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TRANSFORMING PCOMP TO PSHELL

1. INTRODUCTION

NASTRAN uses PCOMP cards usually combined with MAT8 cards to define composite materials. The PCOMP cards are internally converted to PSHELL+MAT2 cards by using the equivalent properties for membrane, bending, out of plane shear and membrane-bending coupling.

Although the way to define the PCOMP cards is more straightforward once the lay-up is defined, the PSHELL+MAT2 cards offer the possibility to manipulate each term and allow the user to implement some especial features on the model. For example a pure membrane behavior without bending stiffness can be defined, or the coupling between membrane and bending can be removed in asymmetric laminates.

For these reasons sometime is very useful to use the PSHELL combined with MAT2 to define the composites. But, the problem is to transform the easily defined PCOMP card in the complex PSHELL+MAT2 cards.

2. THEORETICAL BACKGROUND

The force flows of the shell elements are related with the strains and curvatures of the elements by the A,B and D matrices in the following way:

$$\begin{Bmatrix} n_{xx} \\ n_{yy} \\ n_{xy} \\ m_{xx} \\ m_{yy} \\ m_{xy} \end{Bmatrix} = \begin{bmatrix} A & B \\ B & D \end{bmatrix} \cdot \begin{Bmatrix} \varepsilon_{xx} \\ \varepsilon_{yy} \\ \varepsilon_{xy} \\ k_{xx} \\ k_{yy} \\ k_{xy} \end{Bmatrix}$$

Where:

n: Force flows (N/mm)
m: Moment flows (N)
A,B,D: Stiffness matrices of the laminate
ε: Strains of the laminate
k: Curvatures of the laminate

Membrane:

The matrix [A] relates the force flows with the strains on the laminate in absence of curvatures (membrane behavior):

$$\begin{Bmatrix} n_{xx} \\ n_{yy} \\ n_{xy} \end{Bmatrix} = [A] \cdot \begin{Bmatrix} \varepsilon_{xx} \\ \varepsilon_{yy} \\ \varepsilon_{xy} \end{Bmatrix}$$

If the equation above is divided by the thickness of the laminate:

$$\begin{Bmatrix} \sigma_{xx} \\ \sigma_{yy} \\ \sigma_{xy} \end{Bmatrix} = \frac{1}{t}[A] \cdot \begin{Bmatrix} \varepsilon_{xx} \\ \varepsilon_{yy} \\ \varepsilon_{xy} \end{Bmatrix}$$

Therefore the MAT2 of the membrane behavior (MID1 field) will be:

$$[MID1] = \frac{1}{t}[A]$$

Using a Z0 on the PCOMP card or using an offset on the shell elements will not change the [A] matrix neither the relations stated on the equation above.

Bending:

The matrix [D] relates the moment flows with the curvatures on the laminate in absence of neutral axis strains (pure bending behavior):

$$\begin{Bmatrix} m_{xx} \\ m_{yy} \\ m_{xy} \end{Bmatrix} = [D] \cdot \begin{Bmatrix} k_{xx} \\ k_{yy} \\ k_{xy} \end{Bmatrix}$$

This expression can be rewritten as:

$$\begin{Bmatrix} \sigma_{xx} \\ \sigma_{yy} \\ \sigma_{xy} \end{Bmatrix} \frac{\frac{t^3}{12}}{\frac{t}{2}} = [D] \cdot \begin{Bmatrix} \varepsilon_{xx} \\ \varepsilon_{yy} \\ \varepsilon_{xy} \end{Bmatrix} \frac{1}{\frac{t}{2}}$$

Simplifying and re-ordering:

$$\begin{Bmatrix} \sigma_{xx} \\ \sigma_{yy} \\ \sigma_{xy} \end{Bmatrix} = \frac{12}{t^3}[D] \cdot \begin{Bmatrix} \varepsilon_{xx} \\ \varepsilon_{yy} \\ \varepsilon_{xy} \end{Bmatrix}$$

Therefore the MAT2 of the membrane behavior (MID2 field) will be:

$$[MID2] = \frac{12}{t^3}[D]$$

Using a Z0 on the PCOMP card will change the [D] matrix (because the bending stiffness will be calculated taken into account a different offset of the center of gravity of the section regarding the nodes location) but it will not change the relation stated on the equation above. The offset on the shell elements will not change the [D] matrix or the equation above.

Out of Plane Shear:

The following matrix relates the out of plane (or transverse) shear stresses with the shear deformations on a single ply:

$$\begin{Bmatrix} \tau_{13} \\ \tau_{23} \end{Bmatrix} = \begin{bmatrix} G_{13} & 0 \\ 0 & G_{23} \end{bmatrix} \begin{Bmatrix} \gamma_{13} \\ \gamma_{23} \end{Bmatrix}$$

When the matrix is rotated an angle θ the following expression can be applied:

$$\begin{Bmatrix} \tau_{xz} \\ \tau_{yz} \end{Bmatrix} = \begin{bmatrix} \cos(\theta) & -\sin(\theta) \\ \sin(\theta) & \cos(\theta) \end{bmatrix} \begin{Bmatrix} \tau_{13} \\ \tau_{23} \end{Bmatrix}$$

$$\begin{Bmatrix} \gamma_{xz} \\ \gamma_{yz} \end{Bmatrix} = \begin{bmatrix} \cos(\theta) & -\sin(\theta) \\ \sin(\theta) & \cos(\theta) \end{bmatrix} \begin{Bmatrix} \gamma_{13} \\ \gamma_{23} \end{Bmatrix}$$

$$\begin{bmatrix} \cos(\theta) & \sin(\theta) \\ -\sin(\theta) & \cos(\theta) \end{bmatrix} \cdot \begin{Bmatrix} \tau_{xz} \\ \tau_{yz} \end{Bmatrix} = \begin{bmatrix} G_{13} & 0 \\ 0 & G_{23} \end{bmatrix} \begin{bmatrix} \cos(\theta) & \sin(\theta) \\ -\sin(\theta) & \cos(\theta) \end{bmatrix} \begin{Bmatrix} \gamma_{xz} \\ \gamma_{yz} \end{Bmatrix}$$

$$\begin{Bmatrix} \tau_{xz} \\ \tau_{yz} \end{Bmatrix} = \begin{bmatrix} \cos(\theta) & -\sin(\theta) \\ \sin(\theta) & \cos(\theta) \end{bmatrix} \begin{bmatrix} G_{13} & 0 \\ 0 & G_{23} \end{bmatrix} \begin{bmatrix} \cos(\theta) & \sin(\theta) \\ -\sin(\theta) & \cos(\theta) \end{bmatrix} \begin{Bmatrix} \gamma_{xz} \\ \gamma_{yz} \end{Bmatrix}$$

The material stiffness matrix for each ply is calculated as:

$$[m]'_i = \begin{bmatrix} \cos(\theta) & -\sin(\theta) \\ \sin(\theta) & \cos(\theta) \end{bmatrix} \begin{bmatrix} G_{13} & 0 \\ 0 & G_{23} \end{bmatrix} \begin{bmatrix} \cos(\theta) & \sin(\theta) \\ -\sin(\theta) & \cos(\theta) \end{bmatrix}$$

When combining all the ply matrices to get the equivalent laminate matrix the contribution of each ply on each direction is different because the tangential stress distribution through the thickness is very complex for laminated composite materials. For homogeneous materials this distribution is simpler (parabolic with a 0 value at the outer faces). The parabolic distribution on homogeneous materials leads to use a ratio of equivalent thickness of 5/6 for transverse shear (which is the mean value of shear stress calculated integrating the shear stress through the thickness).

The way to combine all these ply matrices is very complex. You can find the formulation at the Reference manual of NASTRAN >> Additional Topics >> Composites >> Transverse Shear Theory

You can neglect this out of plane shear stiffness using a 0 value for the MID3 field of the PSHELL if MID2 field has been filled (If MID2 field is not entered MID3 must be blank). In fact, this is the usual situation because the out of plane shear flexibility is typically ignored. The PCOMP is usually combined with MAT8 cards that normally do not have G1Z and/or G2Z defined. This implies that the out of plane shear stiffness is infinite and therefore any transversal deformation will be only due to bending.

Using a Z0 on the PCOMP card or using an offset on the shell elements will not change the out of plane shear stiffness at all.

Membrane-Bending Coupling:

The membrane bending coupling is the effect of bending generated by membrane loads. This happens when any of the centers of gravity of the cross section of the laminate is not at the midplane of the laminate (asymmetric laminates, PCOMPS with Z0). When this takes place, some eccentricity is included on the laminate and bending deformations are created with axial loads (and reciprocally some axial loads can result from the application of bending moment).

The MID4 field of the PSHELL is used to represent this behavior.

The [B] matrix of the laminate expresses the coupling as:

$$\begin{Bmatrix} n_{xx} \\ n_{yy} \\ n_{xy} \end{Bmatrix} = [B] \cdot \begin{Bmatrix} k_{xx} \\ k_{yy} \\ k_{xy} \end{Bmatrix} \; with \; (\{\varepsilon\} = \{0\})$$

Or:

$$\begin{Bmatrix} m_{xx} \\ m_{yy} \\ m_{xy} \end{Bmatrix} = [B] \cdot \begin{Bmatrix} \varepsilon_{xx} \\ \varepsilon_{yy} \\ \varepsilon_{xy} \end{Bmatrix} \; with \; (\{k\} = \{0\})$$

In this case obtaining the material matrix is more complex because the strains distributions are more complex (axial + bending). The final result is that:

$$[MID4] = -\frac{1}{t^2}[B]$$

The sign minus is due to the way the plies are entered on the PCOMP card (from lower to upper face) which is the contrary criterion to the one implemented on the programs commonly used (including PATRAN) to calculate the coupling matrix [B].

Using a Z0 on the PCOMP card will change the [B] matrix (because the bending-axial coupling will be calculated taken into account a different offset of the center of gravity of the section regarding the nodes location) but it will not change the relation stated on the equation above. The offset on the shell elements will not change the [B] matrix or the equation above.

3. TRANSFORMING PCOMPS TO PSHELL+MAT2 ON NASTRAN

The way to carry out this transformation is very simple. Once the finite element model is available with the PCOMP cards on it (and their related MAT cards, usually MAT8) the ECHO command on the case control shall be set to punch:

ECHO=PUNCH

In order to accelerate the model run, all the subcases can be removed from the NASTRAN input since the only purpose of this run is to replicate the model. The finite element model now can be run and a punch file (with extension .pch) will be created. This file contains all the cards that NASTRAN has read from the input file. About the end of the punch file the conversion of the PCOMP cards is summarized (you can look for the ID of the PCOMP to search one specific card).

On this conversion the PCOMP cards are transformed in a PSHELL plus four MAT2 cards. Each MAT2 represents one of the four behaviors of the PSHELL properties (membrane, bending, transverse shear, and membrane-bending coupling). Each of the ID for the MAT2 generated is related with the corresponding field of the PSHELL card.

The transformation performed in the punch file (PSHELL+MAT2 cards) can directly replace the PCOMP definition of the original input file of NASTRAN. This replacement should not make any difference on the results obtained on the finite element model. Of course, all the stress or strains related with plies will not be available since converting the PCOMP into its homogeneous equivalent shell will miss the information related to the existing plies.

When using Z0 at the PCOMP the stress/strain recovery points of the equivalent PSHELL card will be modified to remain on the outer surfaces of the element.

Therefore the generated PSHELL and MAT2 cards can replace the definition of the PCOMP in the NASTRAN input file in the next runs allowing the user to manipulate the constants of the materials that define more directly the stiffness of the shell element.