Improvements to One-Step Simulation in LS-DYNA

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INTRODUCTION

The followings are new additions and improvements for the keyword *CONTROL_FORMING_ONESTEP since our last update:

1) Damage accumulation,
2) Maximum thickness scale factor,
3) New options QUAD and QUAD2.

DAMAGE ACCUMULATION:

Damage accumulation *D* is calculated based on (refer to manual section *MAT_ADD_EROSION):

$$D = \left(\frac{\varepsilon_p}{\varepsilon_f}\right)^{\mathrm{DMGEXP}}$$

A new load curve LCSDG and a new variable DMGEXP is added in the keyword. In the example below, load curve #500 provides plastic failure strain vs. stress triaxiality and DMGEXP is assumed to be 1.254. Since the damage accumulation is written into the file onestepresult as history variable #6, the variable NEIP in *DATABASE_EXTENT_BINARY should be set to at least ‘6”.

```
*CONTROL_FORMING_ONESTEP
$   OPTION              AUTODB   TSCLMIN    EPSMAX              LCSDG    DMGEXP
         7                            0.8       0.3                500     1.254
*DEFINE_CURVE
500
-0.3,0.6
-0.2,0.3
0.0,0.2
0.2,0.25
0.4,0.46
0.65,0.28
0.9,0.18
*DATABASE_EXTENT_BINARY
$    NEIPH     NEIPS    MAXINT    STRFLG    SIGFLG    EPSFLG    RLTFLG    ENGFLG
                   6         7         1
$   CMPFLG    IEVERP    BEAMIP     DCOMP      SHGE     STSSZ
                   1                   2
```

The damage accumulation contour map from the file onestepresult can be plotted in LS-PrePost, as in Figure 1.

New variable TSCLMAX:

During the early stage of product design, the initial product specifications may lead to large strains and excessive thinning on the formed panel. The ensuing one-step results would not be suitable to be used in a crashworthiness simulation. However, these kinds of forming issues are certain to be fixed as a natural part of the design and stamping engineering process. A new variable TSCLMAX (just like variables TSCLMIN and EPSMAX) is thus created to impose artificial limits on the upper bound thickening (indication of wrinkles). The variables provide convenient way to run a crash simulation with approximate and reasonable forming effects before the design is finalized. In the keyword below (which is a part of the firewall model with original thickness of 0.75mm), TSCLMAX is set 1.1 to limit the max thickening in the part to 0.825mm:

```
*CONTROL_FORMING_ONESTEP
$   OPTION   TSCLMAX    AUTODB   TSCLMIN    EPSMAX
         7       1.1                 0.9       0.3
```

The upper-bound truncated thickness contour map is shown in Figure 2(bottom), while Figure 2(top) shows thickness contour map with no TSCLMAX.

NEW OPTIONS FOR *CONTROL_FORMING_ONESTEP- QUAD2, TRIA, AND QUAD:

When one-step forming method (with keyword *CONTROL_FORMING_ONESTEP) was first introduced back in 2011, all quadrilateral elements in the model were split into two triangular elements internally for calculation. As of Revision 112682, this original formulation (with no option) is set as option TRIA. A new option QUAD (Revision 112071) is now available supporting quadrilateral elements with improved algorithm in various areas, which leads to better results (Figure 4). In addition, this option greatly improves calculation speed under multiple CPUs in SMP mode. Another new option QUAD2 is yet one more improvement over the option QUAD with enhanced element formulation, which further improves results in terms of thinning and plastic strain (Figure 3) with slightly longer CPU times. The option QUAD2 is set as the default for this keyword as of Revision 112682 and is the recommended option. Comparing Figures 3, 4 and 5, QUAD2 gives the best results, with expected higher thinning around the round shaped corners and smoothed thickness contour. Plastic strain contour distribution is also more reasonable without some of the noises observable in QUAD and TRIA options.

The following partial keyword input is an example of using the option QUAD2. Note the draw bead force parameter AUTOBD is set at 0.5. Calculation speed comparison among options QUAD, QUAD2 and TRIA can be found in `Table 0-1`.

```
*KEYWORD
*include
model.k
*CONTROL_TERMINATION
1.0
*CONTROL_FORMING_ONESTEP_QUAD2
$#  option  maxthick    autobd   thinmin    epsmax
         7                 0.5
```

```
*CONTROL_FORMING_ONESTEP_AUTO_CONSTRAINT
         1
*CONTROL_IMPLICIT_GENERAL
$#  imflag       dt0    imform      nsbs       igs     cnstn      form    zero_v
         1    0.2500         2         1         0         0         0         0
*CONTROL_IMPLICIT_TERMINATION
$#  deltau    delta1     ketol     ietol     tetol     nstep
  0.001000     0.000     0.000     0.000     0.000         0
*CONTROL_IMPLICIT_NONLINEAR
$#  nsolvr    ilimit    maxref     dctol     ectol  not used     lstol      rssf
        12        11       200  0.010000  0.100000     0.000     0.000     0.000
$#   dnorm    diverg     istif   nlprint
         0         0         0         2
$#  arcctl    arcdir    arclen    arcmth    arcdmp
         0         0     0.000         1         2
*CONTROL_IMPLICIT_SOLVER
5
*PART

   5000000   5000000   5000000
*SECTION_SHELL
   5000000        16        1.        5.        1.
      0.72      0.72      0.72      0.72
...
```

Calculation speed comparisons among the three options can be found in Table 1.

Table 0-1 Calculation speed improvement with and without option _QUAD.

	Number of elements	Calculation speed (D.P. SMP Rev.112720, 8 CPUs)		
		Option TRIA	Option QUAD	Option QUAD2
A hat shape part	71000	21.0 min	14.1 min	16.6 min
A upper dash panel	61700	24.5 min	11.5 min	17.2 min

ACKNOWLEDGEMENT:

The features and improvements in this article were requested by Amit Nair and Dilip Balsod of LSTC. Their valuable feedback during the development is highly appreciated.

REVISION INFORMATION:

1) Revision 108229: variables LCSDG and DMGEXP are available.
2) Revision 111311: variable TSCLMAX is available.
3) Revision 112071: option QUAD is available.
4) Revision 112682: original formulation is designated as option TRIA. A new option QUAD2 is available.

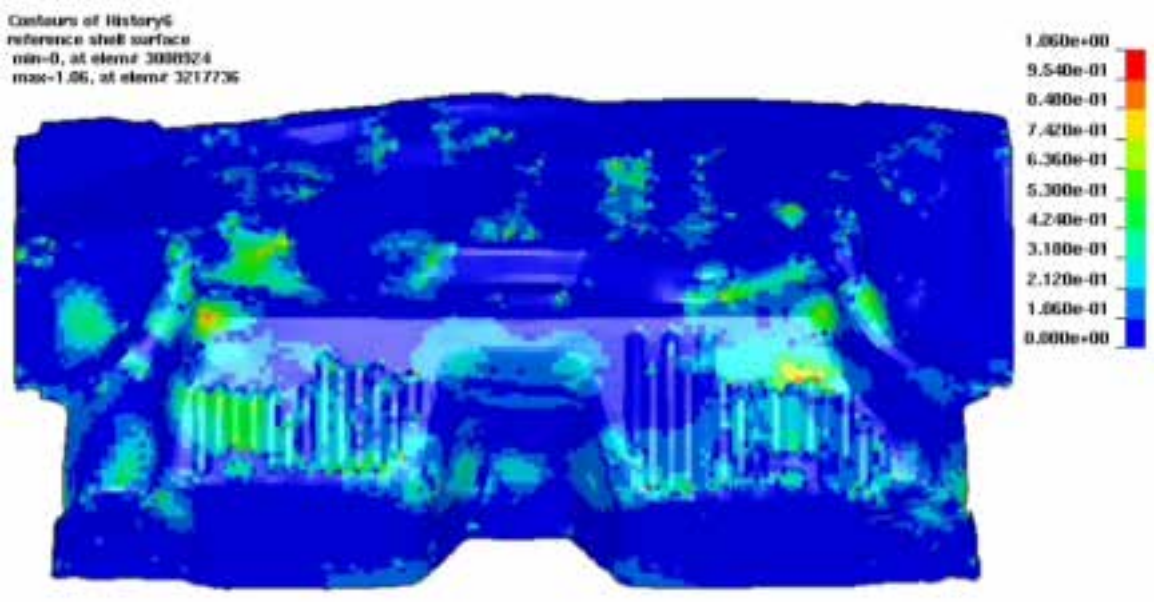

Figure 1. Damage accumulation in one-step simulation.

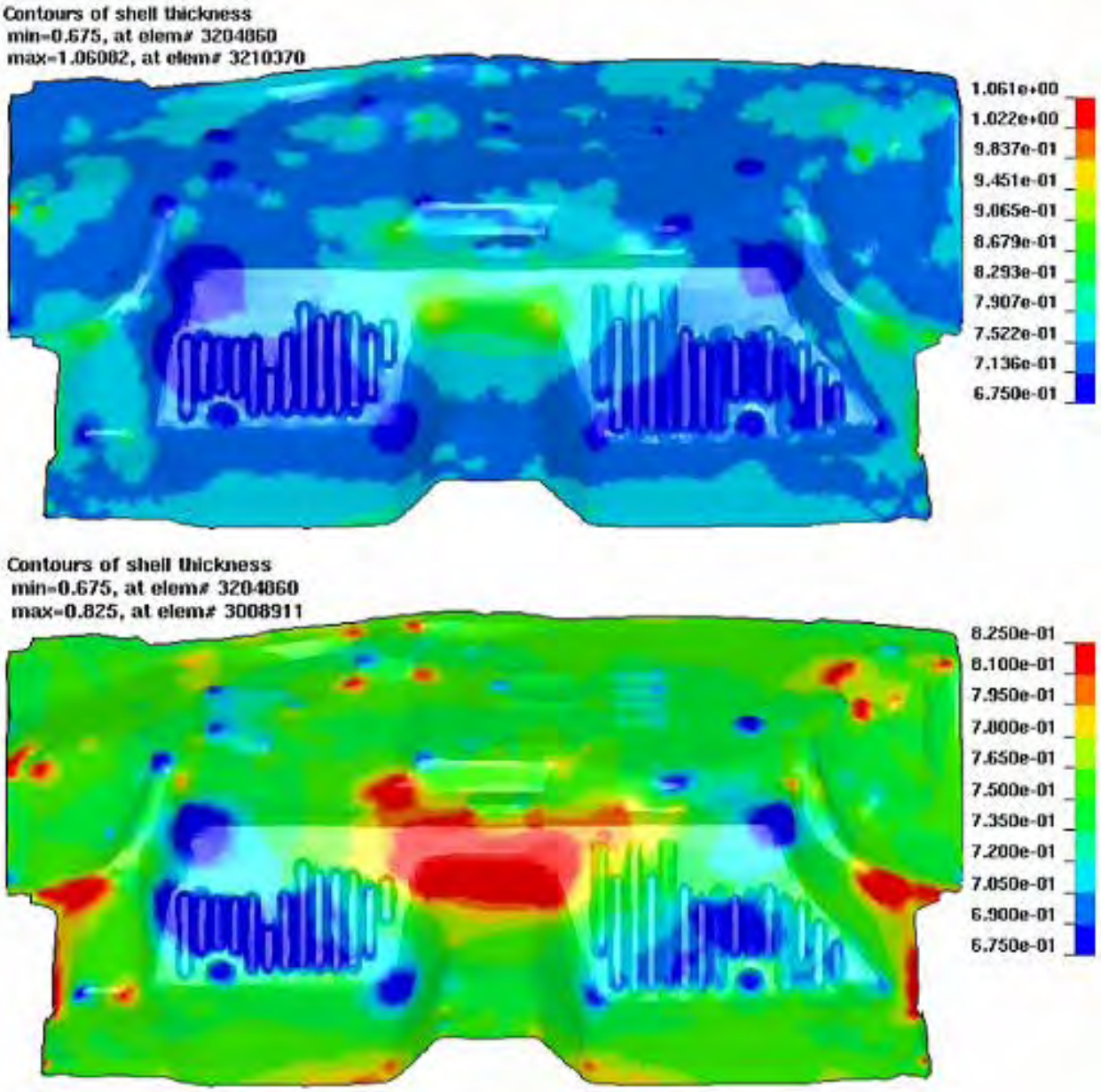

Figure 2. Maximum thickness scale factor (TSCLMAX) to limit the upperbound thickness values – top: no TSCLMAX; bottom: TSCLMAX=1.1); original thickness 0.75mm.

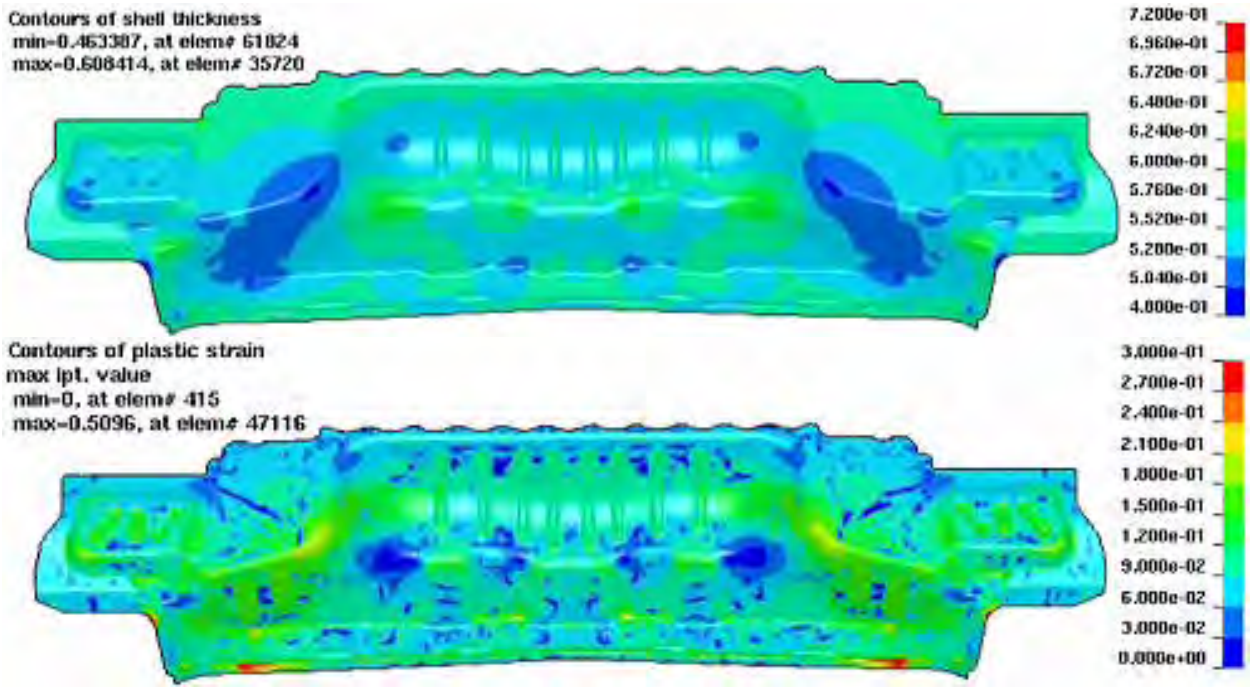

Figure 3. Option QUAD2 (default, recommended) – thickness (top) and plastic strain (bottom) contours.

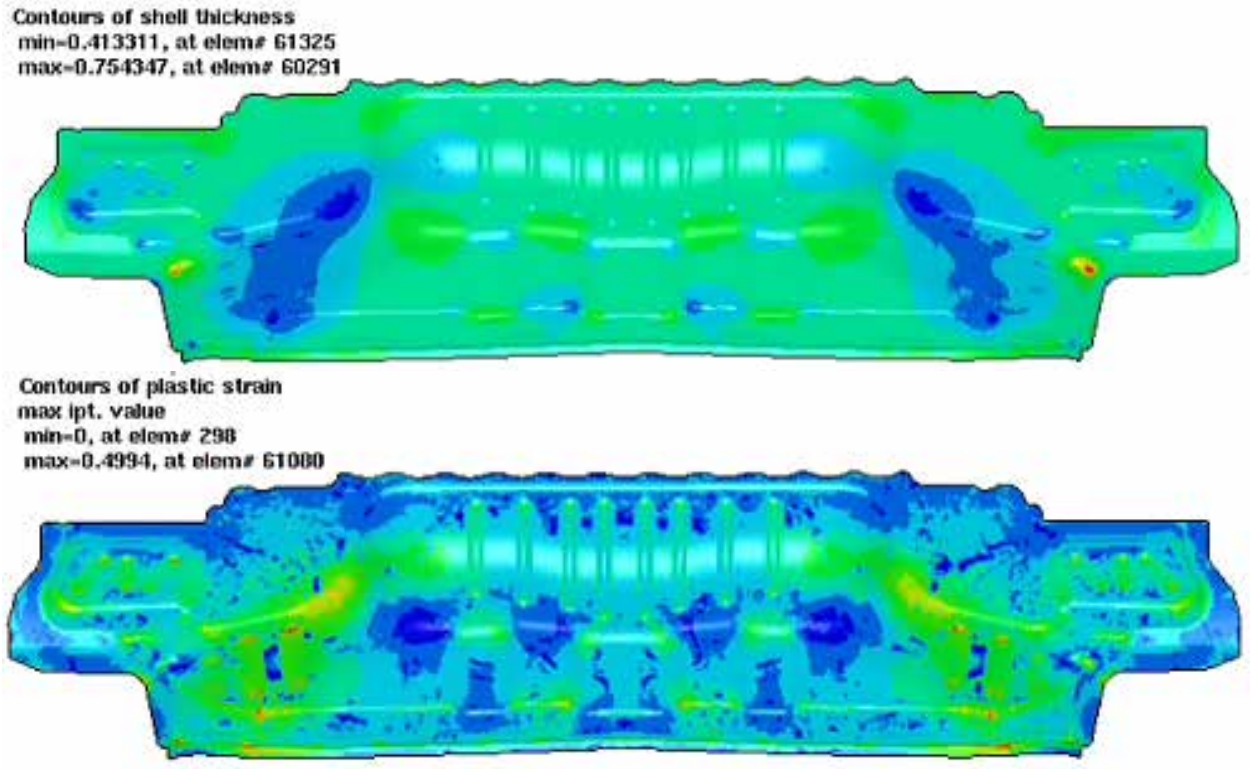

Figure 4. Option QUAD – Thickness (top) and plastic strain (bottom) contours.

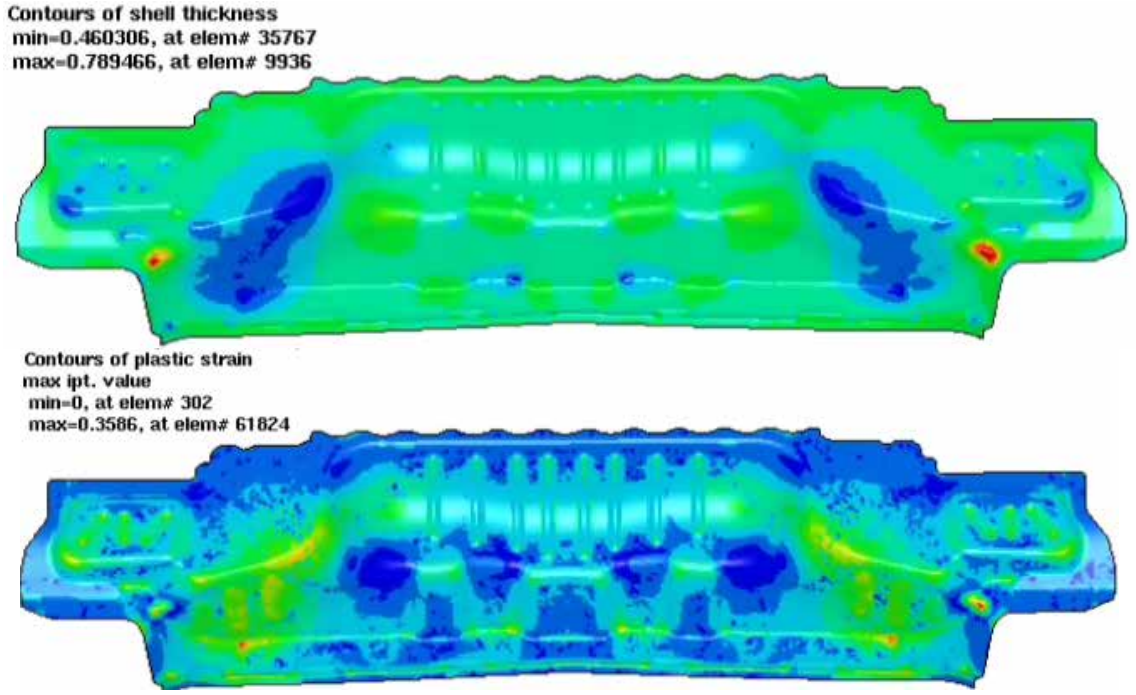

Figure 5. Option TRIA – Thickness (top) and plastic strain (bottom) contours.