LARGE DEFLECTIONS OF VARIABLE STIFFNESS COMPOSITE LAMINATES BY A HIGHER ORDER DEFORMATION THEORY

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Summary. Static deflections of laminated composite plates with curvilinear fibers are studied in the non-linear regime. Here, the fiber angle changes linearly with respect to the horizontal coordinate. A p-version finite element, which is derived following third-order shear deformation theory (TSDT), is employed.

1 INTRODUCTION

The description of a plate response to static loads is of clear practical interest. In some practical situations, including in aeronautical structures, plates are subjected to transverse deflections around or larger than their thickness. Here, the plate experiences geometrically non-linear behaviour and the linear solutions have no application. In these cases, to have a more stiffened plate or to better account for a non-uniform stress state, laminated plates could be designed using curvilinear fibers instead of straight ones. Here, without incurring weight penalties, the deflection can be optimized by tailoring the fiber angles of different layers.

Higher order shear deformation theory provides for, in many situations, an accurate way of modeling laminated panels. It is, for example, used in Ref. [1] to find the deflections of a laminated plate with straight fibers. But the appearance of automated tow-placement technology turned easier the use of laminates with curved fibers (variable stiffness composite laminates-VSCL), which may have advantages over straight fiber laminates. The design of these plates requires a structural analysis that can be carried out with h-version finite element methods [2]. However, the p-version finite element method is known to provide accurate results with relatively reduced models [3]. In the following paper, the authors employ a new p-version FEM to analyze variable stiffness composite laminates deflections in the non-linear regime.

2 VSCL P-VERSION PLATE FINITE ELEMENT

In this section, a p-version finite element with hierarchical basis functions for thick laminated plates will be presented. The plates are rectangular with width \( a \) and length \( b \). To have a VSCL plate, curvilinear fibers with the angle in the \( k^{th} \) layer of laminate as

\[
\theta^k(x) = 2(\tau_1 - \tau_0) |x| / a + \tau_0
\]

are used where \( \tau_0 \) and \( \tau_1 \) are orientations of the fiber at the centre and edge of the plate. One can see a CSCL and a VSCL plate in the Fig. 1.
3 RESULTS AND DISCUSSION

Results obtained here are in good agreement with the results of other publications. Using VSCL yields to a change in the deflection of the plate, as one can see in Table 1. Here a three-layer square plate with length 0.5 and thickness 0.005, subjected to a uniform load of 0.1 MPa is analyzed. Plate properties are as CSCL-1 (0,90,0), CSCL-2 (45,-45,45), VSCL-1 (\(<\pi/6, \pi/4, -\pi/6, -\pi/4, \pi/6, \pi/4\>) , VSCL-2 (\(<\pi/6, 0, -\pi/6, -\pi/4, -\pi/6, 0\>) , VSCL-3 (\(<0, \pi/4, -\pi/6, 0, -\pi/4\>) , and VSCL-4 (\(<0, \pi/6, -\pi/6, 0, -\pi/6\>)). In this case, the smallest deflection is found for the CSCL-1 plate, while for another three, VSCL-1, 3, and 4 have deflections smaller than the CSCL-2. A comprehensive investigation of the non-linear deflection of VSCL vs. CSCL will be presented in the full paper.

<table>
<thead>
<tr>
<th>Materials</th>
<th>CSCL-1</th>
<th>CSCL-2</th>
<th>VSCL-1</th>
<th>VSCL-2</th>
<th>VSCL-3</th>
<th>VSCL-4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deflection</td>
<td>1.1096</td>
<td>1.3399</td>
<td>1.3763</td>
<td>1.1383</td>
<td>1.2818</td>
<td>1.1744</td>
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</tbody>
</table>

Table 1. Maximum deflection of variable and constant stiffness composite laminated plates.

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