Improving Crash Analysis Through the Estimation of Residual Strains Brought About by Forming Metal

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ABSTRACT

This paper describes a method that can be used to estimate the residual strains from the forming of sheet metal without running forming simulations. For a first-order crash analysis, using estimated residual strains rather than the strains reported from several forming simulations increases the speed of the design process. The method estimates residual forming strains from the part geometry itself and assumes that the part was formed from a planar sheet of metal.

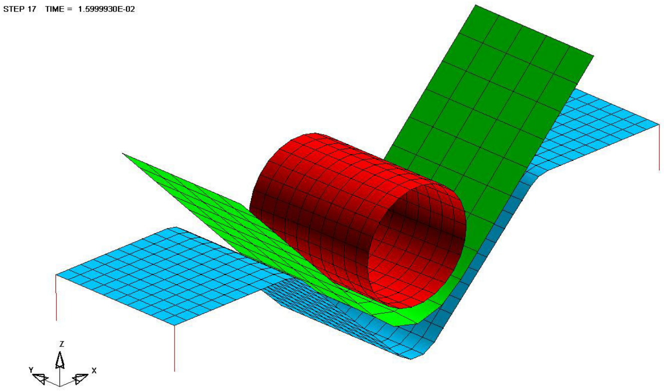
The importance of considering the forming history of a part is demonstrated by comparing crash analysis results with and without the consideration of these residual strains. Along with this, physical test results will be compared of a part as formed and an identical part which was heat treated to relieve some of the cold working strains.

Once the importance of considering forming history has been established, an alternative method of estimating residual strains will be examined. Crash analysis results using forming simulation residual stresses and strains will be compared to analysis results using estimated strains from the alternative method.

Finally the scope of application of this strain estimation method will be discussed.

1 Importance of Including Forming Strains

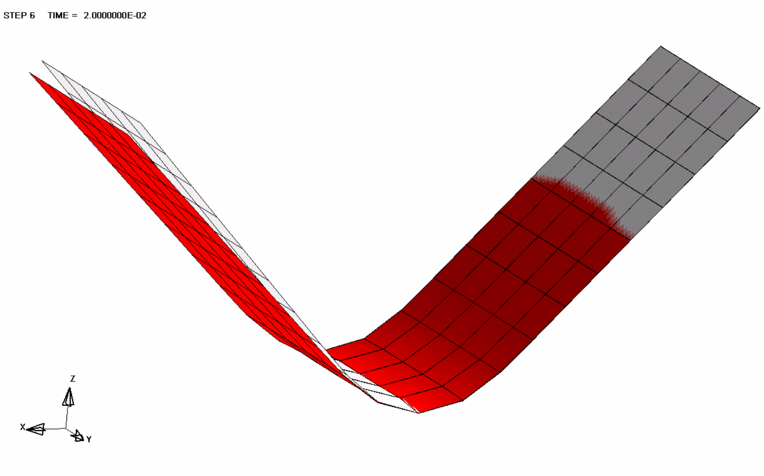
An LS-DYNA model was created to analyze the forming process of a simple part. The guidelines in the paper: Input Parameters for Metal Forming Simulation using LS-DYNA, by Bradley N. Maker were followed in creating the model and the LS-DYNA input deck is included in the appendix.



Forming Simulation

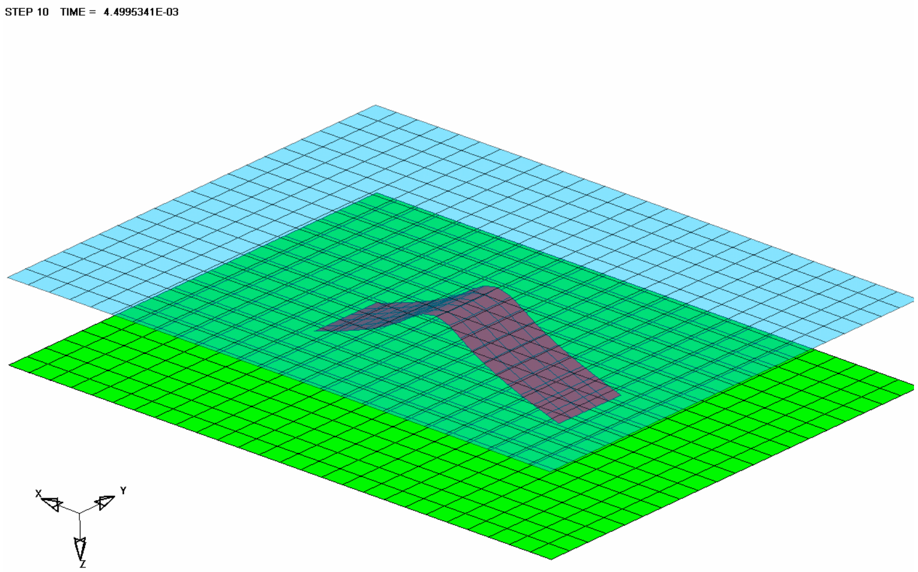
The *INTERFACE_SPRINGBACK keyword was used so that the residual stresses and strains from the analysis would be written to a *dynain* file. This same dynain file is included in an LS-DYNA implicit run that models the spring back.

The spring back model was developed using the guidelines from: Input Parameters for Springback Simulation using LS-DYNA also by Bradley N. Maker. This model is included in the appendix. Once again, the *INTERFACE_SPRINGBACK keyword was used so the residual stresses and strains could be used in the crash simulation.



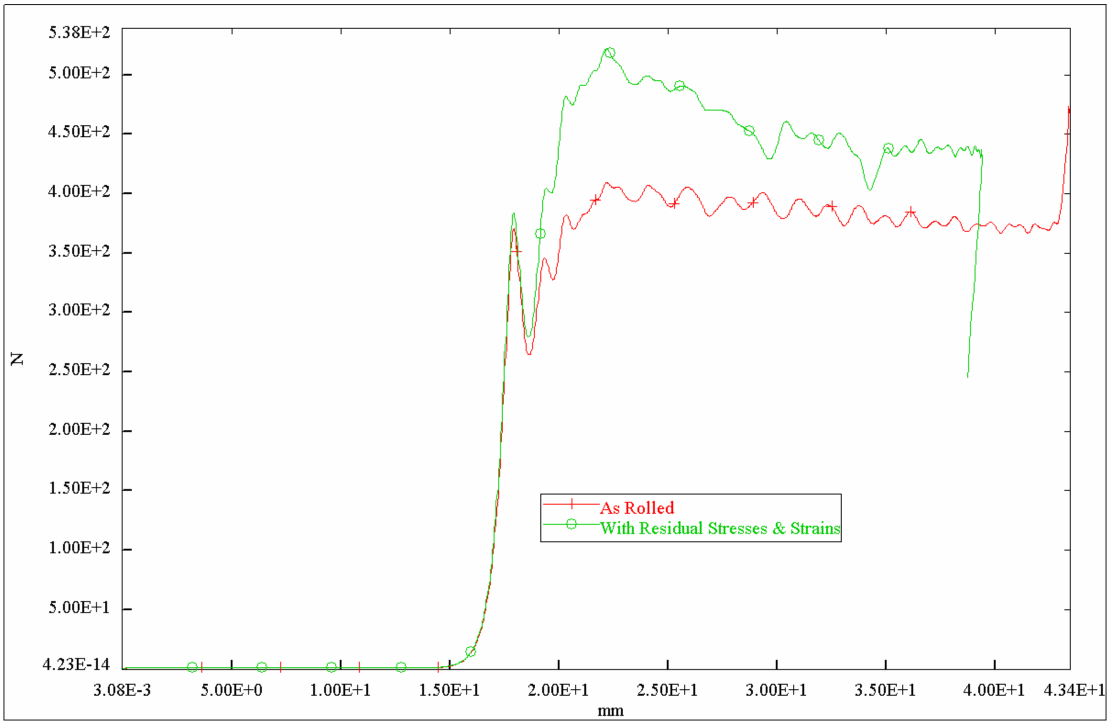
Spring Back Simulation

Two LS-DYNA crash models were developed. One model used the *INITIAL_STRESS_SHELL cards from the dynain file obtained from the spring back analysis while the other model did not use them. Running these two models allow the comparison of crash analysis results with and without the consideration of cold work from the forming process. The LS-DYNA input deck for this is included in the appendix.



Crash Simulation

The Graph below represents the force versus displacement relationship from both of the crash simulations.



Comparison of Force versus Displacement Curves

The table below lists the percentages of error that result when the forming stresses and strains are ignored. The crash analysis using residual stresses and strains is assumed to be ideal.

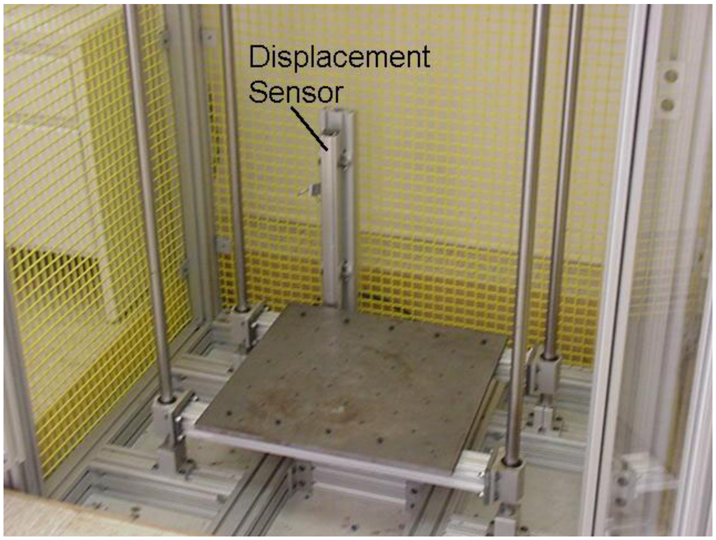
Model	1st Peak Load	Error	Displacement	Error
As Rolled	410 N	-21%	43.4 mm	+11%
With Stresses and Strains	522 N	0	39.2 mm	0

Error Analysis Table

Physical Test

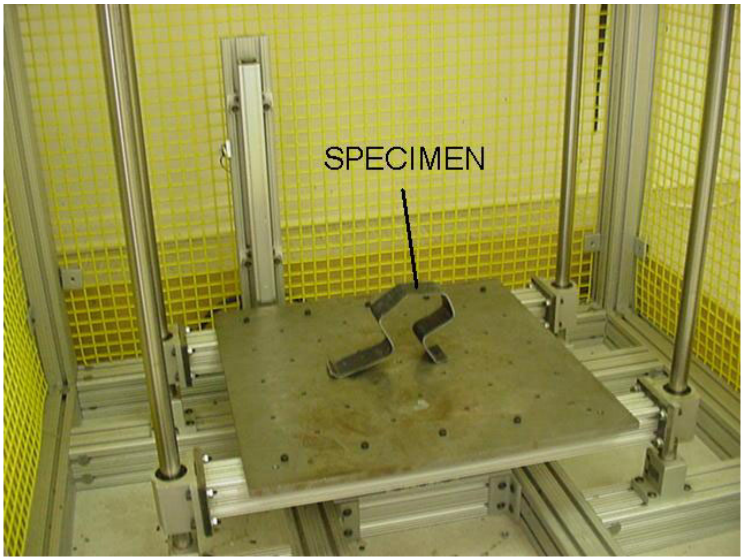
A physical drop tower test was run on two identical parts. One part was heat treated for 8 hours at 800º F then air-cooled to relieve some of the strains from forming while the other was crushed without any treatment after forming.

Drop Tower Test Machine



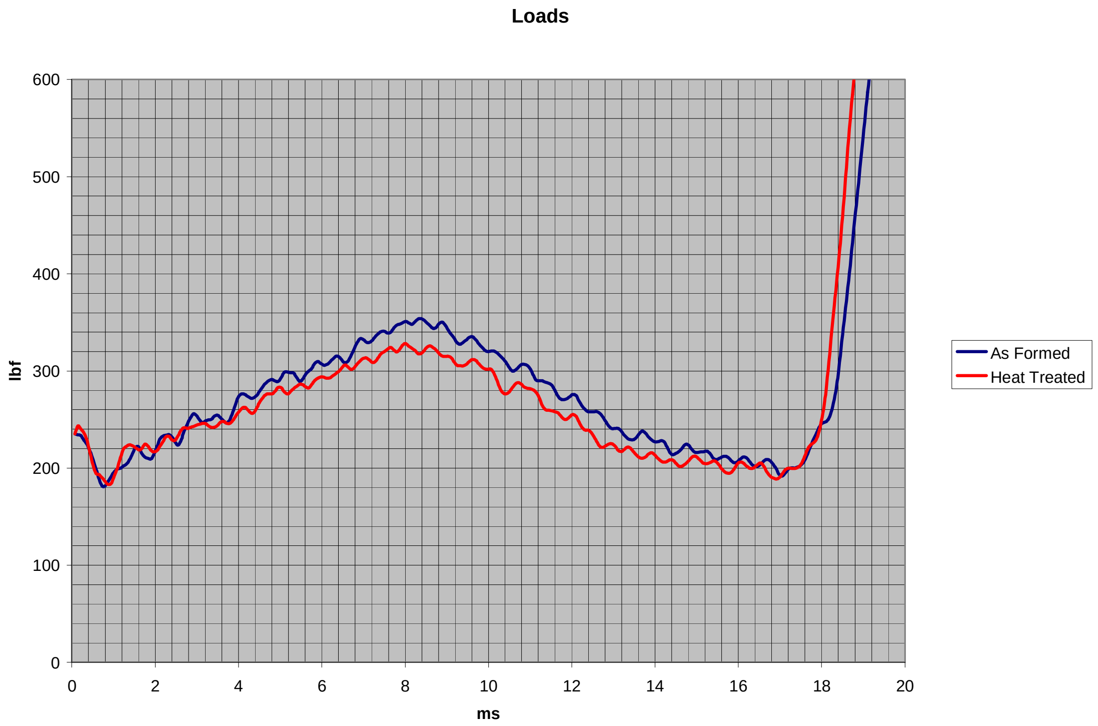
Displacement Sensor in Drop Tower

Load Sensor in Drop Tower

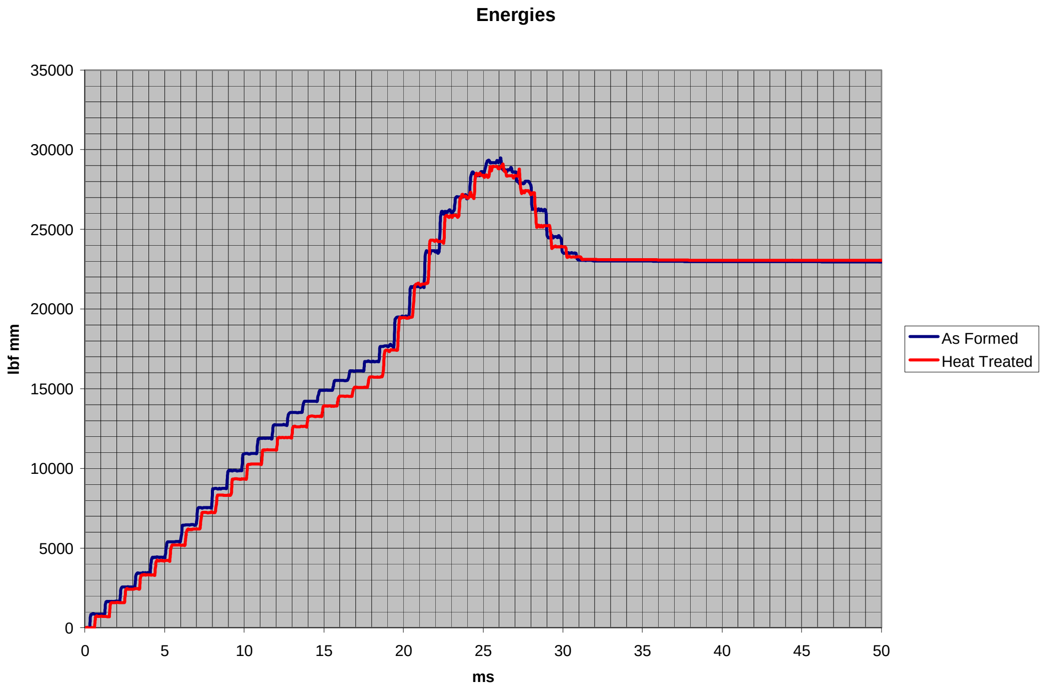


Placement of Specimen on Mounting Plate

The parts tested had just one 90º bend. The results are as follows.



Crushing Force vs. Time



Energy Absorbed vs. Time

Crushing Force vs. Displacement

The table below lists the percentages of discrepancy between the heat treated and non-heat treated parts when crushed in the drop tower.

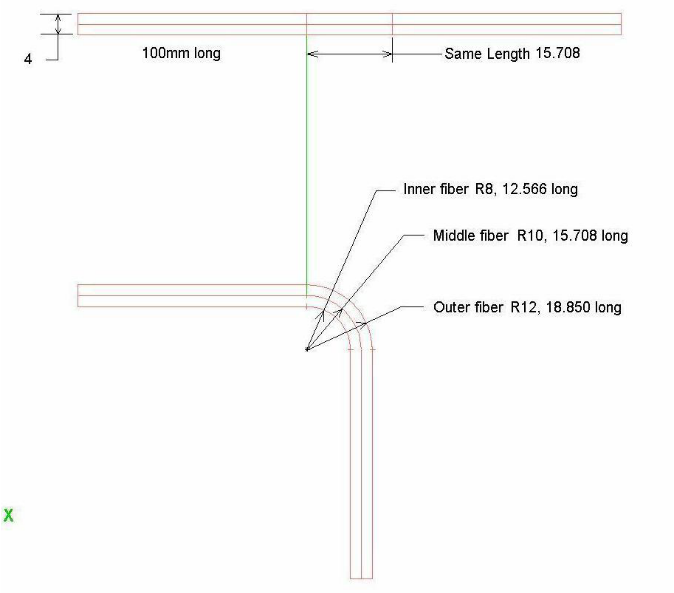
Model	1st Peak Load	Delta	Displacement at 1st Peak Load	Delta
As Formed	350 lbf	0	203.13 mm	0
Heat Treated	318 lbf	-9 %	203.73 mm	+0.3%

Error Analysis Table

Whether or not all of the cold work from forming was removed from the heat treated part is unknown. The purpose of the physical test is to show that there is a difference in crushing performance based on the amount of cold work or residual strains in a formed part.

2 Theory behind Strain Estimation

The illustration below illustrates the change in length of the inner and outer fibers after bending 90º.



Approximate Fiber Lengths after Bending 90º

The average plastic strain in the bend area for each fiber is the change in fiber length divided by the original length. All fibers are 15.708 mm long before bending over an 8mm radius die. After bending, the fiber lengths become:

$$l_f = r_f \theta$$

where θ is the bend angle in radians.
r is the radius of the fiber

Average plastic strains along each fiber are estimated by:

$$\varepsilon_f = \frac{r_f \theta - l_m}{l_m}$$

where l_m is the approximate length of the middle fiber. Putting this all in terms of radii and angles gives:

$$\varepsilon_f = \frac{r_f \theta - r_m \theta}{r_m \theta}$$

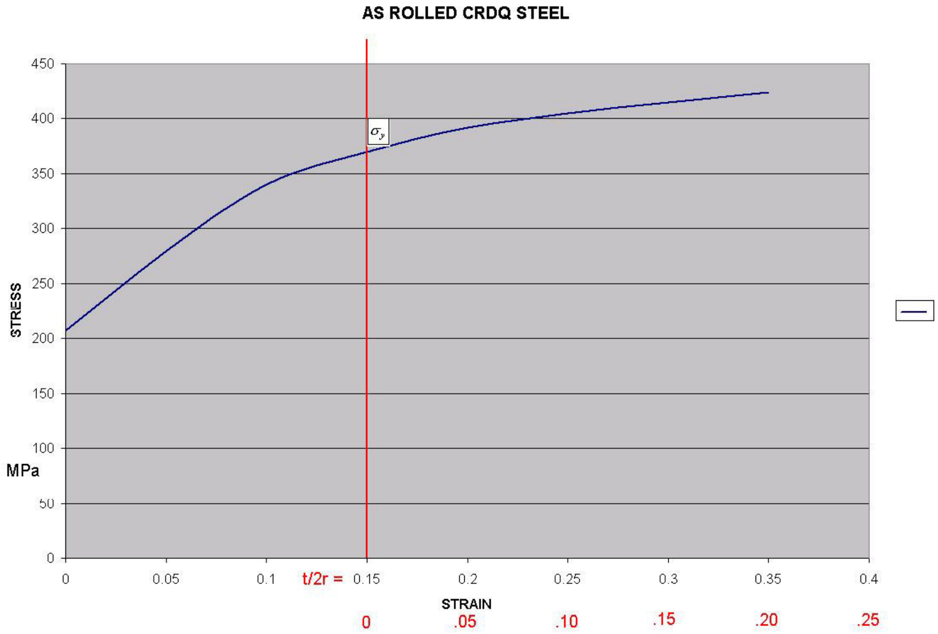
Canceling out the angle and expressing in terms of the middle radius and metal thickness gives an expression for the average plastic strain in the bend area of the outer and inner fibers.

$$\varepsilon = \pm \frac{t}{2 r_m}$$

where *t* is the thickness of the formed part and r_m is the mid-surface radius of the part.

3 Manual Application of Method

Although tedious, material properties could be modified in the bend area of parts by offsetting the stress-strain curve by the estimated plastic strain. The new yield strength would become the as-rolled stress level when the as-rolled strain is equal to t/2r -.002. The new stress value when the new strain is at .05, for example, would be the same as when the as rolled strain is at t/2r + .048.

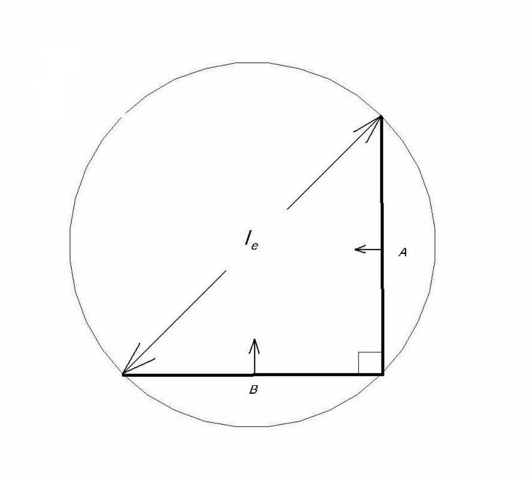


Using Offset Stress-Strain Curve in Bend Area

It may be a good idea to use a de-rating factor on t/2r since that absolute value of strain occurs at the outer and inner-most fibers.

4 Automation of the Method

An algorithm has been developed and implemented in a computer program for the processing of LS-Dyna input files to obtain estimated residual plastic strains from the forming process. To adapt the formula t/2r to shell elements, a formula in terms of the angle between two neighboring elements and their length was needed. The following observation was made.



Let ϕ be the angle between segments A and B.

Note that:

$$\frac{\sin\phi}{l_e} = \frac{1}{2r}$$

And:

$$\frac{t\sin\phi}{l_e} = \frac{t}{2r} = \left|\varepsilon_p\right|$$

From this observation, the following conclusions are made.

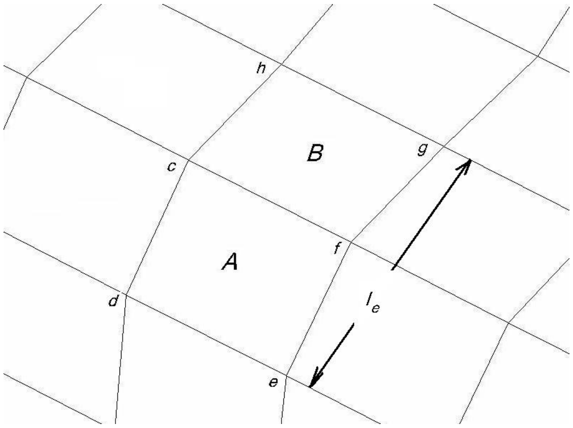
The average plastic strain from forming in a given element can be estimated by:

(1) The angle between its normal vector and those of its neighboring elements [ϕ]

(2) The thickness of the element. [t]

(3) The length of the element and the length of its neighboring elements. [l_e]

Algorithm



1 Parse the LS-Dyna input file.

2 For each element, (element A) do:
  2.1 Determine thickness (get PID to find SID)
  2.2 For each element edge do:
    2.2.1 Find a neighboring edge if it exists
    2.2.2 Estimate plastic strain, ε_p
      2.2.2.1 Calculate normal vector of element A.

$$\overrightarrow{fc} \times \overrightarrow{cd} = \overrightarrow{N_A}$$

      2.2.2.2 Calculate normal vector of element B

$$\overrightarrow{cf} \times \overrightarrow{fg} = \overrightarrow{N_B}$$

      2.2.2.3 Calculate the angle between normals

$$\phi = \cos^{-1}\left(\frac{\overrightarrow{N_A} \bullet \overrightarrow{N_B}}{\left|\overrightarrow{N_A}\right|\left|\overrightarrow{N_B}\right|}\right)$$

      2.2.2.4 Calculate distance of farthest edges, l_e

Average the distances of each pair of nodes belonging to separate elements.

$$l_e = \frac{\left|\overrightarrow{dh}\right| + \left|\overrightarrow{dg}\right| + \left|\overrightarrow{eh}\right| + \left|\overrightarrow{eg}\right|}{n}$$

where: n=4 for (2) quadrilateral elements
n=2 for (1) quad and (1) tria element
n=1 for (2) triangular elements

      2.2.2.5 Calculate plastic strain relating elements A and B. (B is current neighbor being evaluated)

$$\varepsilon_p = \frac{t \sin\phi}{l_e}$$

      2.2.2.6 Store ε_p for comparison to values from other neighboring elements.

    2.2.3 Next edge

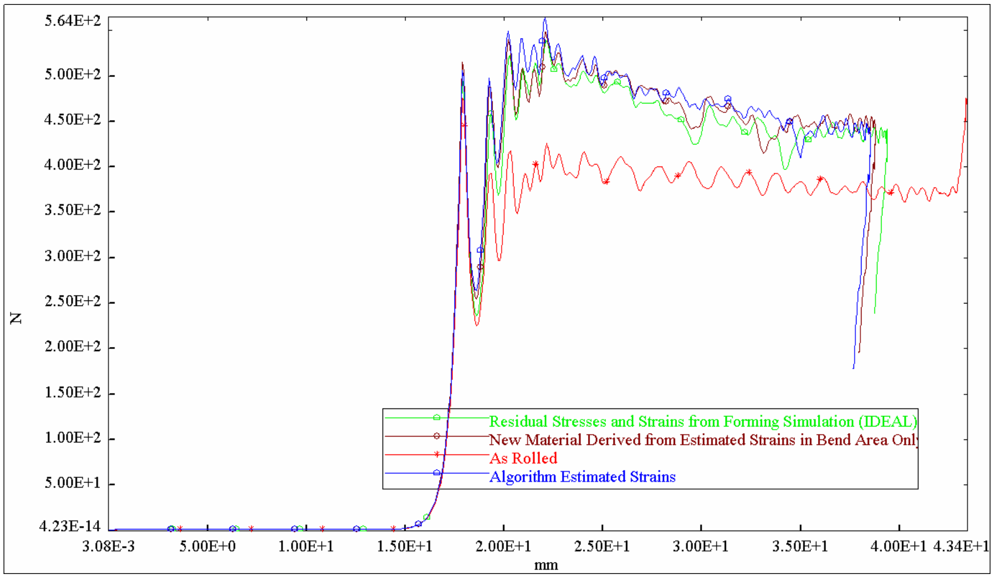
  2.3 Store highest ε_p found for element A.

  2.4 Write out *INITIAL_STRESS_SHELL cards.

```
*INITIAL_STRESS_SHELL
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
$      EID    NPLANE    NTHICK
         A        40         5
         0         0         0         0         0         0         0         0
 -9.062E-1         0         0         0         0         0         0        ep
 -5.385e-1         0         0         0         0         0         0     .59ep
  5.385e-1         0         0         0         0         0         0     .59ep
  9.062E-1         0         0         0         0         0         0        ep
```

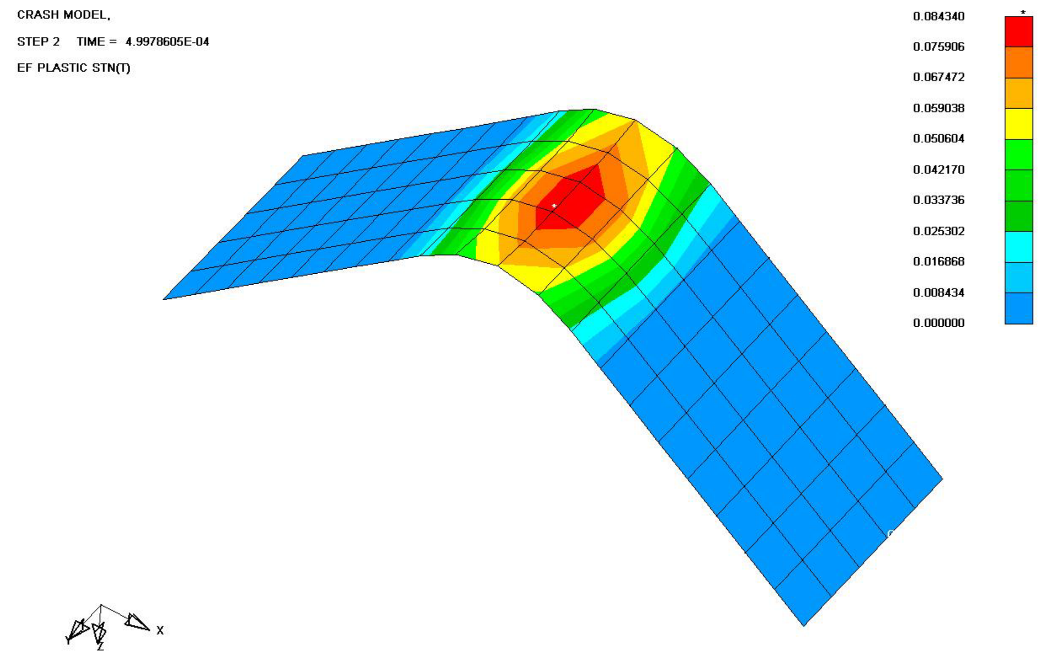
2.5 Next element

3 Comparison of Results Using Different Methods

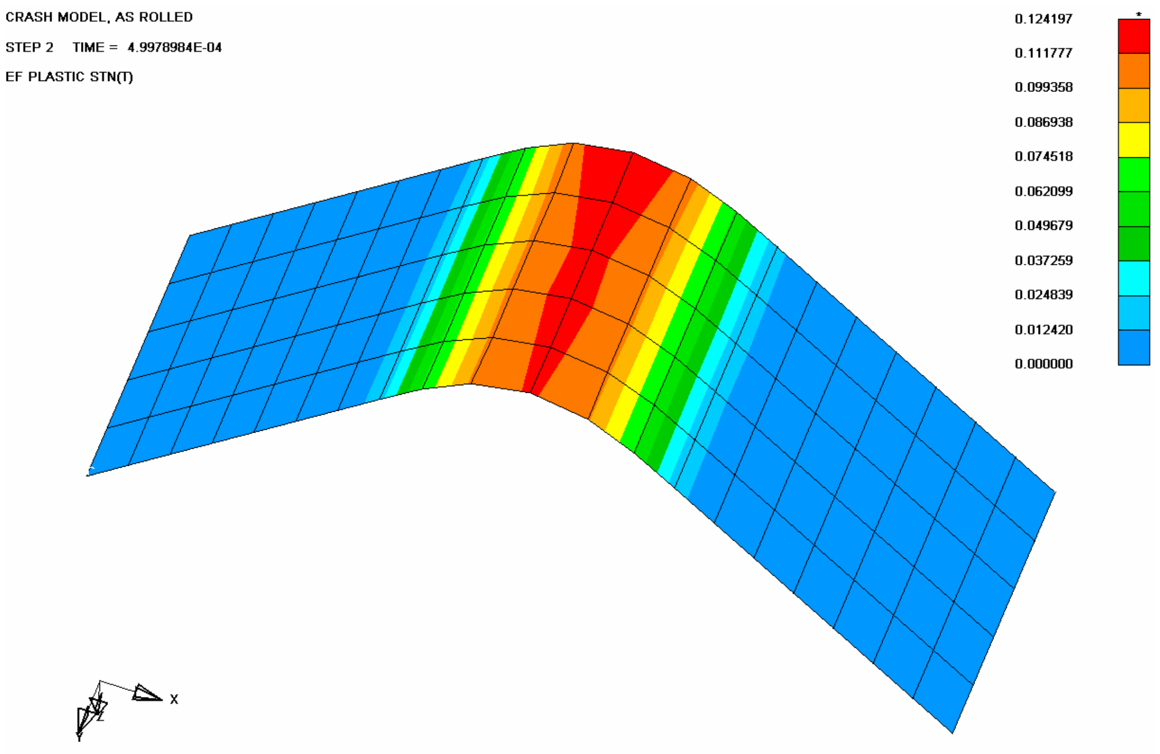


Study 1 [SIMPLE BEND]: Comparison of Force vs. Displacement Curves

The graph above shows force versus displacement curves for four different LS-DYNA crash simulations. The lowest curve was obtained from the simulation using as-rolled steel properties. The manual strain estimation method and the automated method results are relatively close to the results of the simulation that used stresses and strains from the forming simulation. For this simple case, it is evident that considering forming effects (even estimated), will improve performance accuracy.

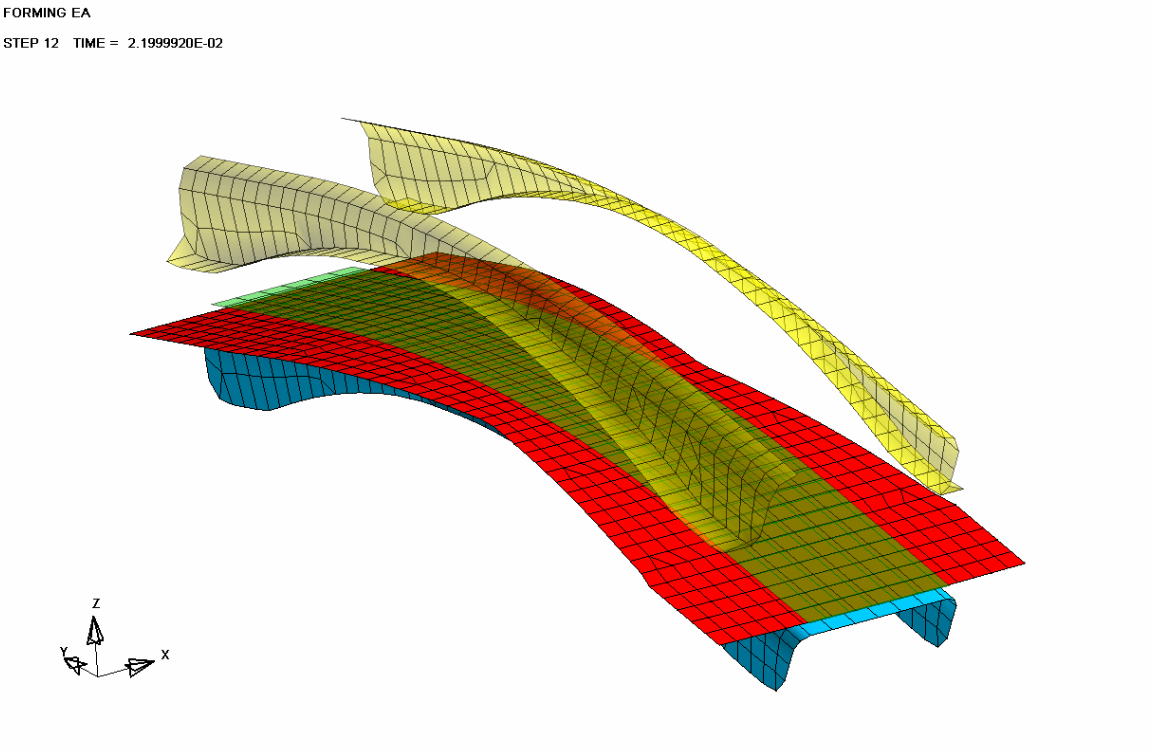


[FORMING] Effective Plastic Strains at Top Fiber



[ESTIMATED] Effective Plastic Strains at Top Fiber

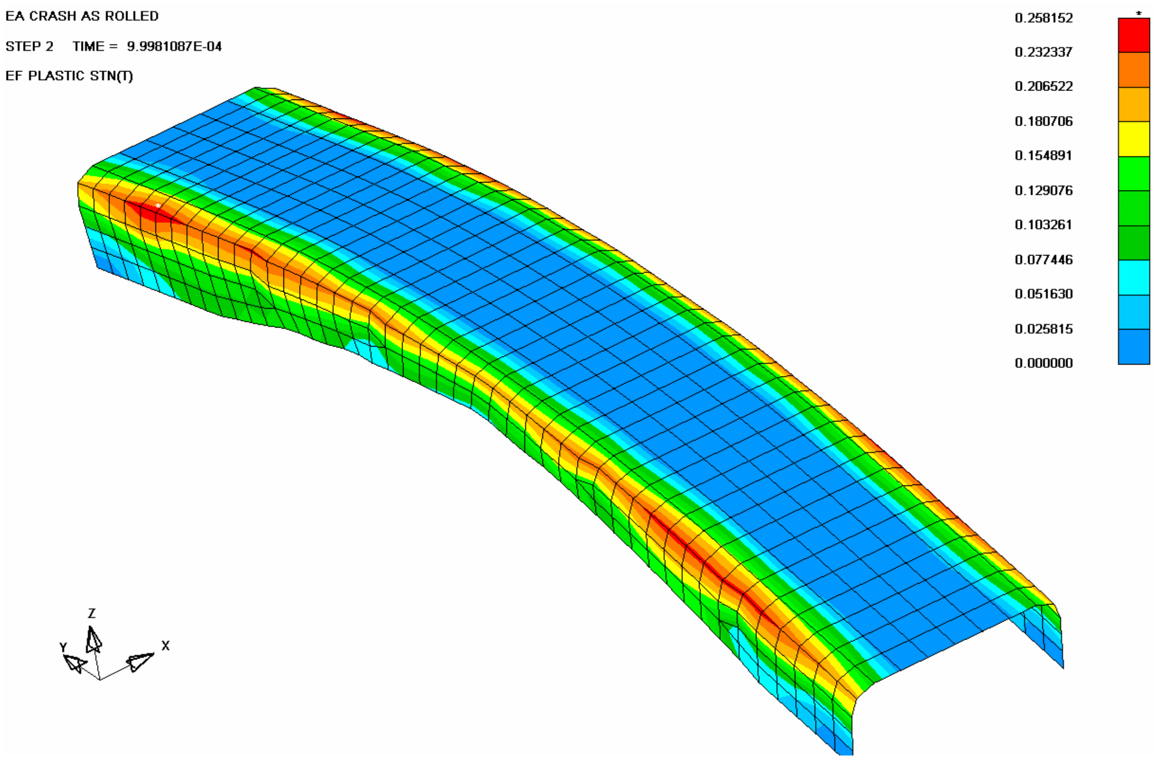
Study of Drawn Bracket



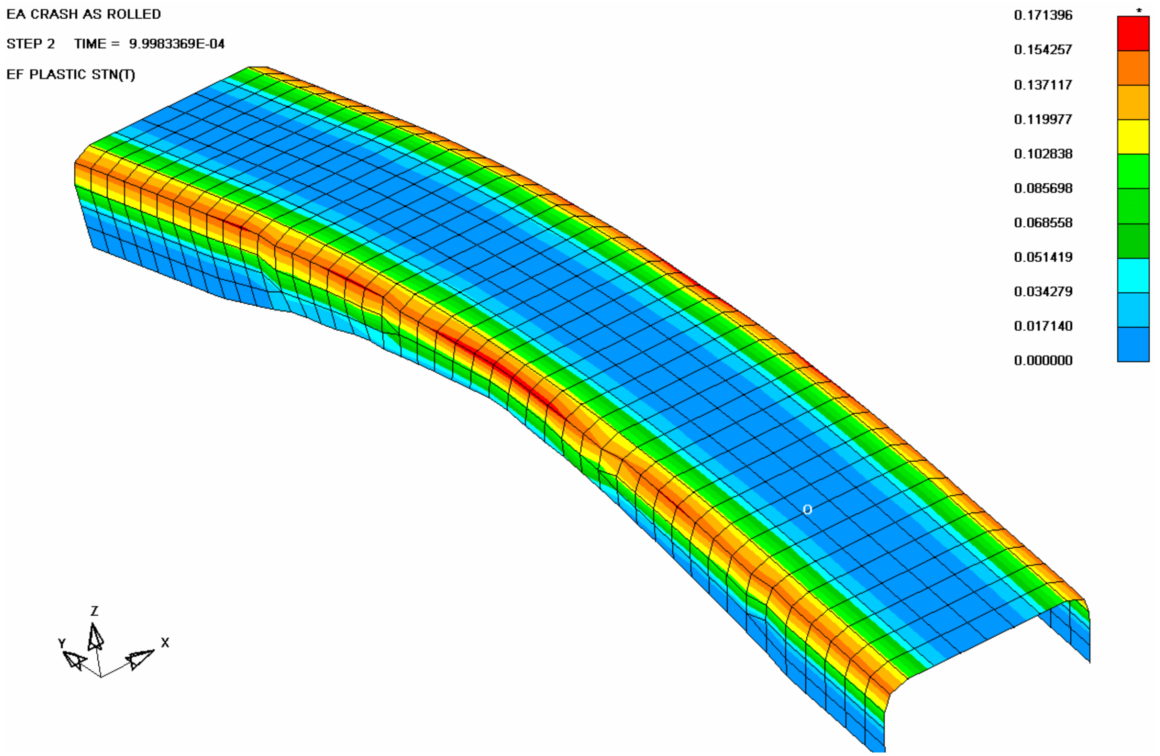
Study 2 Forming Simulation

The forming simulation for a steel bracket models the forming station of a progressive stamping die. A one half inch strip of steel on each short end of the blank carries the part from one station in the die to the next. To model this strip, X and Y constraints were used on one end of the blank while the other end had X constraints assigned. First a pad comes down to press the blank in a crown shape, then two blocks come down to wipe the flanges.

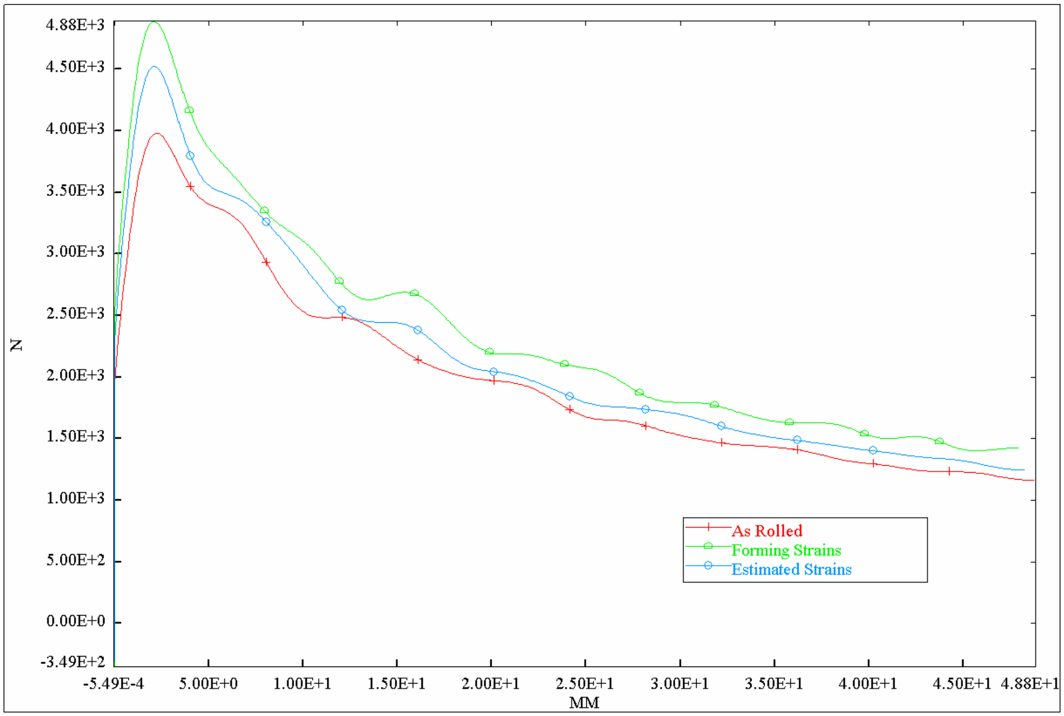
A dynain file is written out to be used as input for the springback simulation. Once the springback simulation has finished, another dynain file is written out so the stresses and strains can be initialized in one of the crash simulations.



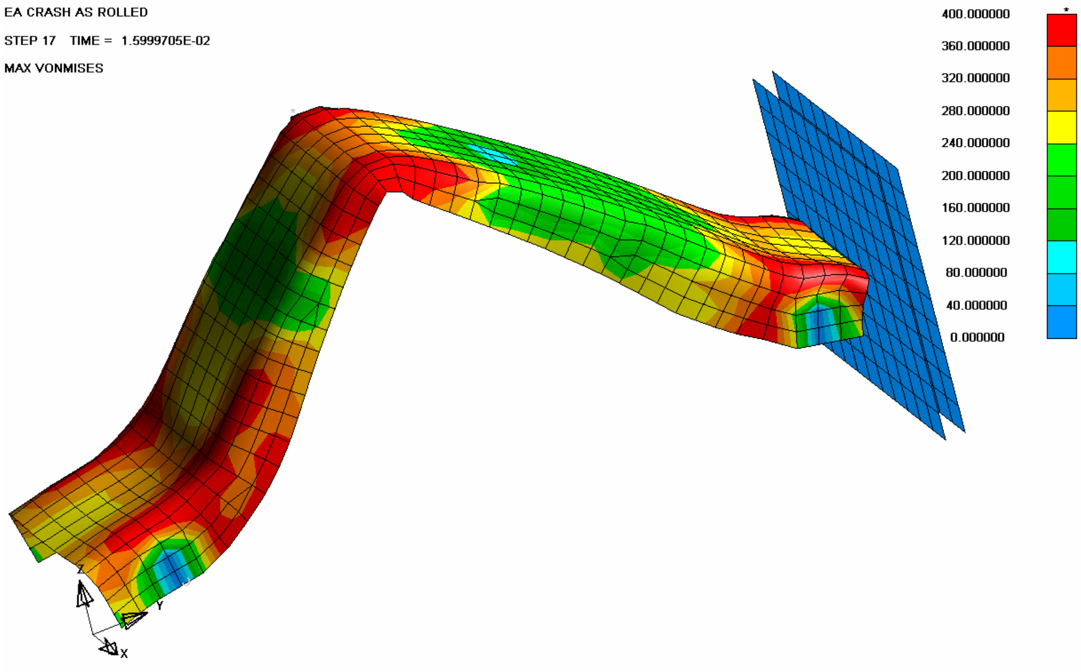
[FORMING] Effective Plastic Strains at Top Fiber



[ESTIMATED] Effective Plastic Strains at Top Fiber



Study 2 [Drawn Part]: Comparison of Force vs. Displacement Curves



Study 2 [Drawn Part]: Crash Model

4 Scope of Method Application

The method applies to formed metal parts where no significant change in material thickness occurs. The residual plastic strains from simple or compound bending are estimated but those resulting from stretching are not. (The strains in stretch formed parts will be underestimated by the method.)

This method should not be used on poor quality meshes.

5 Conclusion

The accuracy of crash analysis on initially-flat metal parts that contain bends and use as-rolled material properties will improve by incorporating the strains that are estimated by this method.

REFERENCES

LSTC (1999), *LS-DYNA User's Manual Version 950,* Livermore Software Technology Corporation.

Cowell, B., *The Effects of Forming and Parameter Mapping on Further Simulation*, 6th annual LS-Dyna User's Conference, 2000

Maker, B., and Zhu, X., *Input Parameters for Springback Simulation using LS-DYNA*, 2001

Maker, B., and Zhu, X., *Input Parameters for Metal Forming Simulation using LS-DYNA, 2000*

ACKNOWLEDGEMENTS

This work has been carried out as part of an independent study at Kettering University under the supervision of Raghu Echempati, Ph.D.

APPENDICES

A1 Forming Analysis Input Deck

```
*KEYWORD
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
$
$ DYNA3D(936) DECK WAS WRITTEN BY: ETA/FEMB VERSION 26
$ DATE  : Jan 24, 2002 at 10:35:52
$
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
$                    (1) TITLE CARD.
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
*TITLE
PUNCH RADIUS 8, THICKNESS 2
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
$                    (2) CONTROL CARDS.
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
*CONTROL_TERMINATION
$   ENDTIM    ENDCYC     DTMIN    ENDNEG    ENDMAS
 0.020E+00         0      .000      .000       100
*CONTROL_TIMESTEP
$   DTINIT      SCFT      ISDO    TSLIMT      DTMS      LCTM     ERODE     MS1ST
      .000      .900         0               -5e-7
*CONTROL_HOURGLASS
$      IHQ        QH
         4      .100
*CONTROL_BULK_VISCOSITY
$       Q2        Q1
     1.500      .060
*CONTROL_SHELL
$   WRPANG    ITRIST     IRNXX    ISTUPD    THEORY       BWC     MITER
    20.000         2        -1         1         2         2         1
*CONTROL_CONTACT
$   SLSFAC    RWPNAL    ISLCHK    SHLTHK    PENOPT    THKCHG     ORIEN
      .010
$   USRSTR    USRFAC     NSBCS    INTERM     XPENE
         0         0        10         0     4.000
*CONTROL_ENERGY
$     HGEN      RWEN    SLNTEN     RYLEN
         1         2         1         1
*CONTROL_DAMPING
$   NRCYCK     DRTOL    DRFCTR    DRTERM    TSSFDR    IRELAL     EDTTL    IDRFLG
       250      .001      .995
*CONTROL_OUTPUT
$    NPOPT    NEECHO    NREFUP    IACCOP     OPIFS    IPNINT    IKEDIT
         0         0         0         0      .000         0       100
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
$                    (3) DATABASE CONTROL CARDS - ASCII HISTORY FILE
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
*DATABASE_HISTORY_NODE
$      ID1       ID2       ID3       ID4       ID5       ID6       ID7       ID8
      1219       556
*DATABASE_HISTORY_SHELL_SET
$      ID1       ID2       ID3       ID4       ID5       ID6       ID7       ID8
        12
```

```
*SET_SHELL_LIST
$      SID       NUM       DA1       DA2       DA3       DA4
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$     EIDS      EID2      EID3      EID4      EID5      EID5      EID7      EID8
         7         8         9        10        11        12        13        14
        27        28        29        30        31        32        33        34
        47        48        49        50        51        52        53        54
        67        68        69        70        71        72        73        74
        87        88        89        90        91        92        93        94
$OPTION : BEAM    BEAM_SET   NODE   NODE_SET
$         SHELL   SHELL_SET  SOLID  SOLID_SET
$         TSHELL  TSHELL_SET
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
$                    (4) DATABASE CONTROL CARDS FOR ASCII FILE
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
$*DATABASE_OPTION
$       DT
$
$OPTION : SECFORC RWFORC NODOUT ELOUT  GLSTAT
$         DEFORC  MATSUM NCFORC RCFORC DEFGEO
$         SPCFORC SWFORC ABSTAT NODFOR BNDOUT
$         RBDOUT  GCEOUT SLEOUT MPGS   SBTOUT
$         JNTFORC AVSFLT MOVIE
*DATABASE_NODOUT
  .400E-04
*DATABASE_ELOUT
  .400E-04
*DATABASE_GLSTAT
  .400E-04
*DATABASE_DEFORC
  .400E-04
*DATABASE_RBDOUT
  .400E-04
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
$                    (5) DATABASE CONTROL CARDS FOR BINARY FILE
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
*DATABASE_BINARY_D3PLOT
$  DT/CYCL      LCDT    NOBEAM
  .100E-02
*DATABASE_BINARY_D3THDT
$  DT/CYCL      LCDT    NOBEAM
  .100E-02
$*DATABASE_BINARY_OPTION
$  DT/CYCL      LCDT    NOBEAM
$
$OPTION : D3DRFL D3DUMP RUNRSF INTFOR
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
*DATABASE_EXTENT_BINARY
         0         0         3         1         1         1         1         1
         0         0         0         0         0         0
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
```

```
$                   (6) DEFINE PARTS CARDS
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*PART
$HEADING
 PART PID =        1 PART NAME :BLANK
$      PID       SID       MID     EOSID      HGID      GRAV    ADPOPT      TMID
         1         7         3
*PART
$HEADING
 PART PID =        2 PART NAME :DIE
$      PID       SID       MID     EOSID      HGID      GRAV    ADPOPT      TMID
         2         8         1
*PART
$HEADING
 PART PID =        4 PART NAME :PUNCH
$      PID       SID       MID     EOSID      HGID      GRAV    ADPOPT      TMID
         4         6         2
*PART
$HEADING
 PART PID =        5 PART NAME :SPR00001
$      PID       SID       MID     EOSID      HGID      GRAV    ADPOPT      TMID
         5         5         4
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
$                   (7) MATERIAL CARDS
*MAT_PIECEWISE_LINEAR_PLASTICITY
$MATERIAL NAME:HRDQ (Hot Rolled, Draw Quality Steel)
$      MID        RO         E        PR      SIGY      ETAN      EPPF      TDEL
         3 7.830E-09 2.070E+05 3.000E-01 2.480E+02 0.000E+00 0.000E+00 0.000E+00
$        C         P      LCSS      LCSR
                    .000E+00  .000E+00
$     EPS1      EPS2      EPS3      EPS4      EPS5      EPS6      EPS7      EPS8
 0.000E+00 5.000E-02 1.000E-01 1.500E-01 2.000E-01 2.500E-01 3.000E-01 3.500E-01
$      ES1       ES2       ES3       ES4       ES5       ES6       ES7       ES8
 2.480E+02 3.260E+02 3.730E+02 4.000E+02 4.150E+02 4.250E+02 4.350E+02 4.500E+02
*MAT_RIGID
$MATERIAL NAME:DIE
$      MID        RO         E        PR         N    COUPLE         M     ALIAS
         1 7.830E-09 2.070E+05 2.800E-01 0.000E+00 0.000E+00 0.000E+00
$      CMO      CON1      CON2
       1.0       4.0       7.0
$LCO or A1        A2        A3        V1        V2        V3

*MAT_RIGID
$MATERIAL NAME:PUNCH
$      MID        RO         E        PR         N    COUPLE         M     ALIAS
         2 7.830E-09 2.070E+05 2.800E-01 0.000E+00 0.000E+00 0.000E+00
$      CMO      CON1      CON2
       1.0       4.0       7.0
$LCO or A1        A2        A3        V1        V2        V3

$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
$                   (7.1) SECTION CARDS
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*SECTION_SHELL
$PROPERTY NAME:BLANK
$      SID    ELFORM      SHRF       NIP     PROPT   QR/IRID     ICOMP
         7        16  .100E+01       5.0       1.0        .0
$       T1        T2        T3        T4      NLOC
  .200E+01  .200E+01  .200E+01  .200E+01        .0
*SECTION_SHELL
$PROPERTY NAME:DIE
$      SID    ELFORM      SHRF       NIP     PROPT   QR/IRID     ICOMP
         8         2  .100E+01       2.0       1.0        .0
$       T1        T2        T3        T4      NLOC
 2.000E+00 2.000E+00 2.000E+00 2.000E+00
*SECTION_SHELL
$PROPERTY NAME:PUNCH
$      SID    ELFORM      SHRF       NIP     PROPT   QR/IRID     ICOMP
         6         2  .100E+01       2.0       1.0        .0
$       T1        T2        T3        T4      NLOC
 2.000E+00 2.000E+00 2.000E+00 2.000E+00
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
$                   (8) NODAL POINT CARDS
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
*NODE
$   NODE               X               Y               Z      TC      RC
       1  .000000000E+00  .200000000E+02  .000000000E+00
       2  .399999100E+01  .200000000E+02  .000000000E+00
       3  .799999200E+01  .200000000E+02  .000000000E+00
       4  .119999900E+02  .200000000E+02  .000000000E+00
       5  .159999900E+02  .200000000E+02  .000000000E+00
       6  .200000000E+02  .200000000E+02  .000000000E+00
       7  .240000000E+02  .200000000E+02  .000000000E+00
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
$                   (9) SOLID ELEMENT CARDS
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
*ELEMENT_SOLID
$    EID     PID      N1      N2      N3      N4      N5      N6      N7      N8
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
$                   (10) BEAM ELEMENT CARDS
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
*ELEMENT_BEAM
$    EID     PID      N1      N2      N3
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
$                   (11) SHELL ELEMENT CARDS
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
*ELEMENT_SHELL
$    EID     PID      N1      N2      N3      N4
       1       1       1      22      23       2
       2       1       2      23      24       3
       3       1       3      24      25       4
       4       1       4      25      26       5
       5       1       5      26      27       6
       6       1       6      27      28       7
       7       1       7      28      29       8
       8       1       8      29      30       9
       9       1       9      30      31      10
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
$                   (12) SPRING OR DAMPER ELEMENT CARDS
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
*ELEMENT_DISCRETE
$    EID     PID      N1      N2     VID               S      PF
    1299       5    1468     127       0    .1000000E+01       0    .0000000E+00
    1300       5    1470     556       0    .1000000E+01       0    .0000000E+00
    1301       5    1471     573       0    .1000000E+01       0    .0000000E+00
    1302       5    1469     137       0    .1000000E+01       0    .0000000E+00
*ELEMENT_MASS
$    EID     NID            MASS
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
$                   (14) HOURGLASS AND BULK PROPERTIES CARDS
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
$*HOURGLASS
$      IHQ        QH       IBQ        Q1        Q2
$
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
$                   (15) DEFINE SET CARDS
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
$                   (16) BOUNDARY CONDITION CARDS
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
*BOUNDARY_SPC_NODE
$ NID/NSID       CID      DOFX      DOFY      DOFZ     DOFRX     DOFRY     DOFRZ
      1468         0         1         1         1         1         1         1
      1469         0         1         1         1         1         1         1
      1470         0         1         1         1         1         1         1
      1471         0         1         1         1         1         1         1
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
$                   (17) LOCAL COORDINATE SYSTEM
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
$                   (18) NODAL CONSTRAINT CARDS
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
```

```
$                   (22) DEFINE CONTACT SURFACE
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
$                   (23) DEFINE RIGID WALL
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
$                   (24) NODAL RIGID BODY CARDS
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
$                   (25) JOINT CARDS
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
*SECTION_DISCRETE
$      SID       DRO        KD        V0        CL        FD
         5         0 0.000E+00 0.000E+00 0.000E+00 0.000E+00
$      CDL       TDL
 0.000E+00 0.000E+00
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
*MAT_SPRING_ELASTIC
$      MID         K
         4 3.000E+02
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
*CONTACT_AUTOMATIC_SURFACE_TO_SURFACE
         1                   3                                       1         1
       0.1      0.05       0.0       0.0        20         1       0.0       0.0
       0.0       0.0       0.0       0.0         0         1         0

                                       1
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
*BOUNDARY_PRESCRIBED_MOTION_RIGID
         4         3         2         1         1
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
*DEFINE_CURVE
         1         0         1         1         0         0
              0              0
              .002          -1.26
              .018          -21.42
              .020          -21.68
              .021          -21.68
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
*SET_PART_LIST
         1
         1
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
*INTERFACE_SPRINGBACK_DYNA3D_NOTHICKNESS
         1
*END
```

A2 Spring back Input Deck

```
*KEYWORD
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
$
$ DYNA3D(936) DECK WAS WRITTEN BY: ETA/FEMB VERSION 26
$ DATE  : Jan 24, 2002 at 10:35:52
$
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
$                   (1) TITLE CARD.
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
*TITLE
SPRINGBACK
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
$                   (2) CONTROL CARDS.
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
*CONTROL_IMPLICIT_STABILIZATION
         1        .1
*CONTROL_IMPLICIT_GENERAL
         1      .005
*CONTROL_TERMINATION
$   ENDTIM    ENDCYC     DTMIN    ENDNEG    ENDMAS
 0.020E+00         0      .000      .000
*CONTROL_TIMESTEP
$   DTINIT      SCFT      ISDO    TSLIMT      DTMS      LCTM     ERODE     MS1ST
      .000      .900         0
*CONTROL_HOURGLASS
$      IHQ        QH
         4      .100
*CONTROL_BULK_VISCOSITY
$       Q2        Q1
     1.500      .060
*CONTROL_SHELL
$   WRPANG    ITRIST     IRNXX    ISTUPD    THEORY       BWC     MITER
    20.000         2        -1         1         2         2         1
*CONTROL_CONTACT
$   SLSFAC    RWPNAL    ISLCHK    SHLTHK    PENOPT    THKCHG     ORIEN
      .010
$   USRSTR    USRFAC     NSBCS    INTERM     XPENE
         0         0        10         0     4.000
*CONTROL_ENERGY
$     HGEN      RWEN    SLNTEN     RYLEN
         1         2         1         1
*CONTROL_DAMPING
$   NRCYCK     DRTOL    DRFCTR    DRTERM    TSSFDR    IRELAL     EDTTL    IDRFLG
       250      .001      .995
*CONTROL_OUTPUT
$    NPOPT    NEECHO    NREFUP    IACCOP     OPIFS    IPNINT    IKEDIT
         0         0         0         0      .000         0       100
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
$                   (3) DATABASE CONTROL CARDS - ASCII HISTORY FILE
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
$OPTION : BEAM    BEAM_SET   NODE   NODE_SET
$         SHELL   SHELL_SET  SOLID  SOLID_SET
$         TSHELL  TSHELL_SET
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
$                   (4) DATABASE CONTROL CARDS FOR ASCII FILE
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
$*DATABASE_OPTION
$       DT
$
$OPTION : SECFORC RWFORC NODOUT ELOUT  GLSTAT
$         DEFORC  MATSUM NCFORC RCFORC DEFGEO
$         SPCFORC SWFORC ABSTAT NODFOR BNDOUT
$         RBDOUT  GCEOUT SLEOUT MPGS   SBTOUT
$         JNTFORC AVSFLT MOVIE
*DATABASE_NODOUT
  .400E-04
*DATABASE_ELOUT
  .400E-04
*DATABASE_GLSTAT
  .400E-04
*DATABASE_DEFORC
  .400E-04
*DATABASE_RBDOUT
  .400E-04
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
$                   (5) DATABASE CONTROL CARDS FOR BINARY FILE
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
*DATABASE_BINARY_D3PLOT
$  DT/CYCL      LCDT    NOBEAM
  .100E-02
*DATABASE_BINARY_D3THDT
$  DT/CYCL      LCDT    NOBEAM
  .100E-02
$*DATABASE_BINARY_OPTION
$  DT/CYCL      LCDT    NOBEAM
$
$OPTION : D3DRFL D3DUMP RUNRSF INTFOR
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
*DATABASE_EXTENT_BINARY
         0         0         3         1         1         1         1         1
         0         0         0         0         0         0
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
```

```
$                    (6) DEFINE PARTS CARDS
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
*PART
$HEADING
 PART PID =         1 PART NAME :BLANK
$      PID       SID       MID     EOSID      HGID      GRAV    ADPOPT      TMID
         1         7         3
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
$                    (7) MATERIAL CARDS
*MAT_PIECEWISE_LINEAR_PLASTICITY
$MATERIAL NAME:HRDQ (Hot Rolled, Draw Quality Steel)
$      MID        RO         E        PR      SIGY      ETAN      EPPF      TDEL
         3 7.830E-09 2.070E+05 3.000E-01 2.480E+02 0.000E+00 0.000E+00 0.000E+00
$        C         P      LCSS      LCSR
                      .000E+00  .000E+00
$     EPS1      EPS2      EPS3      EPS4      EPS5      EPS6      EPS7      EPS8
 0.000E+00 5.000E-02 1.000E-01 1.500E-01 2.000E-01 2.500E-01 3.000E-01 3.500E-01
$      ES1       ES2       ES3       ES4       ES5       ES6       ES7       ES8
 2.480E+02 3.260E+02 3.730E+02 4.000E+02 4.150E+02 4.250E+02 4.350E+02 4.500E+02
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
$                    (7.1) SECTION CARDS
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
*SECTION_SHELL
$PROPERTY NAME:BLANK
$      SID    ELFORM      SHRF       NIP     PROPT   QR/IRID     ICOMP
         7        16  .100E+01       5.0       1.0        .0
$       T1        T2        T3        T4      NLOC
  .200E+01  .200E+01  .200E+01  .200E+01        .0
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
$                    (8) NODAL POINT CARDS
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
$                    (14) HOURGLASS AND BULK PROPERTIES CARDS
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
$*HOURGLASS
$      IHQ        QH       IBQ        Q1        Q2
$
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
$                    (15) DEFINE SET CARDS
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
$                    (16) BOUNDARY CONDITION CARDS
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
$                    (17) LOCAL COORDINATE SYSTEM
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
$                    (18) NODAL CONSTRAINT CARDS
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
$                    (22) DEFINE CONTACT SURFACE
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
$                    (23) DEFINE RIGID WALL
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
$                    (24) NODAL RIGID BODY CARDS
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
$                    (25) JOINT CARDS
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
*BOUNDARY_SPC_NODE
        53         0         1         1         1         0         0         0
        86         0         0         0         1         0         0         0
        23         0         0         1         1         0         0         0
*SET_PART_LIST
         1
         1
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
*INTERFACE_SPRINGBACK_DYNA3D_NOTHICKNESS
         1
*INCLUDE
 formstrs
*END
```

A3 Crash Model Input Deck

```
*KEYWORD
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
$
$ DYNA3D(936) DECK WAS WRITTEN BY: ETA/FEMB VERSION 26
$ DATE  : Jan 28, 2002 at 14:02:54
$
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
$                    (1) TITLE CARD.
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
*TITLE
Crash Model, as rolled
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
$                    (2) CONTROL CARDS.
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
*CONTROL_TERMINATION
$   ENDTIM    ENDCYC     DTMIN    ENDNEG    ENDMAS
  .015E+00         0      .000      .000      .000
*CONTROL_TIMESTEP
$   DTINIT      SCFT      ISDO    TSLIMT      DTMS      LCTM     ERODE     MS1ST
      .000      .900         0
*CONTROL_HOURGLASS
$      IHQ        QH
         1      .100
*CONTROL_BULK_VISCOSITY
$       Q2        Q1
     1.500      .060
*CONTROL_SHELL
$   WRPANG    ITRIST     IRNXX    ISTUPD    THEORY       BWC     MITER
    20.000         2        -1         0         2         2         1
*CONTROL_CONTACT
$   SLSFAC    RWPNAL    ISLCHK    SHLTHK    PENOPT    THKCHG     ORIEN
      .100
$   USRSTR    USRFAC     NSBCS    INTERM     XPENE
         0         0        10         0     4.000
*CONTROL_ENERGY
$     HGEN      RWEN    SLNTEN     RYLEN
         1         2         1         1
*CONTROL_DAMPING
$   NRCYCK     DRTOL    DRFCTR    DRTERM    TSSFDR    IRELAL     EDTTL    IDRFLG
       250      .001      .995
*CONTROL_OUTPUT
$    NPOPT    NEECHO    NREFUP    IACCOP     OPIFS    IPNINT    IKEDIT
         0         0         0         0      .000         0       100
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
$                    (3) DATABASE CONTROL CARDS - ASCII HISTORY FILE
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
*DATABASE_HISTORY_NODE
$      ID1       ID2       ID3       ID4       ID5       ID6       ID7       ID8
$      RAM   CORNER1   CORNER2   CORNER3   CORNER4
       981       693       153       127       667
$OPTION : BEAM    BEAM_SET   NODE   NODE_SET
$         SHELL   SHELL_SET  SOLID  SOLID_SET
$         TSHELL  TSHELL_SET
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
$                    (4) DATABASE CONTROL CARDS FOR ASCII FILE
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
*DATABASE_NODFOR
$       DT
     .0001
*DATABASE_NODAL_FORCE_GROUP
         1
$OPTION : SECFORC RWFORC NODOUT ELOUT  GLSTAT
$         DEFORC  MATSUM NCFORC RCFORC DEFGEO
$         SPCFORC SWFORC ABSTAT NODFOR BNDOUT
$         RBDOUT  GCEOUT SLEOUT MPGS   SBTOUT
$         JNTFORC AVSFLT MOVIE
*DATABASE_NODOUT
  .200E-04
*DATABASE_GLSTAT
  .200E-04
*DATABASE_DEFORC
  .200E-04
*DATABASE_NODFOR
  .200E-04
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
$                    (5) DATABASE CONTROL CARDS FOR BINARY FILE
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
*DATABASE_BINARY_D3PLOT
$  DT/CYCL      LCDT    NOBEAM
  .500E-03
*DATABASE_BINARY_D3THDT
$  DT/CYCL      LCDT    NOBEAM
  .500E-03
$*DATABASE_BINARY_OPTION
$  DT/CYCL      LCDT    NOBEAM
$
$OPTION : D3DRFL D3DUMP RUNRSF INTFOR
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
*DATABASE_EXTENT_BINARY
         0         0         3         1         1         1         1         1
         0         0         0         0         0         0
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
$                    (6) DEFINE PARTS CARDS
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
*PART
$HEADING
 PART PID =         1 PART NAME :BLANK
$      PID       SID       MID     EOSID      HGID      GRAV    ADPOPT      TMID
         1         7         3
*PART
$HEADING
 PART PID =         2 PART NAME :BOTTOM
$      PID       SID       MID     EOSID      HGID      GRAV    ADPOPT      TMID
         2         6        12
*PART
$HEADING
 PART PID =         4 PART NAME :RAM
$      PID       SID       MID     EOSID      HGID      GRAV    ADPOPT      TMID
         4         5         4
*PART
$HEADING
 PART PID =         4 PART NAME :RAM
$      PID       SID       MID     EOSID      HGID      GRAV    ADPOPT      TMID
         9         9         9
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
$                    (7) MATERIAL CARDS
*MAT_PIECEWISE_LINEAR_PLASTICITY
$MATERIAL NAME:HRDQ (Ho
$      MID        RO         E        PR      SIGY      ETAN      EPPF      TDEL
         3 7.830E-09 2.070E+05 3.000E-01 2.480E+02 0.000E+00 3.700E-01 0.000E+00
$        C         P      LCSS      LCSR
                      .000E+00  .000E+00
$     EPS1      EPS2      EPS3      EPS4      EPS5      EPS6      EPS7      EPS8
 0.000E+00 5.000E-02 1.000E-01 1.500E-01 2.000E-01 2.500E-01 3.000E-01 3.500E-01
$      ES1       ES2       ES3       ES4       ES5       ES6       ES7       ES8
 2.480E+02 3.260E+02 3.730E+02 4.000E+02 4.150E+02 4.250E+02 4.350E+02 4.500E+02
*MAT_PIECEWISE_LINEAR_PLASTICITY
$      MID        RO         E        PR      SIGY      ETAN      EPPF      TDEL
         4 7.830E-09 2.070E+05 2.800E-01 2.100E+02
$        C         P      LCSS      LCSR

$     EPS1      EPS2      EPS3      EPS4      EPS5      EPS6      EPS7      EPS8
 0.000E+00 3.090E-02 4.090E-02 5.000E-02 1.510E-01 3.010E-01 7.010E-01 9.010E-01
$      ES1       ES2       ES3       ES4       ES5       ES6       ES7       ES8
 2.100E+02 3.000E+02 3.140E+02 3.250E+02 3.900E+02 4.380E+02 5.050E+02 5.270E+02
*MAT_RIGID
$MATERIAL NAME:PUNCH
$      MID        RO         E        PR         N    COUPLE         M     ALIAS
        12 7.830E-09 2.070E+05 2.800E-01 0.000E+00 0.000E+00 0.000E+00
$      CMO      CON1      CON2
       1.0       7.0       7.0
$LCO or A1        A2        A3        V1        V2        V3

$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
$                    (7.1) SECTION CARDS
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
*SECTION_SHELL
$PROPERTY NAME:BLANK
$      SID    ELFORM      SHRF       NIP     PROPT   QR/IRID     ICOMP
         7        16  .100E+01       5.0       1.0        .0
$       T1        T2        T3        T4      NLOC
 2.000E+00 2.000E+00 2.000E+00 2.000E+00
*SECTION_SHELL
$PROPERTY NAME:RAM
$      SID    ELFORM      SHRF       NIP     PROPT   QR/IRID     ICOMP
         5         2  .100E+01       2.0       1.0        .0
$       T1        T2        T3        T4      NLOC
 6.000E+00 6.000E+00 6.000E+00 6.000E+00
*SECTION_SHELL
$PROPERTY NAME:RAM
$      SID    ELFORM      SHRF       NIP     PROPT   QR/IRID     ICOMP
         6         2  .100E+01       2.0       1.0        .0
$       T1        T2        T3        T4      NLOC
 4.000E+00 4.000E+00 4.000E+00 4.000E+00
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
$                    (8) NODAL POINT CARDS
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
*NODE
$   NODE               X               Y               Z      TC      RC
       1  .113365200E+02  .199141300E+02  .420567000E+01
       2  .140417200E+02  .199264900E+02  .125913400E+01
       3  .167468200E+02  .199388500E+02 -.168741700E+01
       4  .194519200E+02  .199512300E+02 -.463397200E+01
       5  .221571800E+02  .199636100E+02 -.758042500E+01
       6  .248615000E+02  .199760400E+02 -.105276600E+02
       7  .275656700E+02  .199885000E+02 -.134752200E+02
       8  .302677800E+02  .200009300E+02 -.164249400E+02
       9  .330318000E+02  .200119600E+02 -.193224200E+02
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
$                    (9) SOLID ELEMENT CARDS
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
*ELEMENT_SOLID
$    EID     PID      N1      N2      N3      N4      N5      N6      N7      N8
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
$                    (10) BEAM ELEMENT CARDS
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
*ELEMENT_BEAM
$    EID     PID      N1      N2      N3
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
$                    (11) SHELL ELEMENT CARDS
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
*ELEMENT_SHELL
$    EID     PID      N1      N2      N3      N4
     101       2     127     154     155     128
     102       2     128     155     156     129
     103       2     129     156     157     130
     104       2     130     157     158     131
     105       2     131     158     159     132
     106       2     132     159     160     133
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
$                    (12) SPRING OR DAMPER ELEMENT CARDS
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
$*ELEMENT_DISCRETE
$    EID     PID      N1      N2     VID               S      PF
$     621       9     693     697       0  .1000000E+01       0  .0000000E+00
```

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$     622         9       667       694         0   .1000000E+01         0   .0000000E+00
$     623         9       127       695         0   .1000000E+01         0   .0000000E+00
$     624         9       153       696         0   .1000000E+01         0   .0000000E+00
*ELEMENT_MASS
$    EID     NID             MASS
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
$                    (14) HOURGLASS AND BULK PROPERTIES CARDS
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
$*HOURGLASS
$      IHQ        QH       IBQ        Q1        Q2
$
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
$                    (15) DEFINE SET CARDS
*INITIAL_VELOCITY
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
         1
         0         0    4705.6         0         0         0
*SET_NODE_LIST
$      SID       DA1       DA2       DA3       DA4
         1
$     NID1      NID2      NID3      NID4      NID5      NID6      NID7      NID8
       698       699       700       701       702       703       704       705
       706       707       708       709       710       711       712       713
       714       715       716       717       718       719       720       721
       722       723       724       725       726       727       728       729
       730       731       732       733       734       735       736       737
       738       739       740       741       742       743       744       745
       746       747       748       749       750       751       752       753
       754       755       756       757       758       759       760       761
       762       763       764       765       766       767       768       769
       770       771       772       773       774       775       776       777
       778       779       780       781       782       783       784       785
       786       787       788       789       790       791       792       793
       794       795       796       797       798       799       800       801
       802       803       804       805       806       807       808       809
       810       811       812       813       814       815       816       817
       818       819       820       821       822       823       824       825
       826       827       828       829       830       831       832       833
       834       835       836       837       838       839       840       841
       842       843       844       845       846       847       848       849
       850       851       852       853       854       855       856       857
       858       859       860       861       862       863       864       865
       866       867       868       869       870       871       872       873
       874       875       876       877       878       879       880       881
       882       883       884       885       886       887       888       889
       890       891       892       893       894       895       896       897
       898       899       900       901       902       903       904       905
       906       907       908       909       910       911       912       913
       914       915       916       917       918       919       920       921
       922       923       924       925       926       927       928       929
       930       931       932       933       934       935       936       937
       938       939       940       941       942       943       944       945
       946       947       948       949       950       951       952       953
       954       955       956       957       958       959       960       961
       962       963       964       965       966       967       968       969
       970       971       972       973       974       975       976       977
       978       979       980       981       982       983       984       985
       986       987       988       989       990       991       992       993
       994       995       996       997       998       999      1000      1001
      1002      1003      1004      1005      1006      1007      1008      1009
      1010      1011      1012      1013      1014      1015      1016      1017
      1018      1019      1020      1021      1022      1023      1024      1025
      1026      1027      1028      1029      1030      1031      1032      1033
      1034      1035      1036      1037      1038      1039      1040      1041
      1042      1043      1044      1045      1046      1047      1048      1049
      1050      1051      1052      1053      1054      1055      1056      1057
      1058      1059      1060      1061      1062      1063      1064      1065
      1066      1067      1068      1069      1070      1071      1072      1073
      1074      1075      1076      1077      1078      1079      1080      1081
      1082      1083      1084      1085      1086      1087      1088      1089
      1090      1091      1092      1093      1094      1095      1096      1097
      1098      1099      1100      1101      1102      1103      1104      1105
      1106      1107      1108      1109      1110      1111      1112      1113
      1114      1115      1116      1117      1118      1119      1120      1121
      1122      1123      1124      1125      1126      1127      1128      1129
      1130      1131      1132      1133      1134      1135      1136      1137
      1138      1139      1140      1141      1142      1143      1144      1145
      1146      1147      1148      1149      1150      1151      1152      1153
      1154      1155      1156      1157      1158      1159      1160      1161
      1162      1163      1164      1165      1166      1167      1168      1169
      1170      1171      1172      1173      1174      1175      1176      1177
      1178      1179      1180      1181      1182      1183      1184      1185
      1186      1187      1188      1189      1190      1191      1192      1193
      1194      1195      1196      1197      1198      1199      1200      1201
      1202      1203      1204      1205      1206      1207      1208      1209
      1210      1211      1212      1213      1214      1215      1216      1217
      1218      1219      1220      1221      1222      1223      1224      1225
      1226      1227      1228      1229      1230      1231      1232      1233
      1234      1235      1236      1237      1238      1239      1240      1241
      1242      1243      1244      1245      1246      1247      1248      1249
      1250      1251      1252      1253      1254      1255      1256      1257
      1258      1259      1260      1261      1262      1263      1264
*SET_SHELL_LIST
$      SID       NUM       DA1       DA2       DA3       DA4
        12        40
$     EIDS      EID2      EID3      EID4      EID5      EID5      EID7      EID8
         7         8         9        10        11        12        13        14
        27        28        29        30        31        32        33        34
        47        48        49        50        51        52        53        54
        67        68        69        70        71        72        73        74
        87        88        89        90        91        92        93        94
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
$                    (16) BOUNDARY CONDITION CARDS
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
*BOUNDARY_SPC_NODE
$ NID/NSID       CID      DOFX      DOFY      DOFZ     DOFRX     DOFRY     DOFRZ
       698         0         1         1         0         0         0         0
       751         0         1         1         0         0         0         0
      1238         0         1         1         0         0         0         0
      1264         0         1         1         0         0         0         0
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
$                    (17) LOCAL COORDINATE SYSTEM
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
$                    (18) NODAL CONSTRAINT CARDS
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
$                    (22) DEFINE CONTACT SURFACE
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
$                    (23) DEFINE RIGID WALL
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
$                    (24) NODAL RIGID BODY CARDS
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
$                    (25) JOINT CARDS
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
*SECTION_DISCRETE
$      SID       DRO        KD        V0        CL        FD
         9         0 0.000E+00 0.000E+00 0.000E+00 0.000E+00
$      CDL       TDL
 0.000E+00 0.000E+00
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
*MAT_SPRING_ELASTIC
$      MID         K
         9 2.000E+02
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
*SET_PART_LIST
        66
         2         4
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
*CONTACT_AUTOMATIC_SURFACE_TO_SURFACE
        66                   2                                           1         1
       0.1      0.05       0.0       0.0        60         1       0.0       0.0
       0.0       0.0       0.0       0.0         0         1         0

*INCLUDE
 relstrs
*END
```

-forming analysis Dyna deck
-springback Dyna deck
-crash Dyna deck