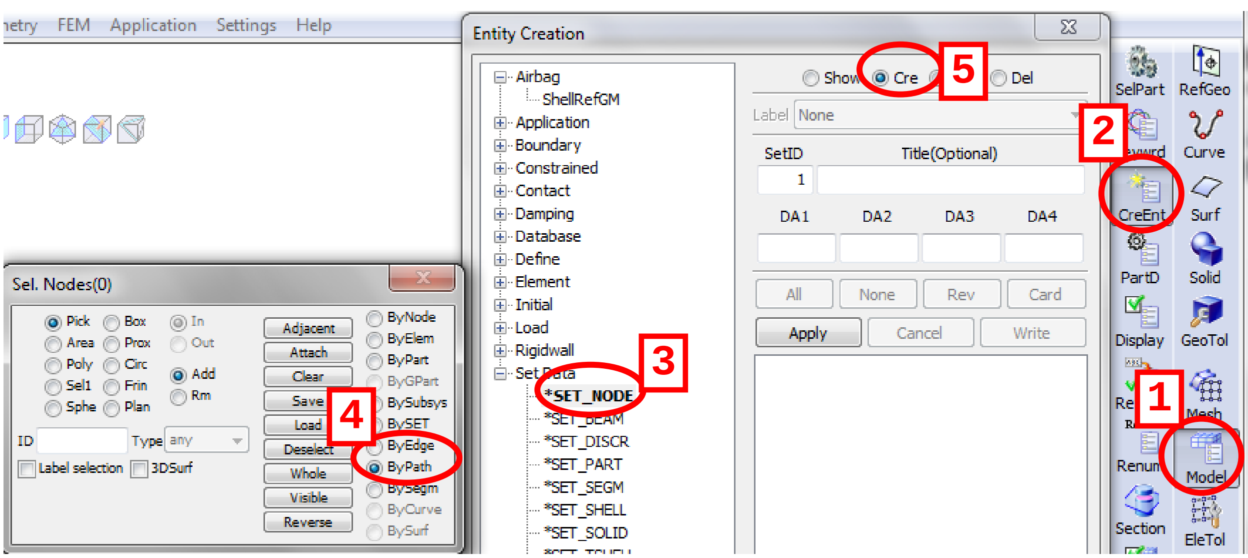

Figure 4. Create a node set "*By Path*" in LS-PrePost4.0.

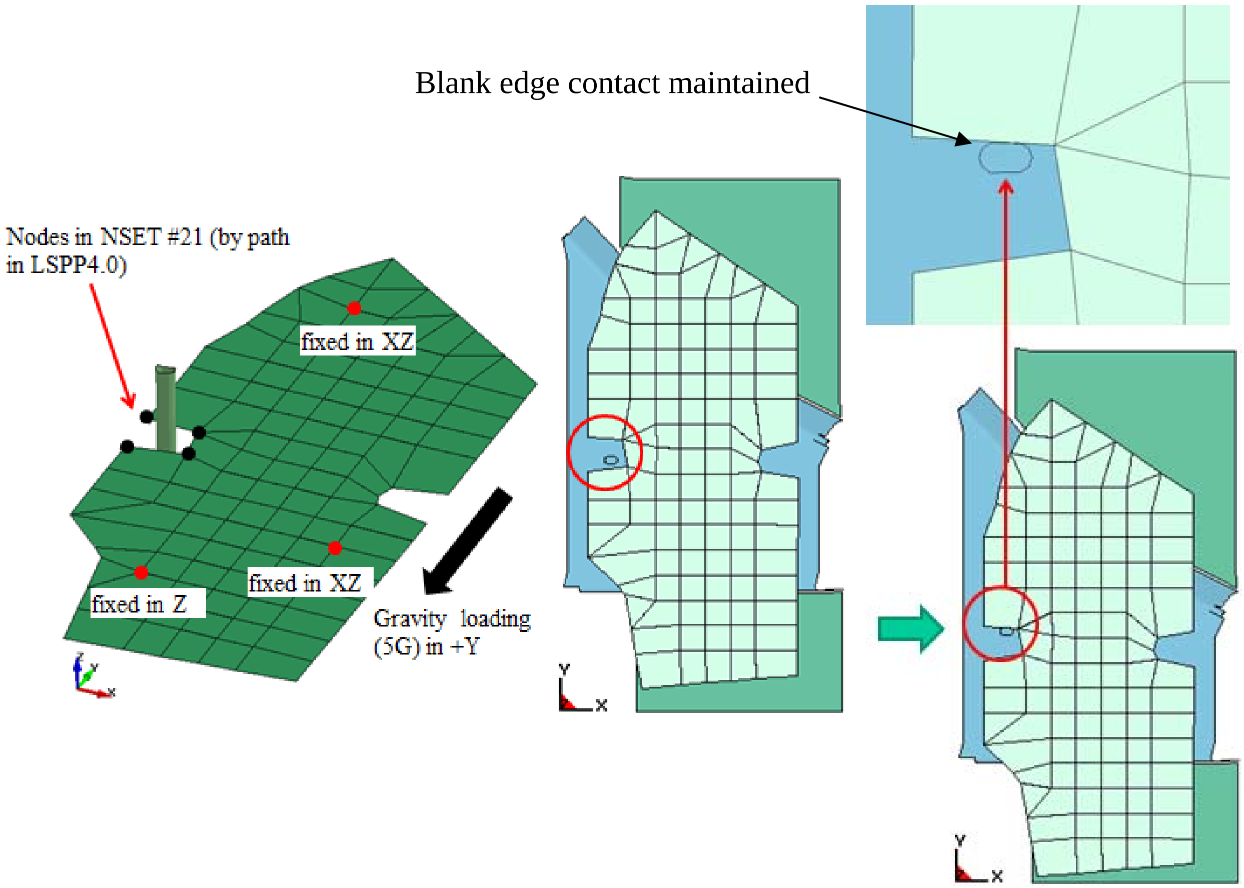

Figure 5. Blank edge/gage pin contact maintained with SOFT=6.

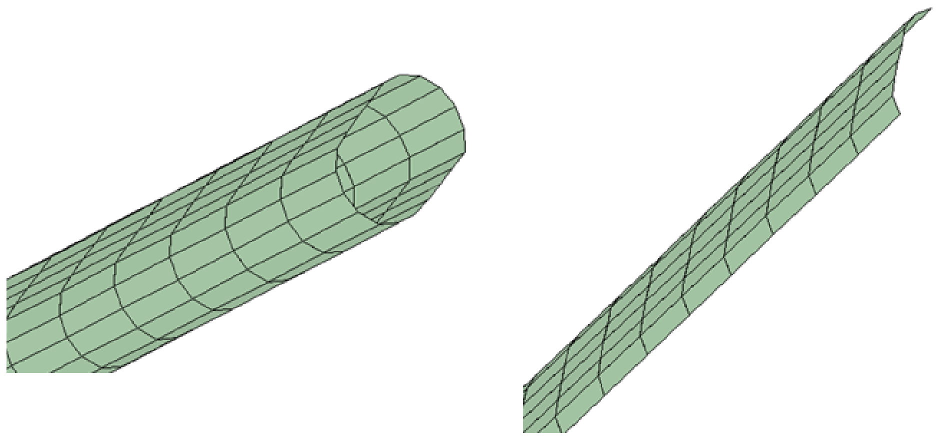

Figure 6. Possible types of gage pin or block.

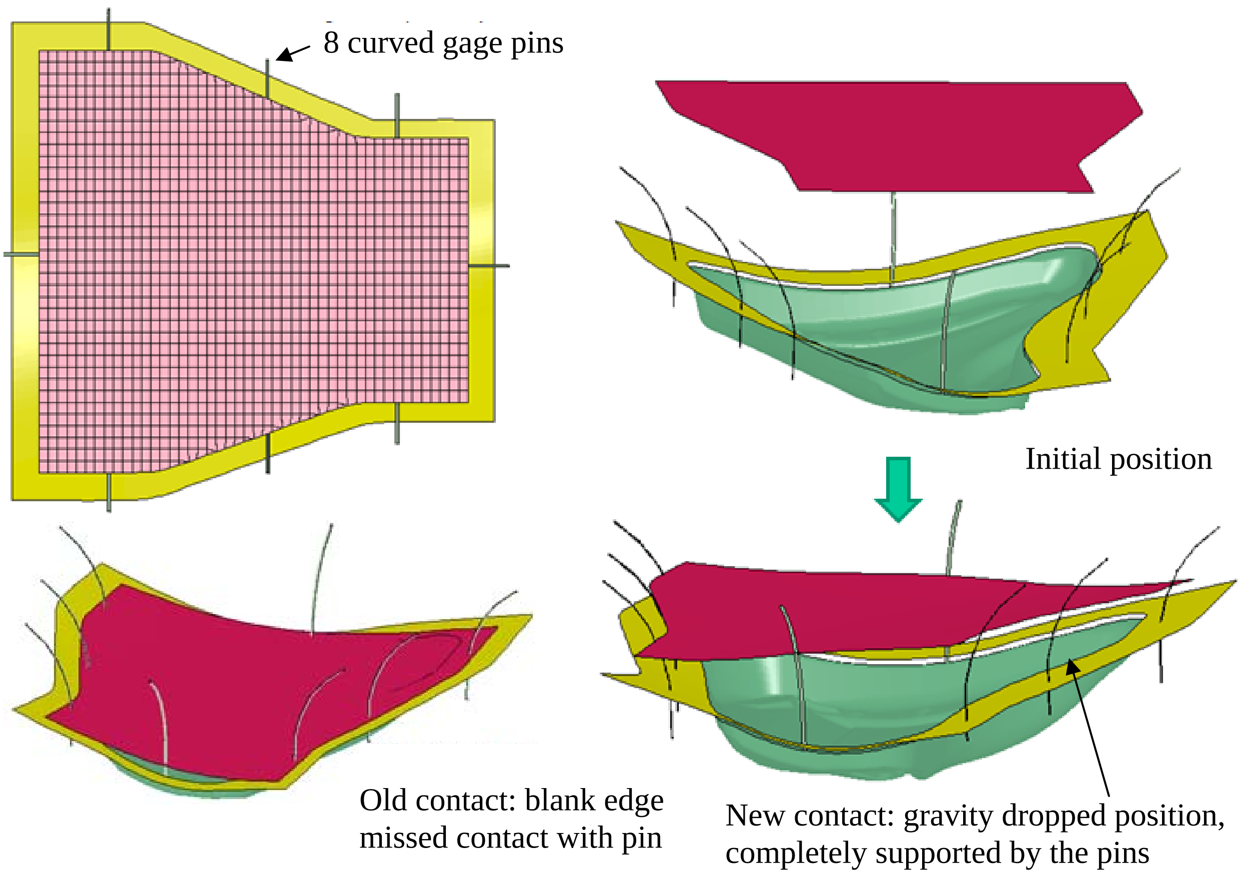

Figure 7. Possible types of gage pin or block.

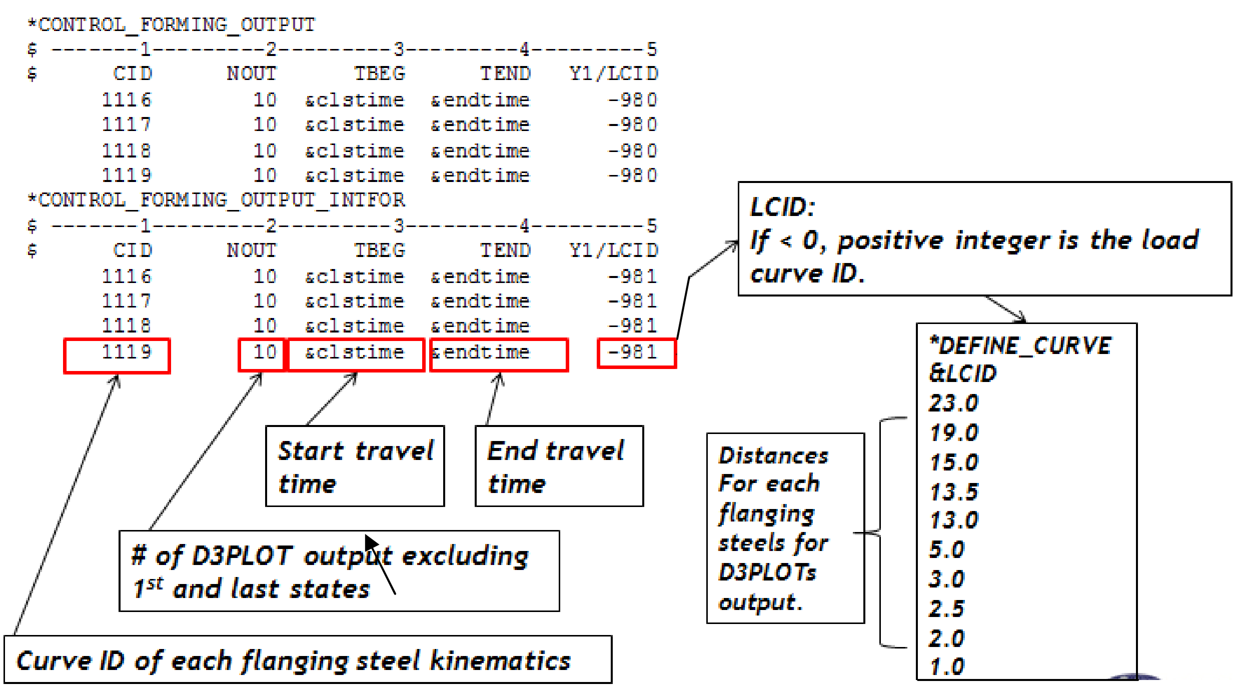

Figure 8. Output control for D3PLOT and INTFOR.

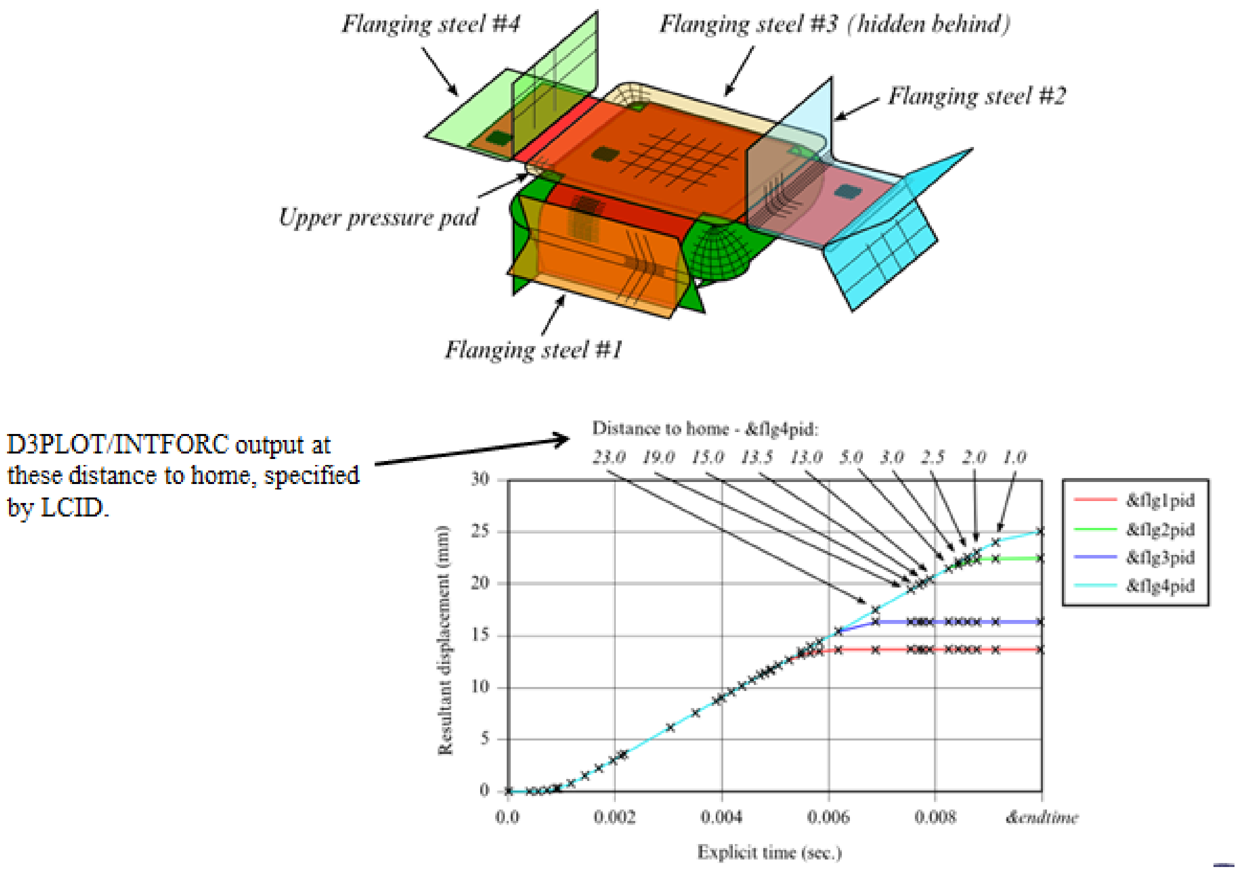

Figure 9. Output control – a flanging example.

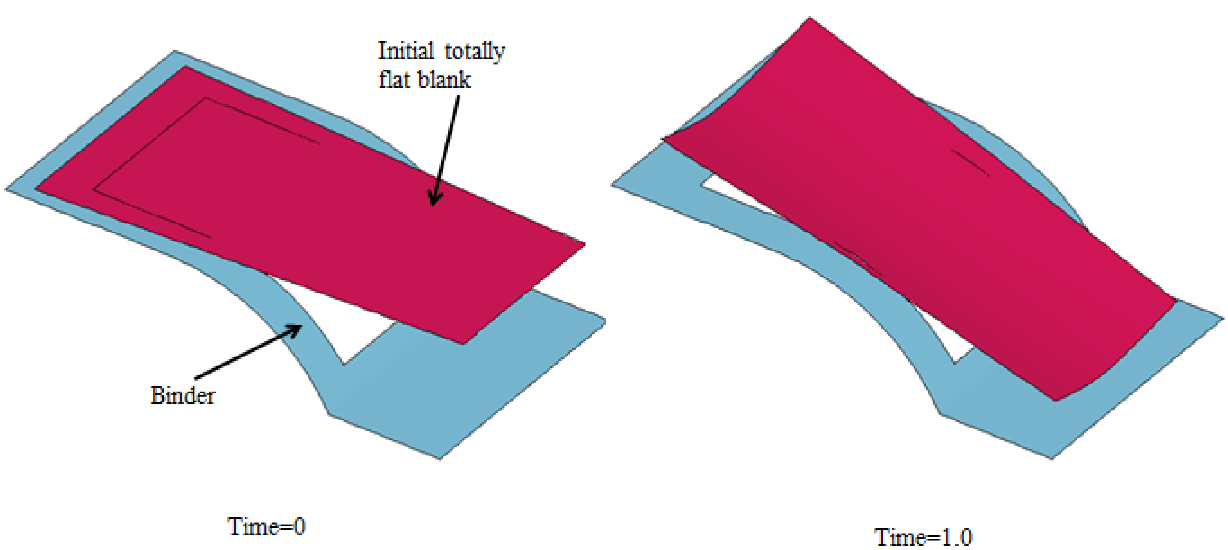

Figure 10. Switch from implicit dynamic to implicit static during gravity loading.

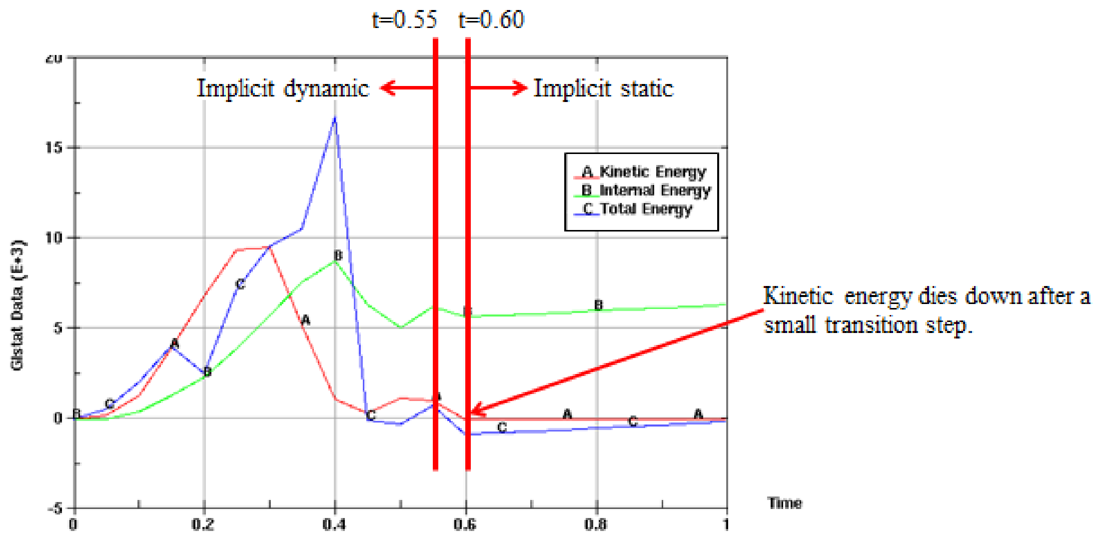

Figure 11. Energy during the switching.

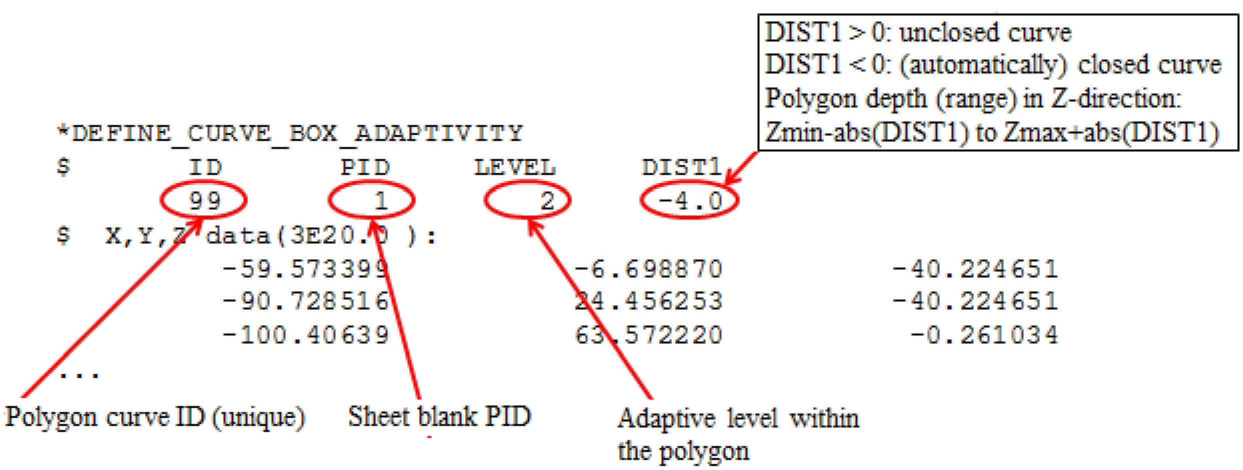

Figure 12. Polygon adaptive box keyword explanation.

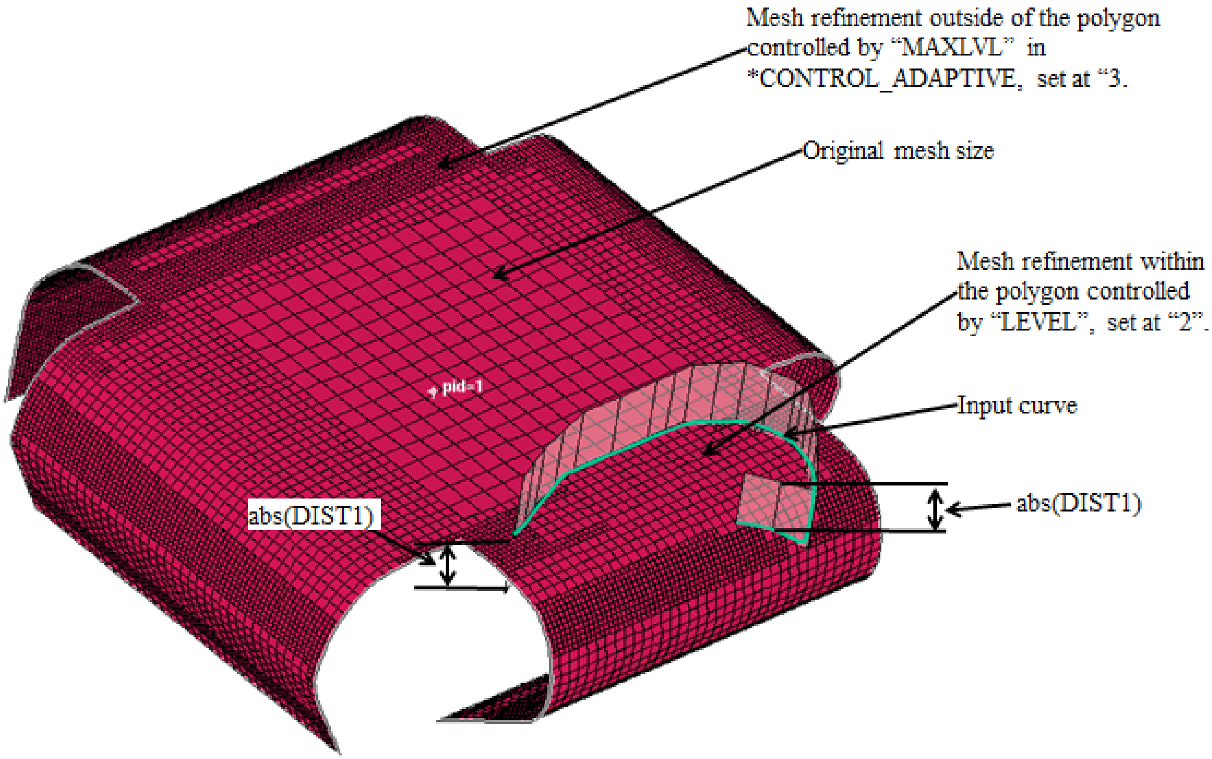

Figure 13. Mesh refinement when defined polygon curve enclose the area of interest, and MAXLVL≠1.

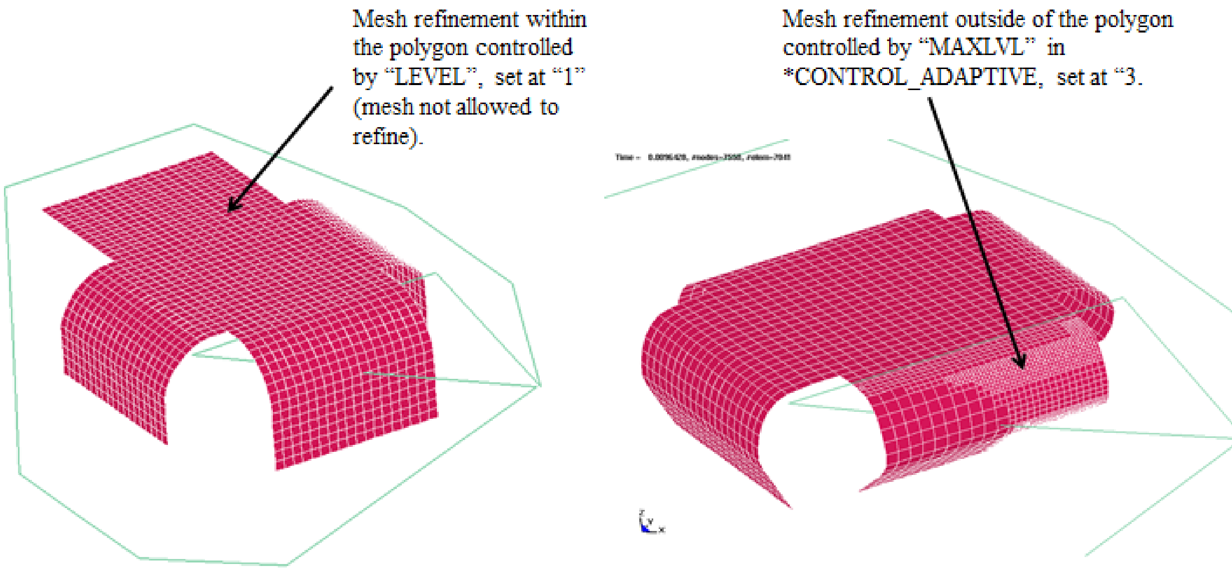

Figure 14. Mesh refinement when defined polygon curve exclude the area of interest, and LEVEL < MAXLVL.

```
*KEYWORD
*INCLUDE_TRIM
sim_trimming.dynain
...
*CONTROL_ADAPTIVE_CURVE
$     IDSET     ITYPE         N      SMIN
   &blksid         2         2       0.6
*CONTROL_CHECK_SHELL
$      PSID    IFAUTO    CONVEX      ADPT    ARATIO     ANGLE      SMIN
  &blksid1         1         1         1 0.250000150.000000  0.000000
*INCLUDE
EZtrim.k
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
*DEFINE_CURVE_TRIM_NEW
$#     tcid    tctype      tflg      tdir     tctol      toln    nseed1    nseed2
      90914         2         0         1  1.250000  1.000000         0         0
sim_trimming_trimline_01.igs
*DEFINE_VECTOR
$#      vid        xt        yt        zt        xh        yh        zh       cid
          1     0.000     0.000     0.000     0.000     0.000  1.000000         0
*CONTROL_FORMING_MAXID
$       pid    maxidn    maxide
          4   5921980   8790292
*END
```

New element/node ID from adaptive trimming will be larger than 8790292 and 5921980, respectively.

Figure 15. An example of defining starting ID for an adaptive trimming.

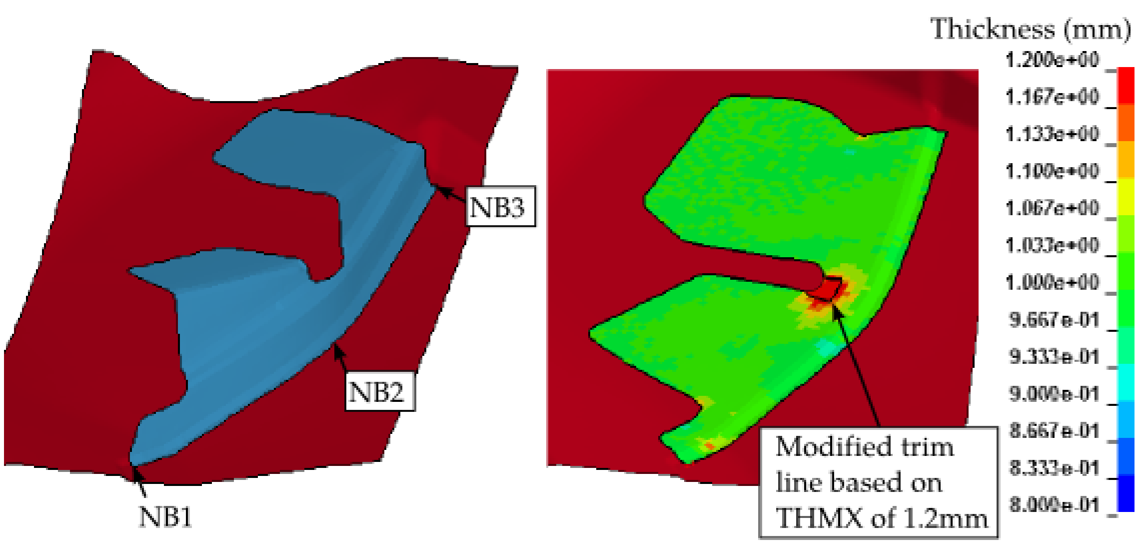

Figure 16. An example of flange before (left) and after (right) unfolding.