Shells with thickness stretch in LS-DYNA

Introduction

Thickness stretch is of considerable importance in problems involving finite thickness strains, contact and surface loads in nonlinear shell applications. As an example, in sheet metal forming applications, the presence of normal stresses in thickness direction improves the accuracy of the solution and also its response on the double-sided contact zone between dies and sheet.

There have been several attempts to account for the through-thickness deformation in the literature, this implementation is inspired by the articles and .

The Belytschko-Tsay shell element is one of the fastest elements for thin shell simulations. This, together with its robustness, is the reason why it is popular in finite element codes. The implementation of the current shell with through thickness is based on the formulation of the Belytschko-Tsay shell with a relaxation of the thickness variable. This ensures that it will be efficient and hopefully also possess properties useful for applications where through thickness deformation is important. A fully integrated version of this shell was implemented by suitably modifying element type 16 (fully integrated Belytschko-Tsay). To make the element suitable for crash analysis a modification was made that decouples the thickness degrees of freedom between elements. This is an option for these new shell elements.

Theory

The kinematics, i.e., position and velocity, of the shell with through thickness stretch can be written in local coordinates as

$$
\begin{aligned}
x_i &= (x_{iI} + s_I \delta_{i3}) N_I(\xi_1, \xi_2) \\
v_i &= (v_{iI} + s_I e_{ij3} \omega_{jI} + \dot{s}_I \delta_{i3}) N_I(\xi_1, \xi_2)
\end{aligned}
$$

where we have set

$$
s_I = \frac{\xi_3}{2} t_I + (1 - \xi_3^2) q_I
$$

The kinematics is based on the Belytschko-Tsay shell with the additional feature that the thickness is variable. The thickness variable is represented by t_I and an additional strain variable q_I to allow for a linear strain through the thickness. The latter is important to avoid "Poisson locking" in bending modes of deformation. The other variables and parameters are

$x_{iI} = i$: th component of coordinate of node I

$v_{iI} = i$: th component of translational velocity of node I

$\omega_{jI} = j$: th component of rotational velocity of node I

$e_{ijk} =$ permutation tensor

$N_I =$ shape function localized at node I

$\delta_{i3} =$ Kronecker delta

$\xi_i = i$: th component of the parental coordinate ranging from -1 to 1

From these expressions, the kinematics of the element can be derived in a straightforward manner, keeping in mind that the thickness variables are not fixed as in other shell formulations.

For the single point integrated shell element, two additional hourglass modes appear related to the thickness degrees of freedom. These are restrained by adding an artificial stiffness proportional to the elastic properties of the material used.

For the fully integrated shell element, the kinematics are adjusted appropriately in order to avoid spurious locking phenomena. The approach taken is to suitably modifying the fully integrated shell element (type 16) in LS-DYNA which has turned out to be successful.

Moreover, an option is added to make the thickness field discontinuous across element edges in order to make the element suitable for crash analysis where the geometries are complicated enough to induce locking for the default shell. For the single point integrated shell element, the thickness is constant in the element whereas for the fully integrated element the thickness is bilinear in the element. For stamping problems where the reference geometry is just a flat sheet, any of the two options are applicable.

When penalty contacts are used, double sided contact are handled in that the normal contact force induces a generalized force on the thickness degrees of freedom that results in thinning of the shell. This is one of the unique features with this shell formulation.

Usage

The `*SECTION_SHELL` keyword should be used as follows

Card 2

Variable	SECID	ELFORM	SHRF	NIP	PROPT	QR/IRID	ICOMP	SETYP
Type	I	I	F	F	F	F	I	I
Default	None	0	1.0	2	0.0	0.0	0	1
Remarks		1						

Card 3

Variable	T1	T2	T3	T4	NLOC	MAREA	IDOF	
Type	F	F	F	F	F	F	I	
Default	0.0	0.0	0.0	0.0	0.0	0.0	1	
Remarks							2	

with the following information of the ELFORM and IDOF variable

ELFORM	Element formulation option, see Remarks below EQ.25: Belytschko-Tsay element with thickness stretch. EQ.26: Fully integrated assumed strain element with thickness stretch.
IDOF	Option to decouple thickness field EQ.1: Thickness field is continuous (default) EQ.2: Thickness field is discontinuous

<u>Remarks:</u>

1. Element types 25 and 26 allow through-thickness stretch. With these options the user can define additional scalar nodes, see *NODE_SCALAR, for each node connected to an element of this type. Moreover, to connect these extra nodes to the elements, the option *ELEMENT_SHELL_DOF should be used for each of these elements. The purpose of the scalar nodes is to hold the extra degrees of freedom associated to the thickness deformation of the shell. If the user omit defining these extra nodes, LS-DYNA will define them automatically but the user cannot prescribe conditions on these nodes.
2. By default the thickness field is continuous between elements. For complicated geometries, such as T-intersections, this tends to lock up the structure. For such cases the user should decouple the thickness degrees of freedom by putting IDOF=2. This is crucial in order for the element to be useful in crash analysis.

References

1. M. Bischoff and E. Ramm, Shear deformable shell elements for large strains and rotations, Int. J. Numer. Methods Eng. 40 (1997) 4427-4449.
2. R.P.R. Cardoso and J-W. Yoon, One point quadrature shell element with through-thickness stretch, Comput. Methods Appl. Mech. Engrg. (in press).