

Smooth Contact©

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Abstract

The purpose of this paper is to introduce a new type of contact: smooth contact. Different from the traditional contact, which is based on node and element, smooth contact fits a surface from the rigid body mesh and calculates the penetrations based on the newly fit surface. This new contact option can have more accurate contact force calculations and give improved springback predictions. In addition, it also reduces user-dependent results.

Introductions

The treatment of sliding and impact along interfaces has always been an important capability in LSDYNA®. Interfaces can be defined in three dimensions by listing in arbitrary order all triangular and quadrilateral segments that comprise each side of the interface. One side of the interface is designed as the slave side, and the other is designated as the master side. Nodes lying in those surfaces are referred to as slave and master nodes, respectively.

Conventional Forming Contact

In sheet metal stamping simulation, a special contact was implemented: *CONTACT_FORMING... which use penalty method. In other words, this method consists of placing normal interface springs between all penetrating nodes and the contact surface. The interface stiffness is chosen to be approximately the same order of magnitude as the stiffness of the interface element normal to the interface. Consequently, the computed time step size is unaffected by the existence of the interfaces. However, if interface pressure becomes large, unacceptable penetration may occur. By scaling up the stiffness and scaling down the time step size, we may still solve such problems using the penalty approach.

The penalty method is based on the triangle or quad elements, rather than on the smooth surface. It may result in some obvious numerical noises when the curvature is large. Figure is an exaggerated example showing the penetration problem associated with the conventional contact method. In this figure, we assume that the master side is a smooth curve, which is represented by three segments. Nodes A and B are slave nodes. It is seen that node A should be in contact with the master surface (the smooth curve), but the conventional method will not find this contact, until when the nodes move closer to the line segment, such as in the position of node B, where the slave node will be regarded as being in contact with the master side. When node A moves to A', the penetration is detected, but it can be very big. As a result, a huge contact force will be applied to node

A' , which in turn, cause significant jump in the contact force. When the contact force is too big, the computation itself can become unstable.

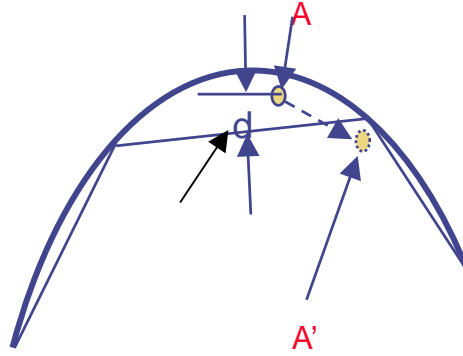


Figure 1. Illustrations of penetration calculation with the conventional contact

One more problem associated with the conventional contact algorithm is related to the contact normal calculations.. In conventional method, each master segment (element) is treated separately. So, is impossible to have the neighboring element information. Accordingly, the contact force is always assumed to happen in the normal direction of the master element. If the curvature is small, this problem is not serious. If the curvature is large, when the slave node move to the vertex region, a small change in location, the slave node might find a different (neighboring) master element, which has been clearly illustrated in Figure . The normal of the contact force will be calculated based on the new master element. As a result, the resultant contact force calculation will have significant perturbations (variations).

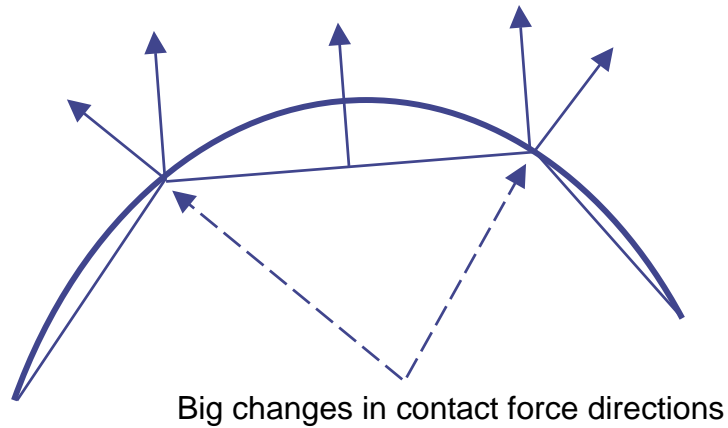


Figure 2 The calculation of contact force orientation in conventional method

From the above analysis, it is seen that conventional contact has some obvious disadvantages. It can result in large errors in the calculations of the penetration and contact normal. As a result, the stress distribution and springback predictions will be negatively affected. The search for an improved contact algorithm has become a hot topic.

Smooth Contact

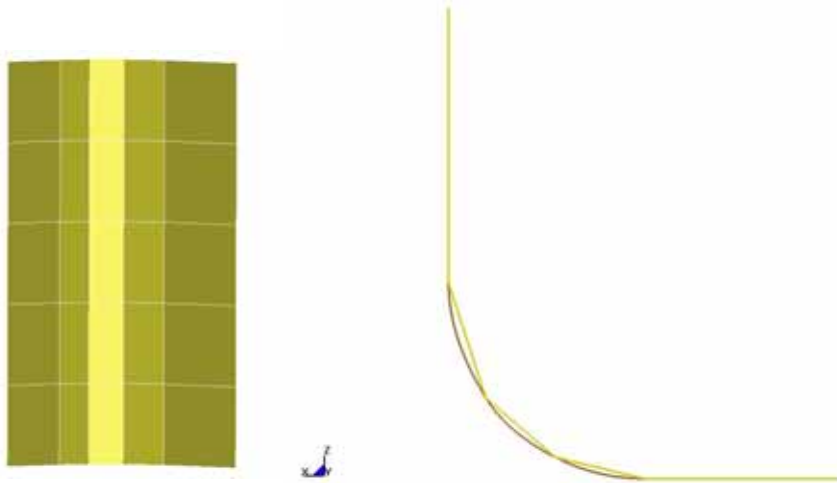
In 1990s, people began to pay attention to the un-smoothness associated with the conventional contact. At first, a smooth contact based on CAD surface (IGES and VDA format) was implemented in LSDYNA®. With this method, users simply use CAD surface to define the contact interfaces.

This approach has only a very limited use due to its limitations. First, the CAD surfaces are usually not clean, in other words, there are many gaps, small patches, overlaps, etc. These 'dirty' CAD surfaces make it extremely difficult for contact search. Second, the computation is much slower than the conventional contact. Usually, the user might need to use six times more CPU time to do the simulations. Finally, there are many different entities in a typical CAD surface; it is extremely difficult to support all of these entities. As a result, the contact based on the CAD surface has only been used for small lab validations.

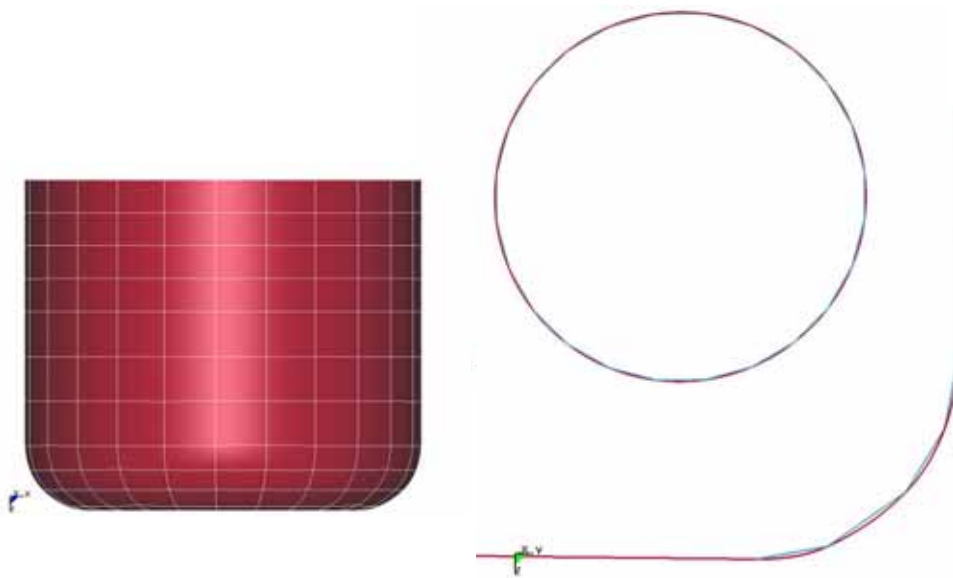
Recently, LSTC developed a new approach that can meet the requirement. In this approach, surface patches are fit by considering the neighboring information. The surface patches will have G1 continuity among the patches boundaries.. The penetration calculations are based on the fit surface patches.

Surface-fitting

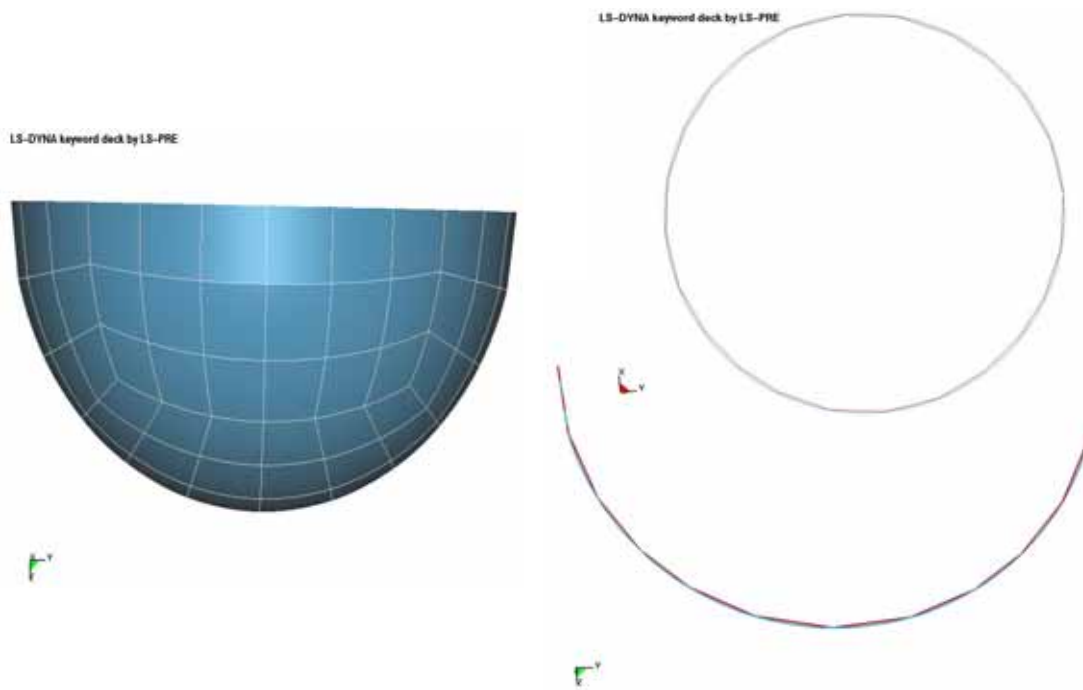
To make it robust, the surface fitting (creating surfaces to fit the mesh geometry) must be reliable since any surface defect can affect the contact force calculation. LSTC has independently developed an edge-detection algorithm, which is critical to the surface fitting. B-Splines were used to describe the surface patches. Many numerical tests have been performed to validate the robustness of this surface fitting algorithm. Figure 1 shows some of the surface-fitting results, from which it clearly shows that new surface can accurately represent the true smooth surface.



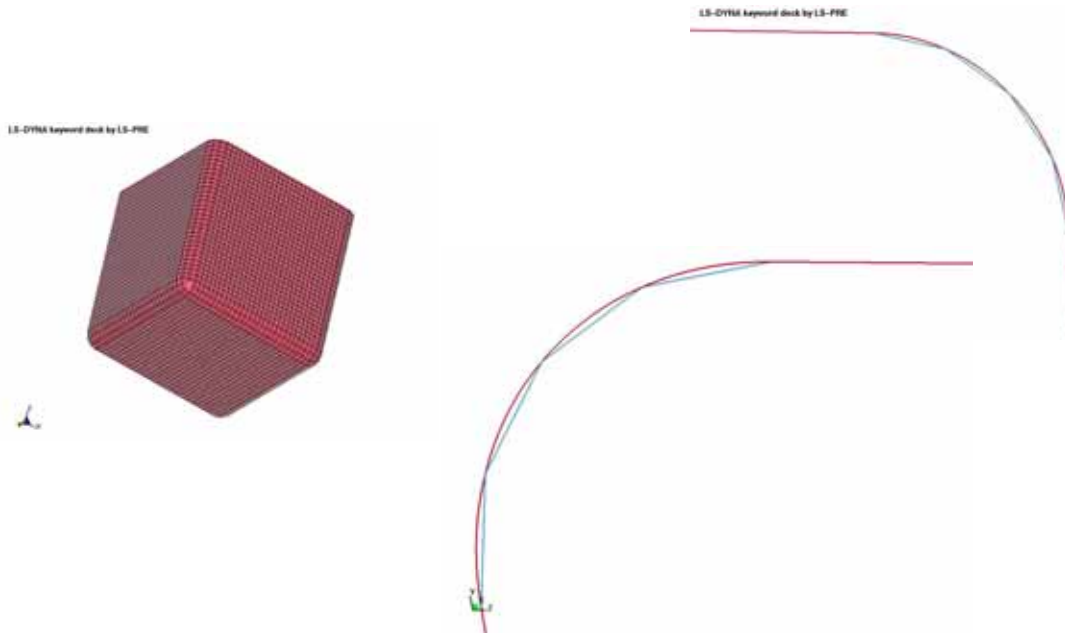
a) surface fitting of a corner



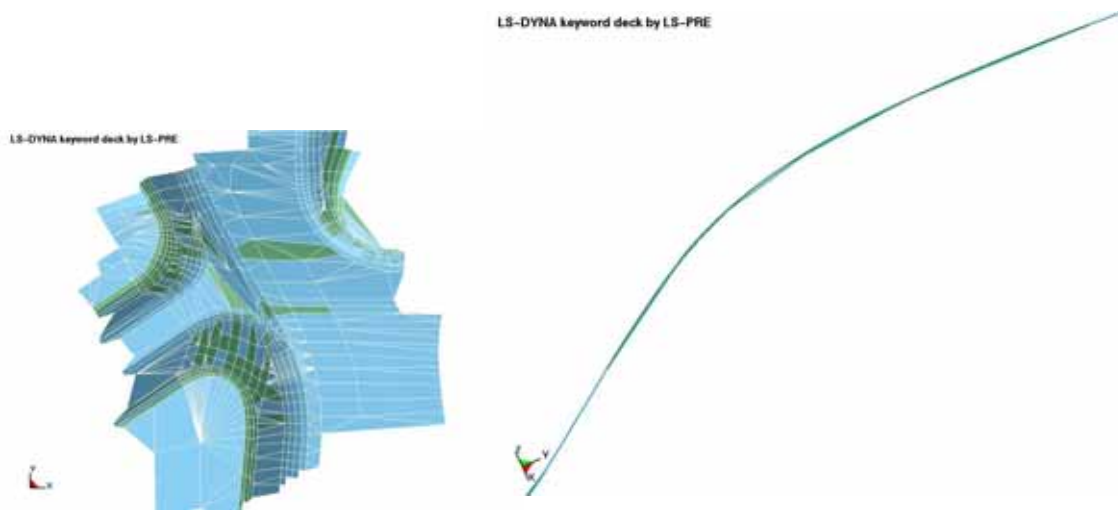
b) Surface fitting of a cylinder



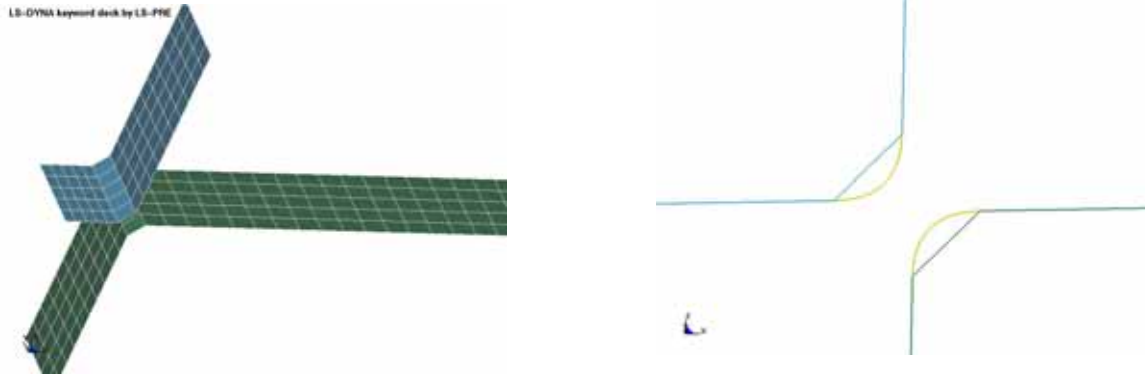
c) Surface-fitting for a half-ball



d) Surface-fitting for a cubic box



e) Surface-fitting for hood-inner (local view)



f)

Figure 1 Surface fitting for different kind of mesh

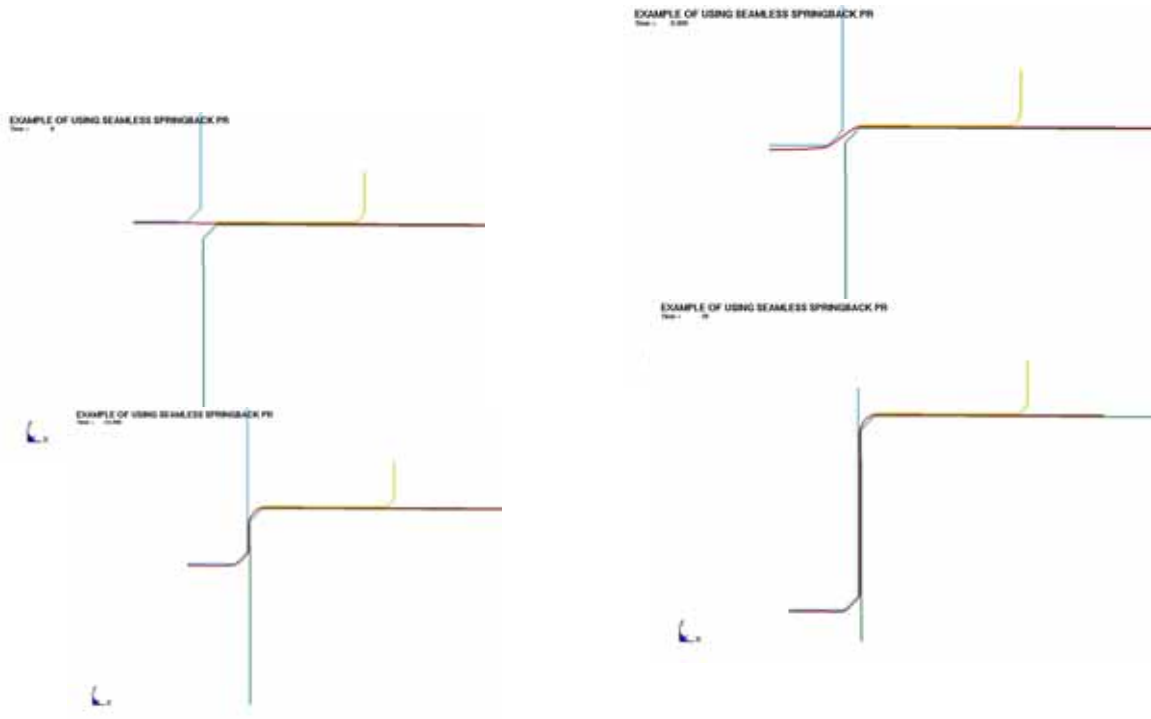
Validations of smooth contact

After the surface-fitting algorithm was fully tested, LSTC developed a new contact searching algorithm based on the surface patch. With the new algorithm, the smooth contact becomes robust and efficient (only 10%~20% overhead).

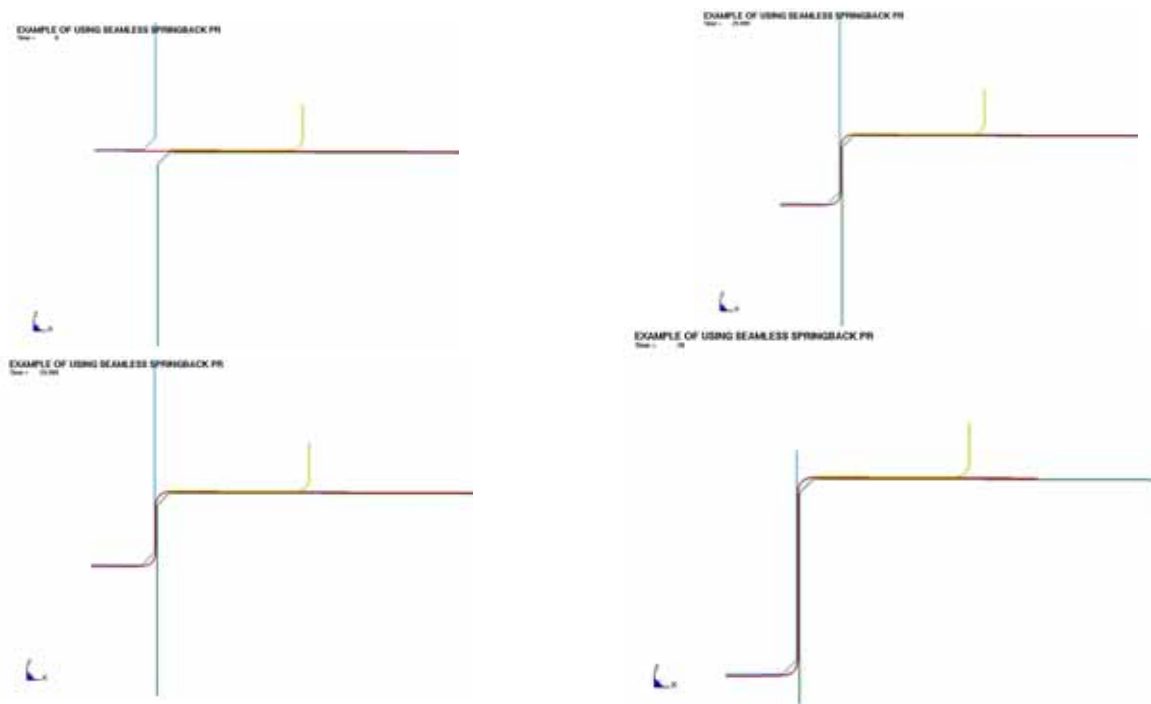
Smooth contact has been implemented in LSDYNA® for both SMP and MPP versions. To activate smooth contact, only an option, ‘_SMOOTH’, should be added to the conventional contact definition. And all the other keywords will still remain the same.

To use the smooth contact, there are some requirements to the mesh quality for the master sides. First, no overlapping of elements is allowed. Second, the element normal should be consistent. Finally, the mesh should be fully connected. With any current commercial preprocessor, it is very easy to generate mesh to satisfy the above requirements.

Many tests have been designed to test the code implementations, A small, but representative, examples is shown here. In this test, only one element is put in the 90-degree angle region for NUMISHEET’93 U-Channel. In the first calculation, no smooth option was added to the contact keyword, and it is seen that blank forms a sharp angle by following the master elements, and the result is shown in Figure 2, a). In the second calculation, a smooth option is added. In figure b), it is seen that the blank in the corner region does not follow the mesh of the rigid bodies, but follow the smooth surface.



a) Without smooth option



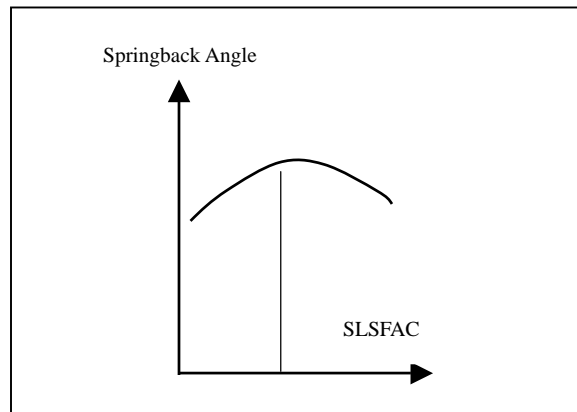
b) With smooth option

Figure 2 Contacts with and without smooth contact option

Some user-dependent results

From previous studies, a set of preferred parameters were obtained. With this preferred parameters, springback predictions become more stable and accurate. However, some of the preferred parameters need to be changed for new materials. Accordingly, user's experience still has obvious effect on the final predictions.

One of the most important parameters is SLSFAC, which defines the contact stiffness. If a large value is used, the contact might be too stiff and the predicted springback might be too small. On the other hand, a small value of SLSFAC can result in large penetrations and also affects the springback prediction. Figure 3 shows the springback angle prediction of Numisheet'93 U-channel with different value of SLSFAC. It is seen that predicted springback depends on the value of SLSFAC. In fact, most of the user-dependent springback predictions come from the use of different value of SLSFAC.



*Figure 3 Effect of SLSFAC on springback prediction Material: high-strength steel; binder pressure: 19.6 KN
Initial coarse mesh, with 3 levels of adaptivity*

Another important factor affects springback prediction is the quality of the rigid body mesh. The number of elements in the radius regions can have obvious effect on springback prediction. It is found that more than six elements are needed to cover a 90 degree angle for the rigid bodies.

With the implementation of smooth contact, smooth surface patches were used for the contact force calculation. As a result, it is expected that the element size of the rigid bodies should have less effect on the springback predictions, and the noises for contact force calculations can be significantly reduced. For validation purpose, a simple test, Numisheet'93 U-channel, was used. In this model, the size of the rigid body elements

was changed for each case. The number of elements covering a 90-degree angle ranges from 1 to 10. Table 1 shows that with only one element covering the 90-degree angle, the predicted springback angle is 19.9, while the predicted angles for the other cases are all around 21 degree. It is obvious that smooth contact has significantly reduced the dependence of the size of rigid body elements.

Table 1 The effect of element size on springback predictions

# of Element	1	2	4	10
Angle	19.9	21.2	20.8	21.5

With the smooth contact, the shortcomings associated with the conventional contact can be significantly overcome. It is expected that there will be much smaller change in the calculation of both contact force and reaction direction with the new contact. In addition, a penetrating slave node can be found in early stage. Therefore, large penetration can be avoided. Accordingly, the contact stiffness, or SLSFAC, should have less effect on the contact force calculations. Numisheet'93 u-channel was used again to demonstrate this advantage of smooth contact. In this study, three cases were used. Case A uses the conventional contact with initial coarse blank mesh and mesh adaptive option; case B uses smooth contact, initial coarse blank mesh and mesh adaptive option; and case C with smooth contact and initial fine mesh without mesh adaptivity. Three values of SLSFAC were used: 0.1, 0.05, and 0.01. The results are shown in Table 2. It is seen that, with conventional contact, the predicted springback angle changes significantly from 4.4 degree to 11.0 degree. While the prediction for the cases using smooth contact, as shown in cases B and C, is more stable. From this study, it is seen that the springback predictions have become much less dependent on SLSFAC. The predicted contact force (punch force) also becomes very smooth, which is shown in Figure 4. Some small oscillations still exist when the mesh adaptivity is used, as seen in Case B.

Table 2 Effect of SLSFAC with smooth contact on springback predictions

SLSFAC	0.1	0.05	0.01
Case A	4.4	5.4	11.0
Case B	16.4	17.0	19.4
Case C	21.3	20.9	20.6

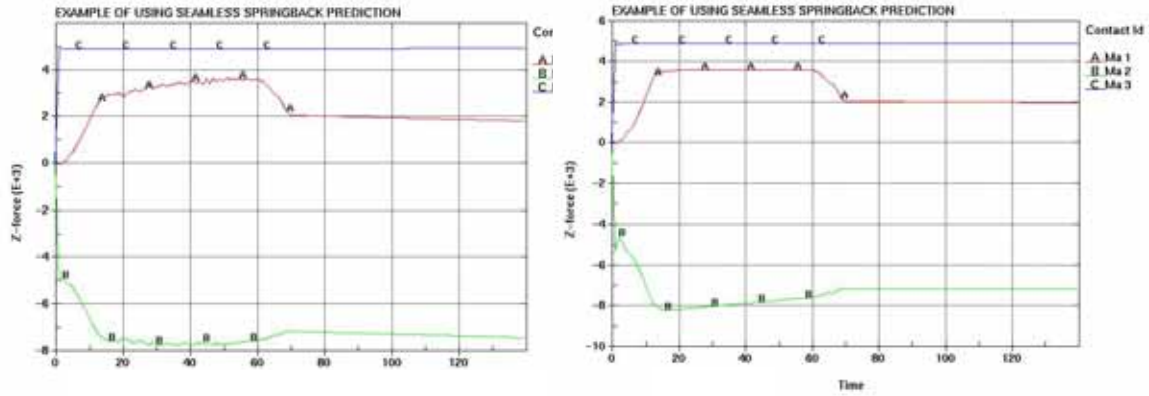


Figure 4 Effect of smooth contact on contact force

To further validate smooth contact, an industrial production part was studied: Numisheet'05 Automotive Underbody Cross Member, as shown in Figure 5. Two calculations were performed: with and without smooth contacts. It is seen that with smooth contact, the contact force is much smoother than that by using conventional contact, as shown in Figure 6.



Figure 5 Numisheet'05 Automotive Underbody Cross Member

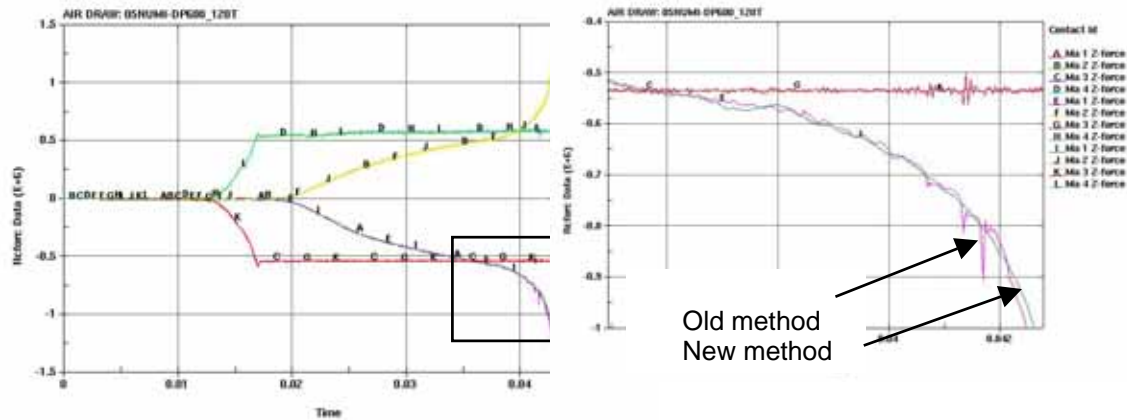


Figure 6 Contact force with and without smooth contact (Automotive Underbody Cross Member)

From the above calculations, smooth contact has been shown to be more accurate and can reduce user-dependent predictions.

Due to the extra calculations required for smooth contact, it usually takes ten to twenty percent more CPU time to perform a forming simulation.

Conclusions

The proposed surface fitting algorithm is robust; it can nicely fit surfaces from different kind of rigid body meshes. With smooth contact, the noises in penetration calculation can be significantly reduced, and the predicted contact force becomes more accurate. As a result, the contact stiffness has much less effect and springback prediction accuracy can be improved. It is expected that user-dependent error can be minimized with this new option.