Modeling Plastic Clips in LS-DYNA® for Low-Energy Impact Analyses

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Abstract

Through several different low-energy automotive impact simulations, it was discovered that capturing plastic clip behavior played a substantial role in predicting the system response. Therefore, a methodology for modeling plastic push-in rivets and snap-fit clip connections was developed in LS-DYNA for use in these low-energy automotive impact analyses. The required geometric discretization, contact definitions, material models and constraints that make up the models are discussed in detail. Pull-out force data was utilized to correlate the response and failure modes of the clip models. In addition, three different levels of clip model complexity were compared with respect to their suitability for different load cases. Simple clip model approaches were easy to pre-process and sufficiently captured most of pull-out failure modes. However, these did not capture shear or off-angle failure. More complex clip models sufficiently captured shear and off-angle failure, but come at a greater pre-processing and development effort. Lastly, some pre-processing methods are discussed to demonstrate how hundreds of clips can be incorporated in a model in very little time.

1. Introduction

Clips are utilized in many different assembled systems and are considered low-level connections due to their inability to carry significant load. It is obvious that these low-level connections will not make a large impact on the overall response of a car in a high speed crash, but with the increasing emphasis on pedestrian and occupant safety, and corresponding low-energy impacts, clips may play a much larger role in computer aided engineering (CAE) for predicting system response, injury criteria, and sensor signals. For example, a significant difference in response was found for a critical accelerometer when clip failure was captured during a low speed rigid wall front crash simulation. Figure 1 illustrates the difference between CAE accelerometer signals where the only modeling difference was whether or not clip failure was captured.

It can be observed from figure 1 that the peak amplitude of the CAE accelerometer signal is more than two times higher than the baseline when clip failure is captured during the low-speed impact event.

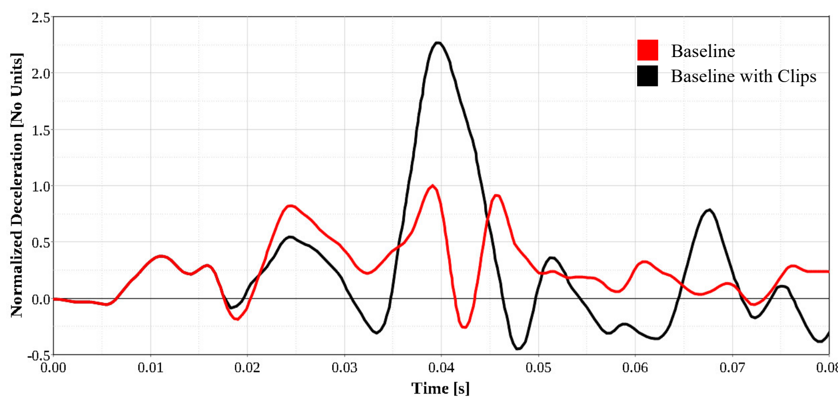

Figure 1: Normalized deceleration signal of critical CAE accelerometer during a 19kph front crash.

A low-speed front crash is one load case where capturing clip failure in CAE can be important. However, the applications for capturing clip failure are not limited to 19kph front crashes, for example, **Matsuura et al.** developed a model of clips connecting fascia parts in order to predict their failure during a low speed bumper impact [1].

This CAE prediction could help designers improve the fascia connections to prevent fascia pieces from disconnecting in the event of a low-speed impact where no other damage occurs [1].

Clips come in many different shapes and sizes, but they all have similar mechanical characteristics. The primary goal of clips is to hold together multiple panels through some form of latch mechanism. Therefore, the 3 common failure modes of most clips are pull-out failure, shear failure, and mating panel failure. Because mating panels are generally much stronger than clips, this paper will only focus on capturing the pull-out and shear failure modes. In addition, clips are typically standardized parts, which makes developing models for a clip relatively easy. Furthermore, this standardization allows for easy incorporation into larger system models. This paper will discuss the process of developing push-in rivet and snap-fit clip models while taking into account global system limitations such as mass scaling, run-times, and contact stiffness. Lastly, pre-processing methods will be discussed so that once a single clip model is developed, hundreds of clips can be incorporated in a large model in very little time.

2. Overview of Clip Modeling Techniques

While it is possible to model clips with a high-degree of accuracy using a small time-step and very small elements, this approach is not practical when the primary goal is to capture clip failure in a much bigger system. Since often the larger system models require special time-step and contact parameters, it is not possible to model clips with extreme detail. Therefore, one must develop simplified clip models such that they are able to sufficiently capture clip failure in a large system without negatively impacting the system by extreme mass scaling, which leads to potential instabilities or by reducing the time-step, which leads much longer run-times. Unfortunately, this process can be significantly more difficult. The objective of this paper, therefore, is to provide large system-oriented modeling techniques that one can use to develop clip models for use in low-energy impact analyses.

Furthermore, a broad range of clip models with varying complexity was developed in order to take into account the assumed differences in computing capabilities, global time-step and contact settings among LS-DYNA users. The following list presents three different general clip model types and also discusses what type users should pursue based on their desired failure modes, computing power, standard contact cards and time-step parameters.

2.1 Clip Model Types

- ***Type I – Beams with Failure***

  Type I clips are discretized simply by a 6-DOF discrete beam element that is connected to the mating panels with spider beams or *CONSTRAINED_NODAL_RIGID_BODY as seen in figure 2. Since the discrete beam is only a single element between the panels, a force vs. strain curve can be defined along with a specified failure strain for both pull-out and shear failure modes. This clip model type can be used in nearly any situation.

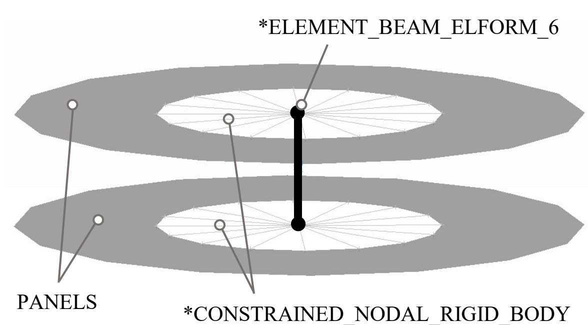

Figure 2: Type I clip model example.

However, it does not sufficiently capture off-angle tensile failure modes or pull-out failure modes where there is variation in mating panel materials and/or thicknesses. The main drawback of a Type I model is that it much stiffer because it does not capture the correct compliance between the clip and panels. Fortunately, run-times and mass scaling are generally not affected with the addition of Type I models in an assembly. Furthermore, no contact definitions (other than panel-to-panel contact) are needed for this model.

- ***Type II – Beams with Failure plus Geometry***

Sometimes clip failure modes are very dependent on the specific mechanics of the clip and surrounding geometry. In this case, one should look into developing clips where the CAE discretization somewhat resembles that of the clip mechanism. With Type II clips, contact can occur between the mating panels and the important geometric aspects of the clip, yet the failure modes are still driven by discrete beams. Figure 3 depicts an example of a Type II clip, where the clip geometry is estimated using "null" shell elements that only act as a contact surface to ultimately impart a load on the discrete beam element through spider beams or *CONSTRAINED_NODAL_RIGID_BODY when the panels undergo enough deformation in pull-out and/or shear modes. This discrete element has a force vs. strain curve defined along with a specified failure strain or force for both pull-out and shear failure modes. When the discrete element fails, the underlying shell elements fail as well. An in-depth example of a Type II clip can be found within the work by Matsuura et al. [1]

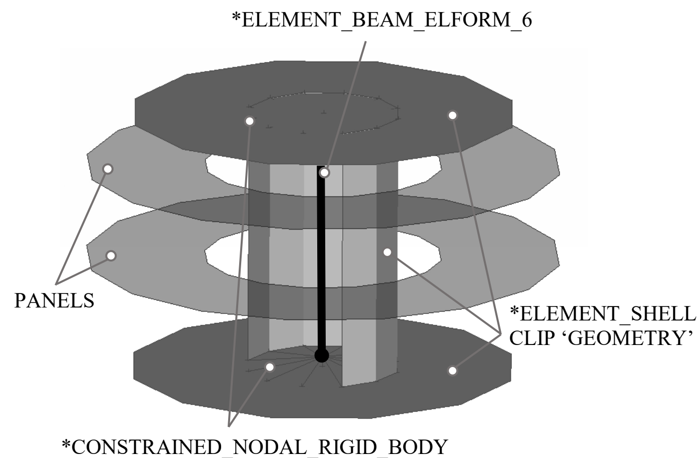

Figure 3: Cross-section of Type II clip model example.

Type II clip models are usually the easiest to develop and incorporate in a large assembly such as a car model since the discrete beam is connected to a local system that can be easily copied to other locations. The main drawback of the Type II model is that it does not sufficiently capture off-angle tensile failure modes or pull-out failure modes where there is variation in mating panel materials and/or thicknesses. Fortunately, run-times and mass scaling are generally not affected with the addition of Type II models in an assembly. Furthermore, Type II clips must be included in an appropriate contact definition, most preferably in a global *CONTACT_AUTOMATIC_SINGLE_SURFACE definition which includes all parts of the larger system.

- ***Type III – 'Equivalent' Geometry***

Type III clip models are discretized simply by closely matching the actual clip geometry and materials, as seen in figure 4. It is imperative that a SOFT = 2 contact algorithm is used for this model type. One can either use solid elements or shell elements depending on the geometry of the clip. If a large system model has a time-step defined through DT2MS in *CONTROL_TIMESTEP, this is where implementing Type III clips can be

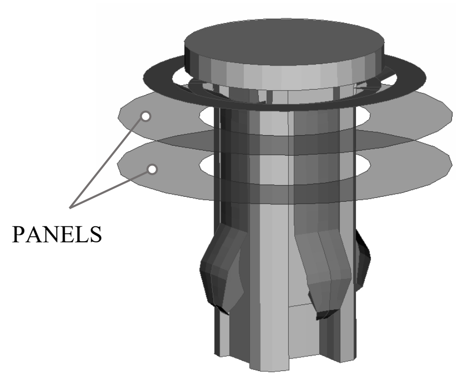

Figure 4: Type III Clip Model Example.

challenging since the analyst must take into account maintaining the contact stiffness for shear failure modes, and the minimum element size so that there is no significant added mass. For example, if the elements are too large, the contact stiffness may be too low for solid elements in shear. Whereas, if the elements are too small, significant amounts of undesirable mass is added to satisfy the stability criterion.

Type III clip models are usually the hardest to develop but are very easy to incorporate in a large assembly such as a vehicle model because uses a local system that can be easily copied to other locations. The main benefit of Type III models is that it is able to sufficiently capture off-angle tensile failure modes and different pull-out failure modes if there is variation in mating panel materials and/or thicknesses. If one is not careful, run-times and mass scaling can be affected with the addition of Type III models in an assembly. Furthermore, Type III clips must be included in a SOFT = 2 contact definition, most preferably in a global *CONTACT_AUTOMATIC_SINGLE_SURFACE definition which includes all parts of the larger system.

2.2 Selection Matrix

The following table serves as a quick summary to help one determine which kind of clip model type to pursue.

Table 1. Summary of model type and corresponding capabilities.

	Type I	Type II	Type III
Pull-out failure	Good	Good	Good
Shear failure	Adequate	Adequate	Good
All failure modes	Poor	Poor	Good
Run-time	Good	Good	Adequate
Added mass	No	No	Maybe
Needs contact	No	Yes	Yes (SOFT = 2 only)
Large model incorporation effort	Depends	Easy	Easy

The following sections will discuss the development of push-in rivet and snap-on clips for model Types I, II, and III.

3. Methodology

3.1 Modeling Push-in Rivets

Push-in rivets, as seen in figure 5, are a relatively simple clip comprised of two separate parts: a grommet and a pin. The grommet gets placed in a hole shared by two different panels, then the pin gets inserted inside the grommet. Upon insertion, the pin causes the grommet barbs to expand outwards, which locks the clip in place.

Push-in rivets usually have two distinct failure modes, the first being in tension where the clip gets pulled out of the panels. The second failure mode is in shear, where the clip itself shears under intense loading. It is important to note that these failure modes are very dependent on the panel hole sizes, materials and thicknesses. For example, the pull-out force of a clip can be 50 percent lower for a hole diameter that is only 10 percent larger.

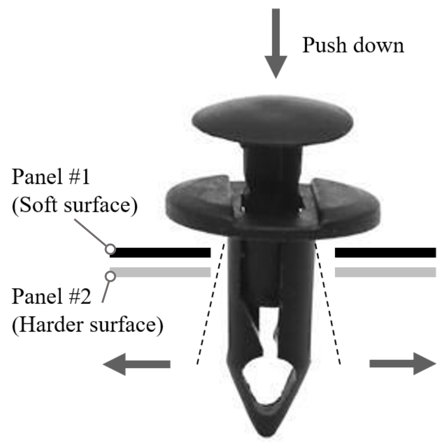

Figure 5: Push-in rivet clip.[2]

While there are many geometric styles for push-in rivets, this paper will attempt to model the clip geometry seen in figures 6, 7 and 8 below:

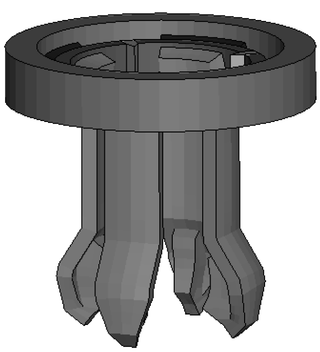

Figure 6: Push-in rivet grommet.

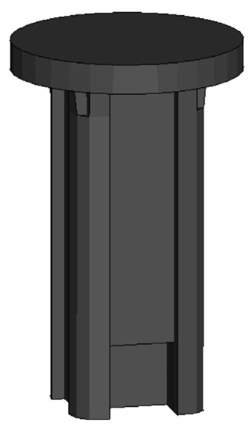

Figure 7: Push-in rivet pin.

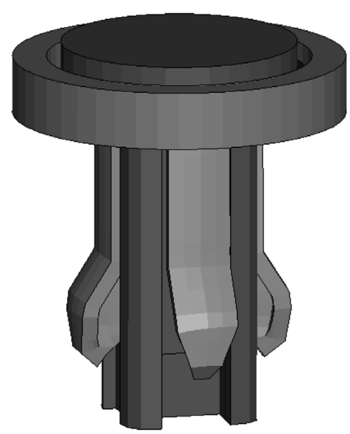

Figure 8: Push-in rivet assembly

Figure 6 depicts the grommet, figure 7 shows the pin, and figure 8 demonstrates the clip assembly when the pin is inserted into the grommet. The following sections will present model Types I, II, and III corresponding to the figures above.

3.1.1 Type I Push-in Rivets

<u>*Discretization*</u>

The two primary failure modes of push-in rivets are in shear and tension. In order to simply capture these modes, a discrete beam element paired with a material type 67 (or 68), which is also known as *MAT_NONLINEAR_ELASTIC_DISCRETE_BEAM, is then connected to the mating panels through spider beams or *CONSTRAINED_NODAL_RIGID_BODY. When the panels deform, a load is applied to the discrete beam. Two separate force vs. stroke load curves along with failure strains define the failure of the discrete element in both shear and tension.

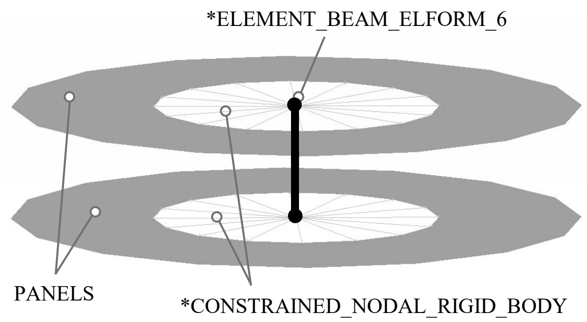

Figure 9: Type I clip model for push-in rivets.

The LS-DYNA deck below shows the *PART and *SECTION inputs for the discrete beam. It should be noted that since the material has a stiffness in translation and rotation, that the VOL and INER inputs are required in *SECTION_BEAM. These inputs should roughly estimate the clip's total volume as well as mass moment of inertia.

```
*PART
$#
SECTION_BEAM_ELFORM_6
$#     pid     secid       mid     eosid      hgid      grav    adpopt      tmid
         7         7       230         0         0         0         0         0
*SECTION_BEAM_TITLE
SECTION_BEAM_ELFORM_6
$#   secid    elform      shrf   qr/irid       cst     scoor       nsm     naupd
         7         6       1.0         2         0       3.0       0.0         0
$#     vol      iner       cid        ca    offset     rrcon     srcon     trcon
      Clip Specific          0       0.0       0.0       0.0       0.0       0.0
```

For this model, the material inputs are very important. In order to determine correct material inputs, it is imperative that two different force vs. stroke data sets are acquired from testing clip hardware in both pull-out and shear modes. If force vs. stroke data is unavailable, then peak force will suffice until test data is acquired. The LS-DYNA deck below shows the inputs for *MAT_NONLINEAR_ELASTIC_DISCRETE_BEAM specific to the push-in rivet clip.

```
*MAT_NONLINEAR_ELASTIC_DISCRETE_BEAM_TITLE
DISCRETE_BEAM
$#     mid        ro    lcidtr    lcidts    lcidtt    lcidrr    lcidrs    lcidrt
       230   1.85E-9      6032      6032      6033      6030      6030      6028
$# lcidtdr   lcidtds   lcidtdt   lcidrdr   lcidrds   lcidrdt
         0         0         0         0         0         0
$#     for       fos       fot       mor       mos       mot
       0.0       0.0       0.0       0.0       0.0       0.0
$#  ffailr    ffails    ffailt    mfailr    mfails    mfailt
       0.0       0.0       0.0       0.0       0.0       0.0
$#  ufailr    ufails    ufailt    tfailr    tfails    tfailt
      10.0      10.0       9.5       0.0       0.0       0.0
```

LCIDT**R**, LCIDT**S**, LCIDT**T** are inputs for load curves that define the translational stiffness in all translation directions. These curves should be derived from the shear and pull-out force vs. stroke data acquired from the tests. The correct orientation assignments depend on the discrete beam element's initial orientation value defined by CID. If CID = 0 then R, S, and T correspond to X, Y, and Z of the global system, respectively. Since CID = 0, shear happens in the global X and Y-directions (beam's local R and S-directions) whereas pull-out happens in the global Z-direction (beam's local T-direction). Furthermore, since translation in shear happens in both X and Y-directions, LCIDTR and LCIDTS share the same load curve. The normalized load curves for shear and tension can found below.

```
*DEFINE_CURVE_TITLE
R_S_Translational_Force
$#     lcid       sidr        sfa        sfo       offa       offo     dattyp      lcint
       6032          0        1.0        1.0        0.0        0.0          0          0
$#                  a1                    o1
                   0.0                   0.0
                   3.7                   2.0
                   9.0                   1.4
                  10.0                   0.0
                  12.0                   0.0
```

```
*DEFINE_CURVE_TITLE
T_Translational_Force
$#     lcid       sidr        sfa        sfo       offa       offo     dattyp      lcint
       6033          0        1.0        1.0        0.0        0.0          0          0
$#                  a1                    o1
                   0.0                   0.0
                   4.0                  0.15
                   8.0                  1.10
                   9.0                  1.10
                   9.5                   0.0
                  10.0                   0.0
```

LCIDR**R**, LCIDR**S**, LCIDR**T** are all inputs for load curves that define the rotational stiffness in R, S, and T-directions, respectively. If the beam is of finite length, one should set SCOOR = -3 or 3 in order to develop torque, if necessary. In this case, rotational stiffness in R and S-directions are the same and thus share the same load curve. To develop the load curve for LCIDRR and LCIDRS, one should test the panel's resistance to X and Y-rotation with the clip inserted. LCIDRT can be set to zero or can have a curve defined with a very low stiffness; since the push-in rivet clip does not inhibit rotation between the panels in the global Z-direction.

Most importantly, UFAILR, UFAILS, and UFAILT define the failure strain of the discrete element in R, S, and T-directions. Since there is a lot of translation that occurs between the panels before the push-in rivet fails, these values are usually somewhat large. To get good agreement with test results, one must fine-tune all load curves and failure strains.

Contact Definitions

Fortunately, this model does not require any extra contact definitions. Just ensure that there is a standard contact defined between the panels, most preferably an *AUTOMATIC_SINGLE_SURFACE contact with either a SOFT = 1 (nodes-to-segment) or SOFT = 2 (segment-to-segment) algorithm.

CAE vs. Test Results

The CAE analysis was performed by constraining the bottom panel nodes with *BOUNDARY_SPC and then defining a time vs. displacement driven *BOUNDARY_PRESCRIBED_MOTION for the top panel. A *DATABASE_SPCFORC was then defined so that the SPC force at each node is written.

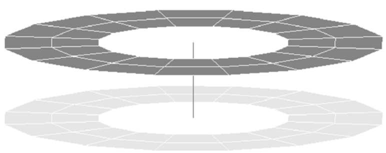

Figure 10: Pull-out at 0mm stroke

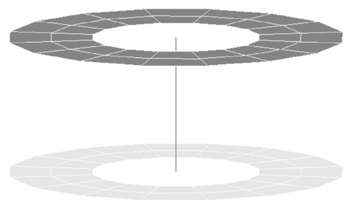

Figure 11: Pull-out at 8mm stroke

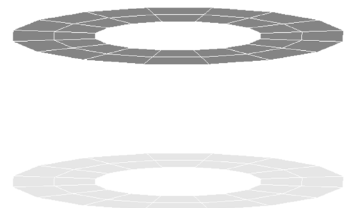

Figure 12: Pull-out at 9.5mm stroke.

The figures above show the sequence of events for pull-out failure mode at 0mm stroke, 8mm stroke, and 9.5mm stroke, respectively. Due to the UFAILT input that was defined in the material model, the discrete beam element was deleted at a stroke of 9.5mm. Furthermore, the sum of the SPC nodal Z-forces of the bottom panel was used to compare with the test data.

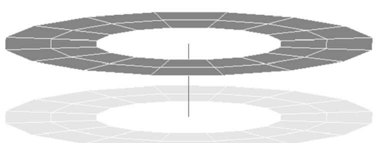

Figure 13: Shear at 0mm stroke

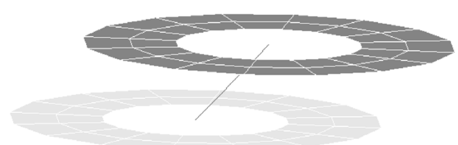

Figure 14: Shear at 9mm stroke

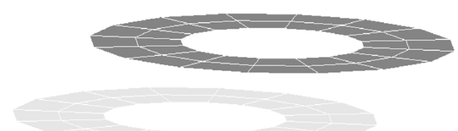

Figure 15: Shear at 10mm stroke.

The figures above show the sequence of events for the shear failure mode at 0mm stroke, 9mm stroke, and 10mm stroke, respectively. Due to the UFAILR and UFAILS inputs that was defined in the material model, the discrete beam element was deleted at a stroke of 10mm. Furthermore, the sum of the SPC nodal X and Y-forces of the bottom panel was used to compare with the test data.

Figure 16: Normalized force vs. strain response of pull-out mode.

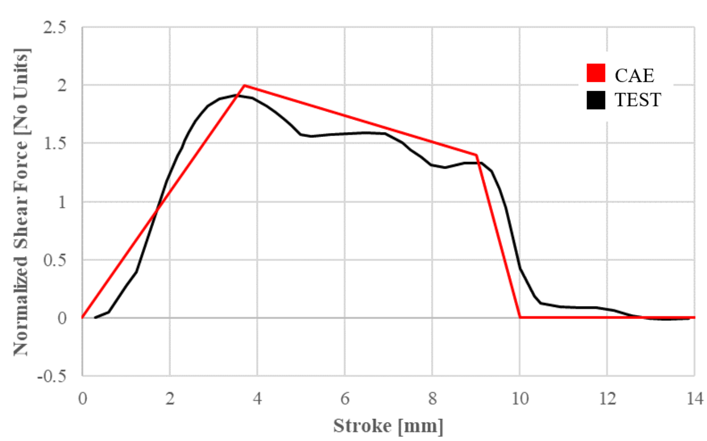

Figure 17: Normalized force vs. strain response of clips in shear mode.

It can be observed from figures 16 and 17 that the CAE response agrees with the test data in both pull-out and shear failure modes. This comes as no surprise, since the response of the discrete element matches the load curves for LCIDTR, LCIDTS, and LCIDTT. It is even possible to input the test data into the load curves and get an exact match to the test data.

An area of improvement for these type I clips discussed above would be to use MAT_68 (*MAT_NONLINEAR_PLASTIC_DISCRETE_BEAM), instead of its elastic component MAT_67. When in shear modes, the clip usually plastically deforms which MAT_67 does not sufficiently capture.

3.1.2 Type II Push-in Rivets

<u>Discretization</u>

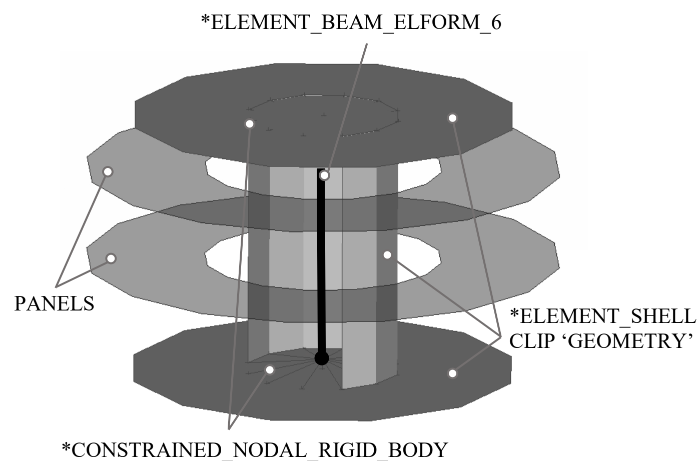

Figure 18: Type II clip model for push-in rivet.

With Type II clips, contact can occur between the mating panels and the important geometric aspects of the clip, yet the failure modes are still driven by discrete beams. Figure 18 depicts a possible Type II clip discretization for a push-in rivet, where the clip geometry is estimated using "null" shell elements that only act as a contact surface to ultimately impart a load on the discrete beam element through spider beams or *CONSTRAINED_NODAL_RIGID_BODY.
The development of this discrete element follows the same procedures found in section 3.1.1, so those procedures will not be discussed in detail here. Rather, the main focus of this section is the development of outer contact shell using a very weak MAT_24 with only single elements in the longitudinal direction. These weak shells share nodes with 'end caps', which are discretized through shell elements and a stronger MAT_24 plastic material. Under shear loading, the contact between the panels and the outer shell causes the discrete beam to be loaded in shear. While under tensile loading, the end caps come into contact with the panels thus imparting a tensile load on the discrete beam. Figures 19, 20 and 21 better illustrate the geometric discretization and the load paths.

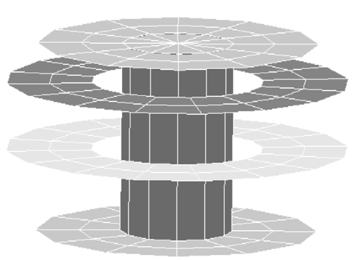

Figure 19: Unloaded Type II rivet.

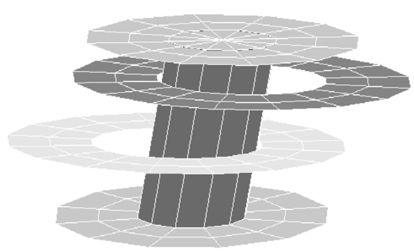

Figure 20: Type II rivet in shear.

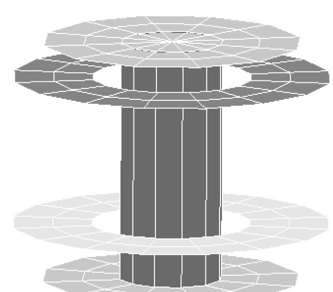

Figure 21: Type II rivet in tension.

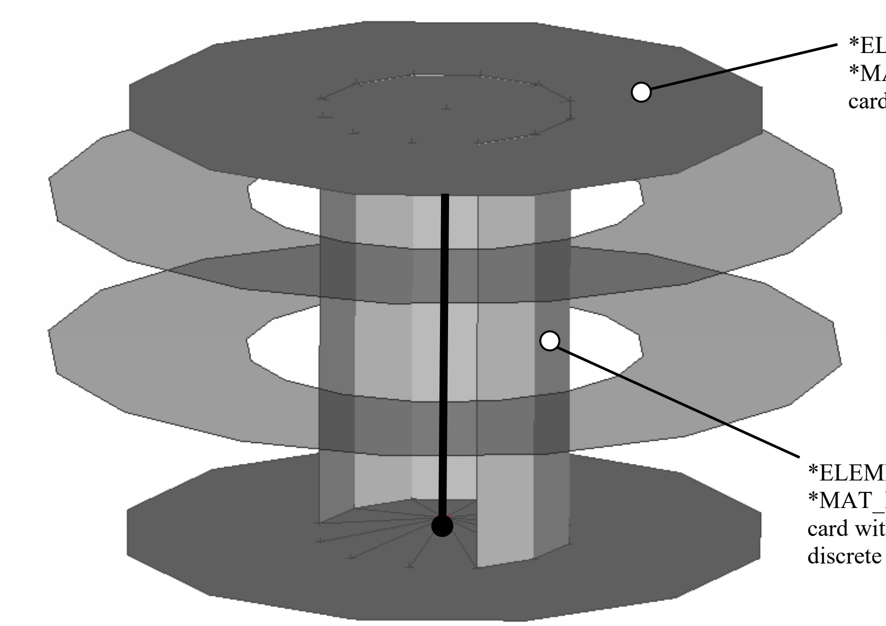

Figure 22: Type II clip model for push-in rivet.

Figure 22 shows the two main changes that upgrades a Type I model into a Type II model. The surfaces act only as a contact surface for load transfer into the discrete beam. This model is a closed system which allows one to easily copy more clip instances in other locations.
While developing these models, it is important to keep in mind the minimum edge-length of the shell elements. If an edge length is too small, it may cause longer run-times or may add too much unnecessary mass.

Contact Definitions

This model requires that a contact is defined between the panels and clip, most preferably an *CONTACT_AUTOMATIC_SINGLE_SURFACE contact with either a SOFT = 1 (nodes-to-segment) or SOFT = 2 (segment-to-segment) algorithm. A separate contact defining contact between the clips and the panels should be avoided in large systems not to effect scalability in a negative way. Ideally, the clip PIDs should be included in a global contact set. The card below is an example contact card that is suitable for this type of clip.

```
*CONTACT_AUTOMATIC_SINGLE_SURFACE_ID
$#     cid
         1ASS_SOFT_2_SBOPT_3
$#    ssid      msid     sstyp     mstyp    sboxid    mboxid       spr       mpr
         3         0         2         0         0         0         0         0
$#      fs        fd        dc        vc       vdc    penchk        bt        dt
       0.2       0.2       0.0       0.0      40.0         0       0.0  1.000E20
$#     sfs       sfm       sst       mst      sfst      sfmt       fsf       vsf
       1.0       1.0       0.0       0.0       1.0       1.0       1.0       1.0
$#    soft    sofscl    lcidab    maxpar     sbopt     depth     bsort    frcfrq
         2       0.1         0     1.025       3.0         5         0         0
$#  penmax    thkopt    shlthk     snlog      isym     i2d3d    sldthk    sldstf
       0.0         0         0         0         0         0       0.0       0.0
$#    igap    ignore    dprfac    dtstif    unused    unused    flangl   cid_rcf
         1         2       0.0     5.E-7                           0.0         0
$#   q2tri    dtpchk     sfnbr    fnlscl    dnlscl      tcso    tiedid    shledg
         0       0.0       0.0       0.0       0.0         0         0         1
```

3.1.3 Type III Push-in Rivets

<u>*Discretization*</u>

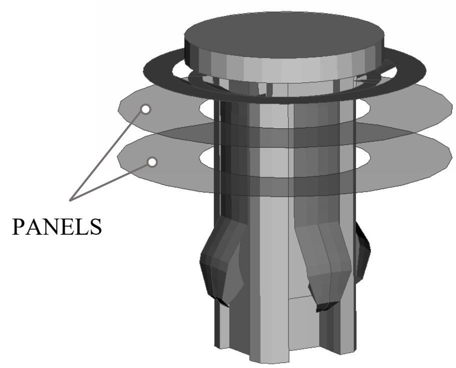

Figure 23: Type III push-in rivet.

With Type III push-in rivets, the main goal is to develop a model that closely resembles the actual geometry of the clip without using overly small elements which will adversely influence mass-scaling or run-times. But at the same time, small enough elements are needed to sufficiently capture all failure mechanisms. Type I and Type II rivet models are only good at capturing failure in pure shear and tension, whereas Type III should attempt to capture all variation in pull-out and shear failure modes if the panel material, hole diameter, and pull-out angles vary in a system such as a car. As seen in figure 24, the grommet was discretized using fully integrated 1mm shell elements and a *MAT_PIECEWISE_LINEAR_PLASTICITY material card that corresponded to the grommet's material. However, the pin was too thick for shell elements, thus fully integrated 1mm solid elements were used. Elements with 1mm length are generally unacceptable for most crash analyses, however, these clips are low stiffness plastic with a relatively high density. It is important to note that this type may lead to added mass, but this added mass would have an insignificant impact on the overall response of the system.

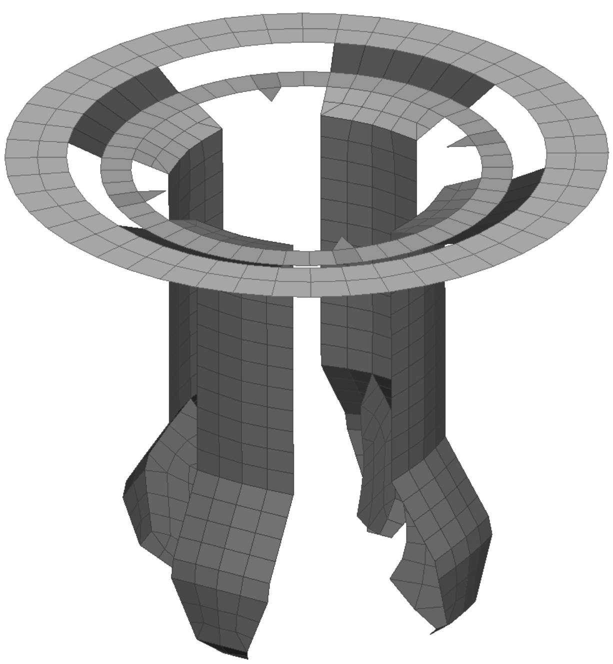

Figure 24: Shell element grommet.

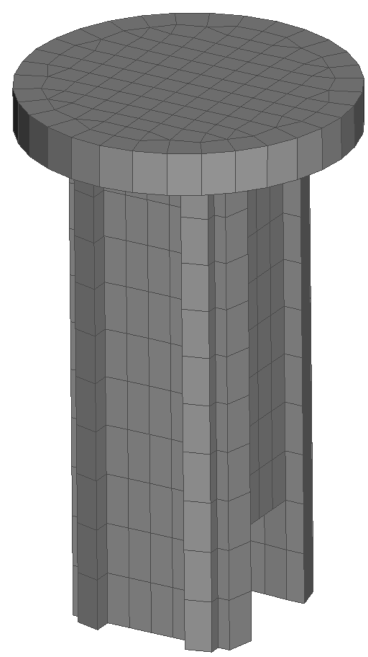

Figure 25: Solid element pin.

While the pull-out failure modes were quite successful for this type of clip, issues arose in shear modes due to insufficient contact stiffness between the panels and the solid pin which lead to excessive penetrations. In addition, an eroding contact was needed in order to capture contact between the pin's inner solids and the panels when the pin's outer solid elements failed in shear. After several trial-and-error runs such as increasing contact stiffness scale factors, decreasing DTSTIF, and decreasing element size, it was found that simply adding thin "null" shell elements to each interior segment of the solid pin was the best way to fix the excessive penetrations and remove the need for an eroding contact in shear modes without any real adverse effects. The updated solid pin can be seen in figures 26 and 27.

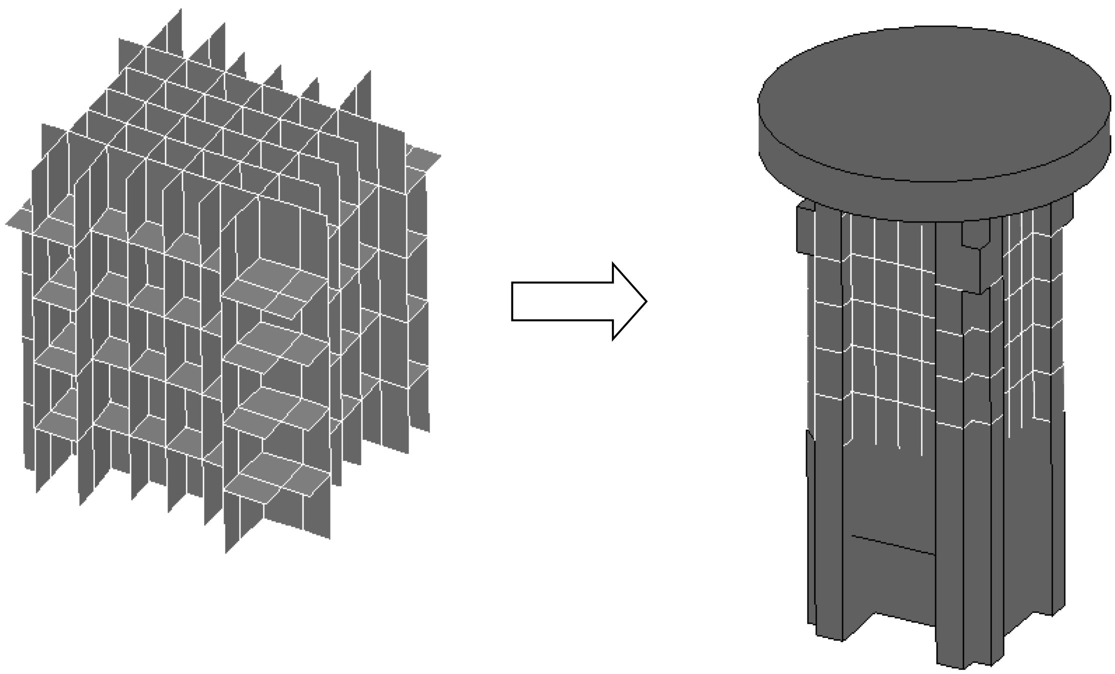

Figure 26: Internal shell segments for pin. **Figure 27:** Solid element pin and internal shells.

These internal shell elements are thick and have a very low stiffness and yield stress but a high density in order to increase contact stiffness without affecting the pin's original stiffness and yield.

Contact Definitions

This model requires that a SOFT = 2 contact with SBOPT = 3/5 and SHLEDG = 1 is defined between the panels and clips. If a *CONTACT_AUTOMATIC_SINGLE_SURFACE contact where the clip PIDs are included in a global contact set is not possible, then two new separate contacts will need to be created. One *CONTACT_AUTOMATIC_SINGLE_SURFACE is needed to define the contact between the clip parts, and one *CONTACT_AUTOMATIC_SURFACE_TO_SURFACE contact is needed where the slave is the clip set and the master is the panel set. However, if the clip is modeled with solids and the solids do not have internal contact shells as seen in figures 26 and 27, then one must use a *CONTACT_ERODING_SURFACE_TO_SURFACE instead of *CONTACT_AUTOMATIC_SURFACE-_TO_SURFACE. The figure below shows a suitable contact card with the inputs needed to capture clip-to-panel contact.

```
*CONTACT_AUTOMATIC_SINGLE_SURFACE_ID
$#     cid
         1ASS_SOFT_2_SBOPT_5
$#    ssid      msid     sstyp     mstyp    sboxid    mboxid       spr       mpr
         3         0         2         0         0         0         0         0
$#      fs        fd        dc        vc       vdc    penchk        bt        dt
       0.2       0.2       0.0       0.0      40.0         0       0.0 1.000E20
$#     sfs       sfm       sst       mst      sfst      sfmt       fsf       vsf
       1.0       1.0       0.0       0.0       1.0       1.0       1.0       1.0
$#    soft    sofscl    lcidab    maxpar     sbopt     depth     bsort    frcfrq
         2       0.1         0     1.025       5.0         5         0         0
$#  penmax    thkopt    shlthk     snlog      isym     i2d3d    sldthk    sldstf
       0.0         0         0         0         0         0       0.0       0.0
$#    igap    ignore    dprfac    dtstif    unused    unused    flangl   cid_rcf
         1         2       0.0     5.E-7                           0.0         0
$#   q2tri    dtpchk     sfnbr    fnlscl    dnlscl      tcso    tiedid    shledg
         0       0.0       0.0       0.0       0.0         0         0         1
```

With this model, SHLEDG = 1 is a necessary contact parameter as it turns off edge extensions for shell edges in segment-to-segment contacts. Without SHLEDG = 1 defined, the diameter of the panel holes become smaller than they actually are. When the hole diameter is too small for the clip, the pull-out force increases exponentially and there may be instabilities that arise from initial penetrations. Figures 28 and 29 below demonstrates the effect of SHLEDG = 1 on shell edge extensions.

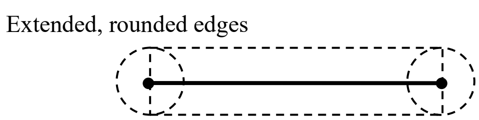

Figure 28: Shell contact surface SHLEDG = 0

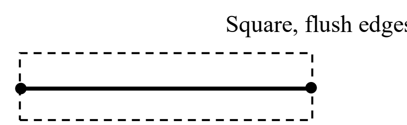

Figure 29: Shell contact surface SHLEDG = 1

SBOPT = 5 is another necessary contact parameter because it enables checking of one segment against the segment it is in contact with, plus its adjacent neighbors. If this option is not enabled, then as a shell edge slides along a shell surface, there will be large spikes in the frictional force for a few cycles as the edge passes over from one segment to the next. This is due to lack of information of depth of penetration and orientation when the sliding edge come into contact with a new segment. With SBOPT = 5, the information from adjacent segments allows for the depth of penetration and orientation to stay consistent throughout sliding, thus, there are no large frictional force spikes. This is very important for capturing the correct removal force of Type III push-in rivets because there is sliding of the shell grommet surfaces against the panel edges in pull-out modes. The main drawback to SBOPT = 5 is that it tends to be softer at open edges than SBOPT = 3. However, SBOPT = 3 is not an option in some cases, as the following will explain in more detail. Figure 30 shows the drastic difference between pull-out failure with 12mm diameter holes for SBOPT = 5 vs SBOPT = 3.

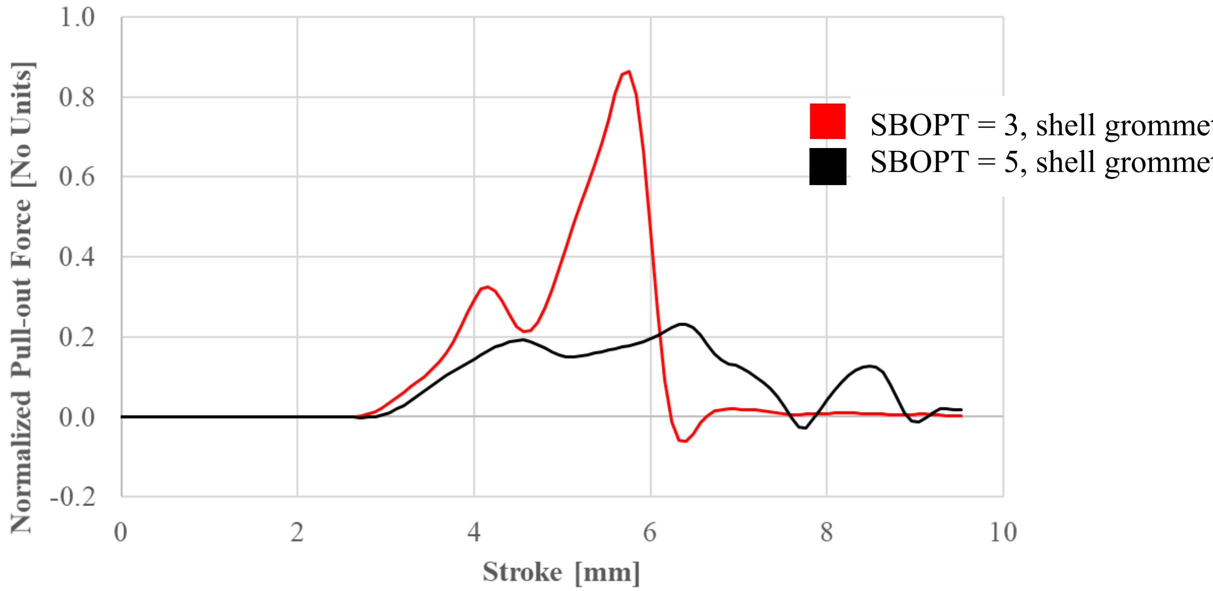

Figure 30: Pull-out failure for a 12mm diameter panel hole.

It can be observed from figure 30 that the normalized pull-out failure when SBOPT = 3 is almost four times higher than the normalized pull-out failure for SBOPT = 5. With a 12mm diameter hole, the normalized pull-out force should be around 0.25. Therefore, SBOPT = 3 is not suitable for Type III push-in rivet clips where the grommet/barb and panel are both comprised of shell elements.

Fortunately, a work-around was found that allows SBOPT = 3 to be used when the grommet is modeled with solid elements rather than with shell elements. The only drawback with modeling the grommet with solid elements is that there are much smaller element lengths because of the thin geometry. In order to sufficiently capture bending in the arms of the grommet, there needs to be 3 solid elements through the thickness of the part. Figures 31 and 32 below demonstrate the change from shell element grommet to a solid element grommet.

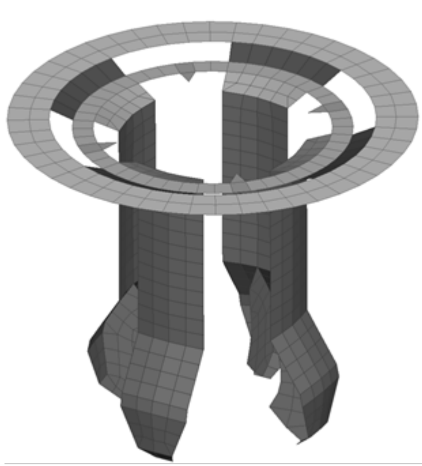

Figure 31: Shell element grommet.

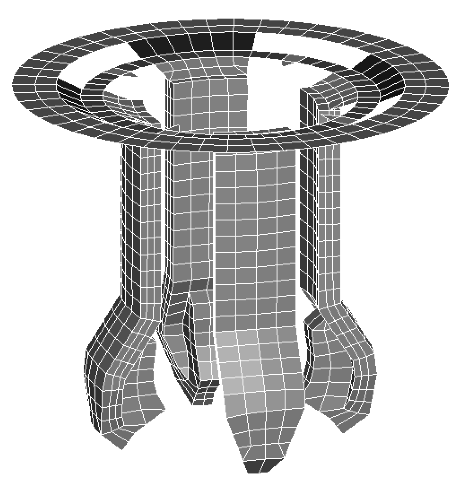

Figure 32: Solid element grommet.

Figure 33 below compares solid element grommet with SBOPT = 3 vs shell element grommet with SBOPT = 5.

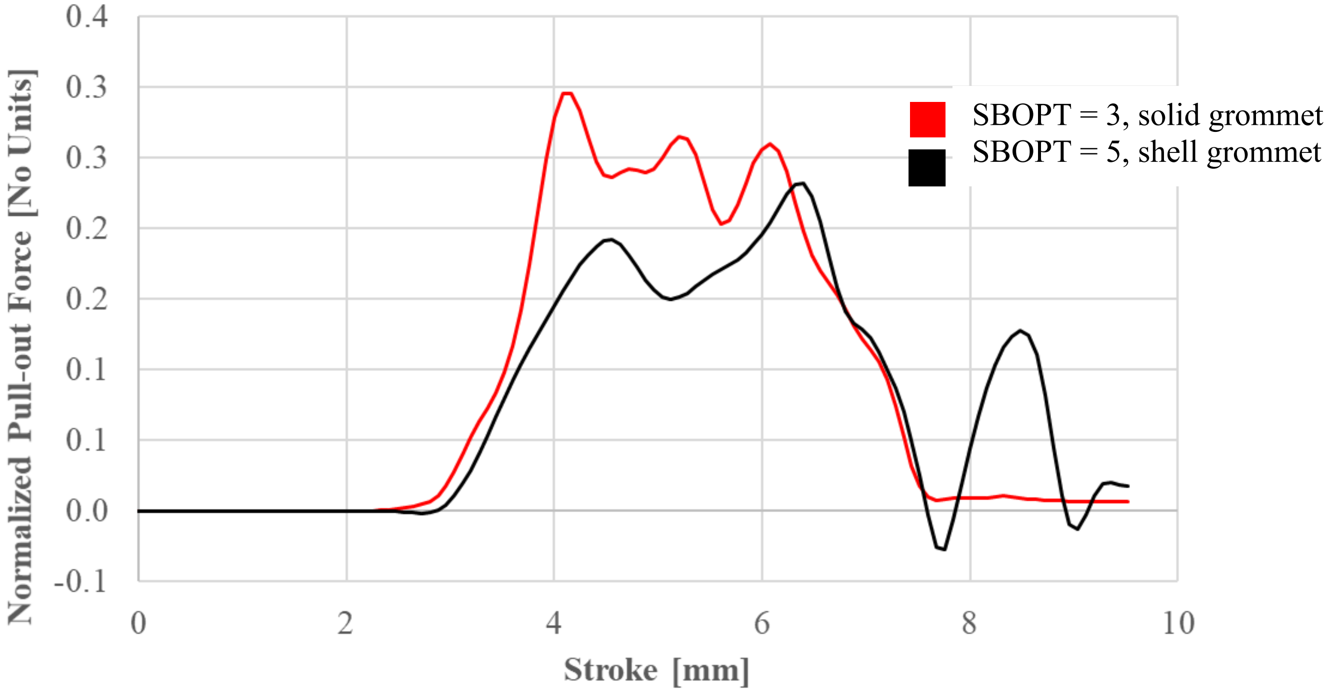

Figure 33: Pull-out failure for a 12mm diameter panel hole.

It can be observed from figure 33 that the force vs. stroke data for solid element grommet with SBOPT = 3 agrees very well with the data for shell element grommet with SBOPT = 5. This is further evidence that shell element grommets with SBOPT = 3 are not suitable for Type III clips, and that if one is to use SBOPT = 3, they need to use primarily solid elements to discretize the clip.

CAE vs. Test Results

The CAE analysis was performed by constraining the bottom panel nodes with *BOUNDARY_SPC and then defining a time vs. displacement driven *BOUNDARY_PRESCRIBED_MOTION for the top panel. A *DATABASE_SPCFORC was then defined so that the SPC force at each node is written. The hole diameter for the panels were 10mm, consistent with the characterization test set-up.

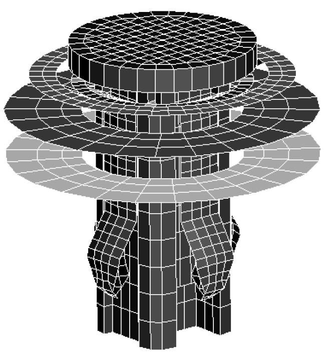

Figure 34: Pull-out at 0mm stroke

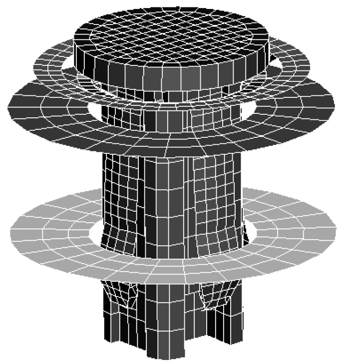

Figure 35: Pull-out at 5mm stroke

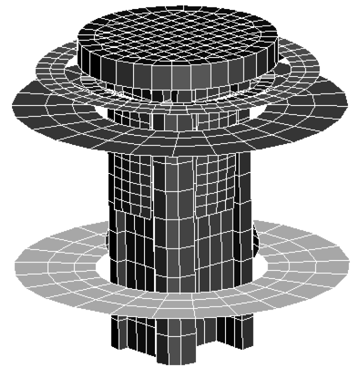

Figure 36: Pull-out at 6.5mm stroke.

The figures above show the sequence of events for pull-out failure mode at 0mm stroke, 5mm stroke, and 6.5mm stroke, respectively. It can be observed in figure 36 that the grommet fails in tension, leading to the full release of the panels.

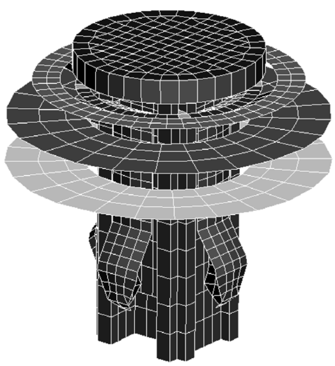

Figure 37: Shear at 0mm stroke

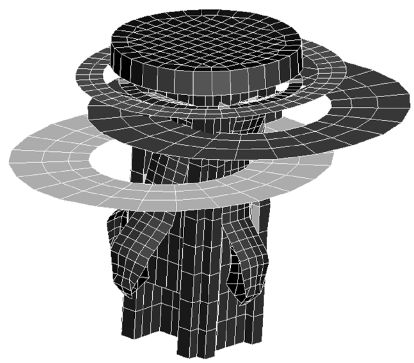

Figure 38: Shear at 6mm stroke

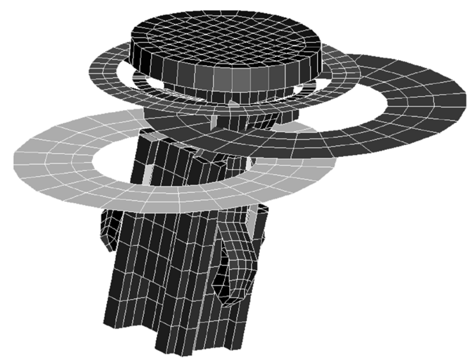

Figure 39: Shear at 9mm stroke.

The figures above show the sequence of events for the shear failure mode at 0mm stroke, 6mm stroke, and 9mm stroke, respectively. It can be observed in figure 39 that the outer solids of the pin have begun failing, but contact still occurs due to the internal shell elements.

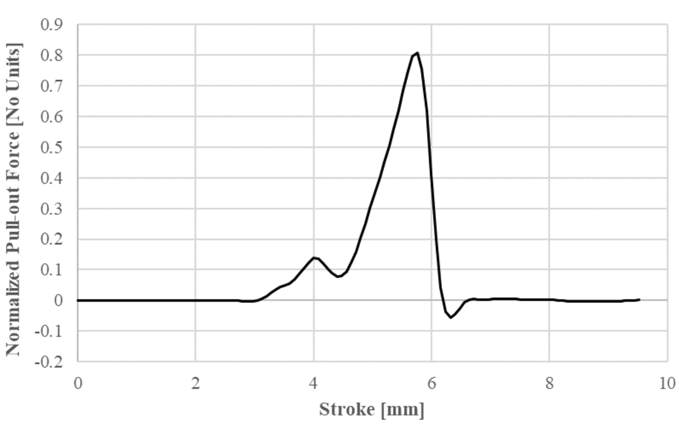

Figure 40: Normalized force vs. strain response of pull-out mode.

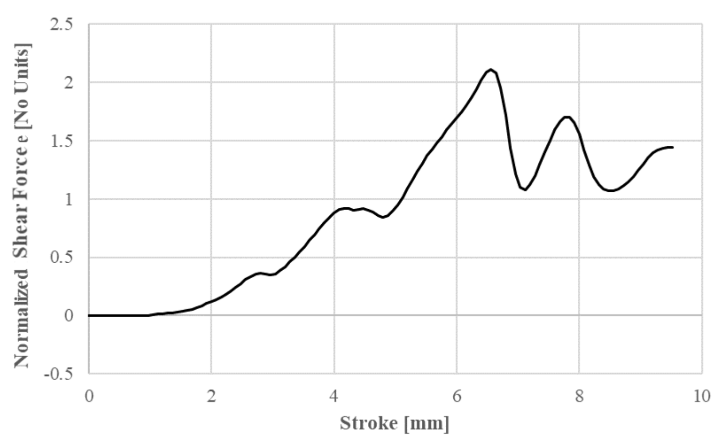

Figure 41: Normalized force vs. strain response of clips in shear mode.

Unfortunately, force vs. stroke test data was not acquired for this specific push-in rivet geometry. However, the CAE data agrees relatively well with earlier test data of a rivet of similar geometry. Figure 40 shows the normalized force vs. stroke in pull-out mode. Figure 41 shows the normalized force vs. stroke in shear mode.

3.2 Modeling Snap-on Clips

The primary purpose of this section is to add another verification study for Type III clips using a completely different style of clip. Snap-on clips are smaller and weaker than push-in rivets, but they have many different failure modes that would be very hard to capture using Type I or Type II model types. Figure 42, 43, and 44 demonstrate the assembly of a snap-on clip.

Figure 42: Snap-on clip.

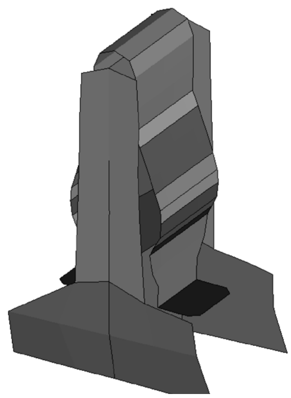

Figure 43: Snap-on clip tower.

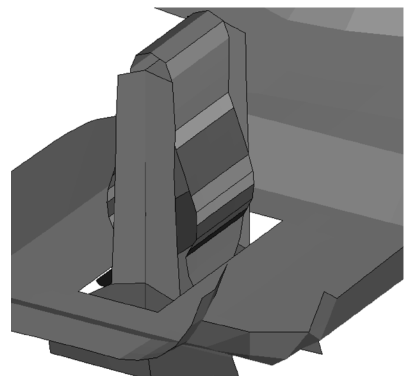

Figure 44: Full assembly to substrate.

Not pictured in figure 43 is that the tower is part of another substrate/panel. From observations of figures 42, 43, and 44, it is obvious that pull out failure for these clips vary greatly depending on the substrate thickness, slot size, substrate material, friction, and even pull-out angle.

3.2.1 Type III Snap-on Clips

<u>*Discretization*</u>

With Type III snap-on clips, the main goal is to develop a model that closely resembles the actual geometry of the clip without using overly small elements, which will adversely influence mass-scaling or run-times. As seen in figure 45, the clip geometry is discretized with fully integrated shell elements with thickness steps of 0.25mm. The edge length of each element is roughly 1mm. The tower and substrate are meshed with a 3mm element size as they are not likely to fail before the clip does.

The clip is assembled to tower in the substrate. If initial penetrations are present, it may be best to do a run with *INTERFACE_SPRINGBACK_LSDYNA where the snap-fit clip is pre-stressed so that initial penetrations are removed and the stresses, strains and nodal displacements

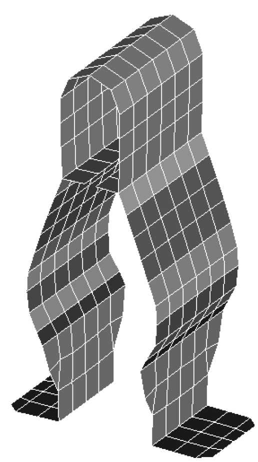

Figure 45: Type III snap-fit clip.

are written out for the clip. The clip can then be copied and reoriented many times with a pre-processor and will always have the initial penetrations removed and corresponding pre-stress in future runs.
The clip's material model is a *MAT_PIECEWISE_LINEAR_PLASTICITY card with the corresponding stress v. strain data derived from coupon tests.

Contact Definitions

This model requires a SOFT = 2 contact with SBOPT = 5 and SHLEDG = 1 is defined between the panels and clips because the clip will be sliding over the shell edges of the substrate. However, it is possible to have SBOPT = 3, but the clip or the substrate needs to be modeled with solid elements. The figure below shows a suitable contact card with the inputs needed to capture clip-to-panel contact.

```
*CONTACT_AUTOMATIC_SINGLE_SURFACE_ID
$#     cid
         1ASS_SOFT_2_SBOPT_5
$#    ssid      msid     sstyp     mstyp    sboxid    mboxid       spr       mpr
         3         0         2         0         0         0         0         0
$#      fs        fd        dc        vc       vdc    penchk        bt        dt
       0.2       0.2       0.0       0.0      40.0         0       0.0  1.000E20
$#     sfs       sfm       sst       mst      sfst      sfmt       fsf       vsf
       1.0       1.0       0.0       0.0       1.0       1.0       1.0       1.0
$#    soft    sofscl    lcidab    maxpar     sbopt     depth     bsort    frcfrq
         2       0.1         0     1.025       5.0         5         0         0
$#  penmax    thkopt    shlthk     snlog      isym     i2d3d    sldthk    sldstf
       0.0         0         0         0         0         0       0.0       0.0
$#    igap    ignore    dprfac    dtstif   unused     unused    flangl   cid_rcf
         1         2       0.0     5.E-7                           0.0         0
$#   q2tri    dtpchk     sfnbr    fnlscl   dnlscl       tcso    tiedid    shledg
         0       0.0       0.0       0.0       0.0         0         0         1
```

CAE vs. Test Results

The CAE analysis was performed by pulling the tower and clip assembly straight out of the substrate through *BOUNDARY_PRESCRIBED_MOTION. A beam connected to substrate tower was used to capture the axial force written through *DATABASE_ELOUT.

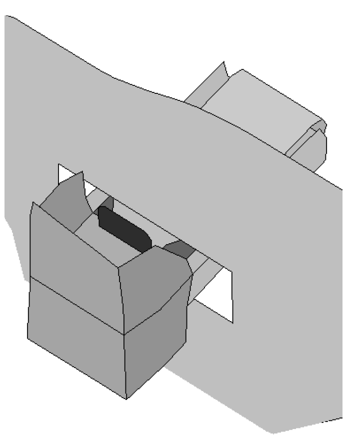

Figure 46: Pull-out at 0mm stroke

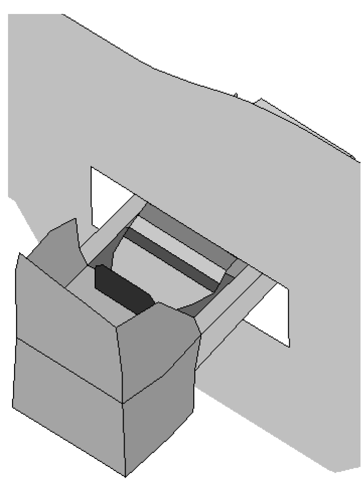

Figure 47: Pull-out at 5mm stroke

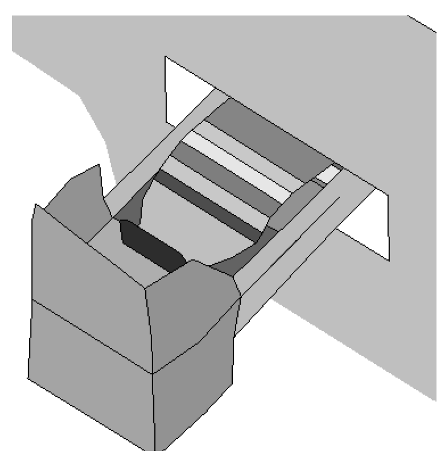

Figure 48: Pull-out at 9mm stroke.

The figures above show the sequence of events for pull-out failure mode at 0mm stroke, 5mm stroke, and 9mm stroke, respectively. The tower and clip assembly is fully released after a pull-out stroke of about 9mm.

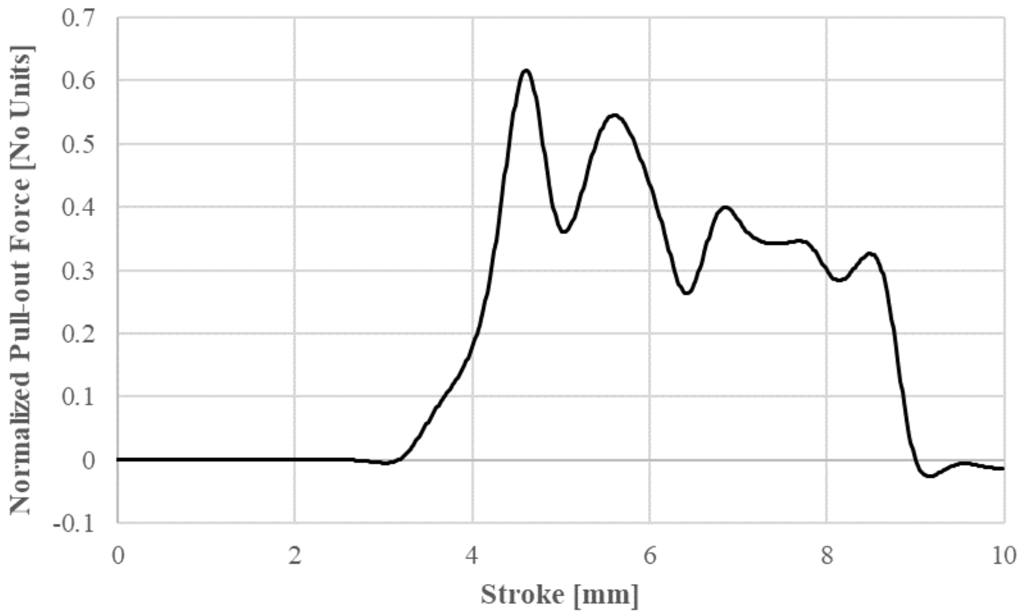

Figure 49: Pull-out force vs. stroke for snap-on clips.

As seen in figure 49 above, the normalized pull-out force peaks at a stroke of 5mm. While there is no force vs. stroke test data for this specific clip, it is known that the average normalized peak force for this clip is around 0.60. The normalized peak force of the CAE snap-on clip is 0.62, therefore, the CAE agrees with the average peak force test data.

4. Pre-processing/Scripting Techniques

Once a clip is developed, one must be able to incorporate many clips seamlessly in a large model such as a car. There are several capabilities in **ANSA** from **BETA CAE** that may make incorporation very easy:

For Type I models, it may be possible to archive them or create a template in ANSA's connection manager. If not, spider + beam bolts can be created at each clip connection point using the connection manager and the beam sections of the bolts can be replaced with the discrete element and corresponding material.

For Type II and III models, the best way to incorporate many clips is to input all desired clip CAD data into the large model, and then input a single CAE clip that corresponds to the CAD. Next, one should correctly position and align the CAE model with a single CAD clip. Once aligned, open the model

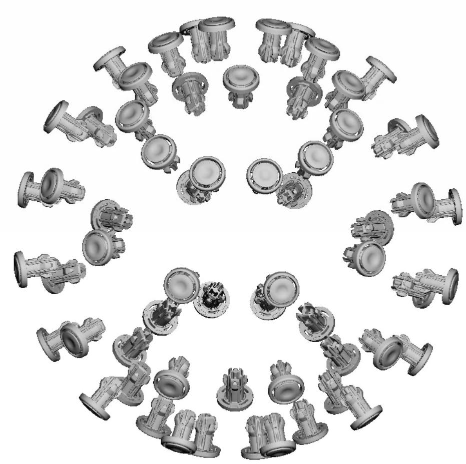

Figure 50: Input CAD into ANSA.

browser on the top left corner and select the CAE clip's ANSAPART. If there are multiple ANSAPARTS for a single clip, it may be easier to combine them into one ANSAPART. Next, click SET PART and select the single CAD ANSAPART that the CAE clip is aligned to then middle-click the mouse button twice. Lastly, right click on the CAD ANSAPART, scroll down and select DM and then SYNC REPRESENATATION. Depending on how many clips there are, it may take a few minutes for the CAE clips to sync (copy and paste) to the rest of the CAD clips.

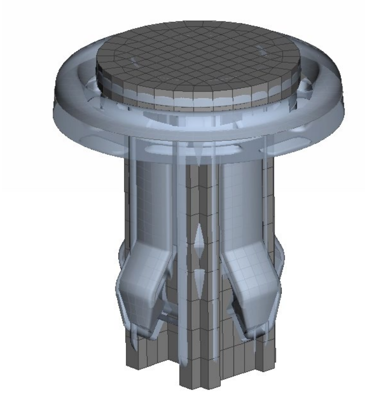

Figure 51: Single CAE clip aligned with CAD.

A quick summary of this process is shown below:

Input all clip CAD > Input single CAE clip > align clip with single CAD clip > open up model browser > select CAE clip > select SET PART > select single CAD clip in workspace > hit enter on keyboard > right click on CAD in model browser > hover cursor over DM > select SYNC REPRESENTATION > wait and delete all CAD when finished.

5. Summary and Recommendations for Future Work

The purpose of paper is to describe the development of simple and complex models for push-in rivet and snap-on clips, to discuss the strengths and limitations of each model type, and to present possible pre-processing techniques that make incorporating standard clips very easy. When clip failure was captured by using Type III clips in a low-speed front crash simulation, it drastically improved the CAE accelerometer signals. Furthermore, the addition of Type III snap-on clips in an instrument panel model improved CAE to test correlation for a head impact test. Capturing accurate clip failure will only become more important as more emphasis is put on low energy impacts to ensure the safety of pedestrians and occupants. This paper represents an introduction to clip modeling, in order to get analysts used to the idea that clip modeling is necessary and useful. While these same techniques may not be adopted be the industry, it is the authors' hope that current clip modeling techniques are vastly improved upon in the years to come.

References

[1] Matsuura, N., Nakagawa, Y., Ito, O., Kaneda, K., & Ueda, Y. "Development of Simple Connection Model for Plastic Parts in Low-Speed Crash Simulation." *12th European LS-DYNA conference*, 2019. Retrieved January 17th, 2020, from https://www.dynalook.com/conferences/12th-european-ls-dyna-conference-2019/connections/matsuura_honda_r-d.pdf

[2] Newegg.com. "100 Pcs Plastic Rivets Car Bumper Fender Retainer Push Type Fastener Clips 8mm." https://www.newegg.com/p/0PS-00E0-05SR8