

# Numerical analysis of laminated shells under in-plane axial compression

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The authors of the paper present numerical stability analysis of axially compressed laminated shells. The analysis is carried out by using the commercial code NX-Nastran and authors' own program. In both cases the Equivalent Single Layer approach is adopted, in which the laminated shell is treated as an orthotropic single layer panel with the resultant stiffness calculated for the multilayered cross-section. Since the distribution of displacement in the thickness direction is assumed to be linear (First Order Shear Deformation), the shell kinematics is consistent with the Reissner-Mindlin type theory.

## 1 Introduction

Laminated shells are typical light structures, sensitive to the loss of stability. Critical load depends on such aspects like slenderness, boundary conditions, imperfections and lamination scheme. The simplest method enabling to evaluate the critical load level is the Linear Eigenvalue Problem (LEP). However, if the structure undergoes large deformations in the pre-buckling range, this approach is insufficient. Therefore the geometrical nonlinearity must be taken into account and the incremental analysis must be carried out. The authors analyse the stability of multilayered cylindrical shell panels in both mentioned ways by using of commercial code NX-Nastran and authors' own program SHELL [1]. In NX-Nastran the structure is discretized with 4-node flat finite element (QUAD4), while in the SHELL program the 8-node doubly curved element is applied. The composite finite shell element formulation used in both programs bases on the Equivalent Single Layer concept. The kinematics of the shell is consistent with the Reissner-Mindlin type theory. As an illustrative example the numerical study of cylindrical shell panel subject to axial compression is presented, as analysed earlier by Becker et al. [2].

## 2 Numerical example

The behaviour of considered shell was examined experimentally (see [2] for details). The geometry of the shell is shown in Figure 1. All layers have equal thickness and are made of T300/5208 graphite-epoxy composite ( $E_1=20.5 \cdot 10^6$  psi,  $E_2=1.3 \cdot 10^6$  psi,  $G_{12}=0.75 \cdot 10^6$  psi,  $\nu_{12}=0.335$ ). The total thickness of the shell is  $t=0.04$  in. The panel is fixed (CC) in the top and bottom stiff plate and simply supported (SS) along straight edges. Since the compressive load is applied to the top plate, the rigid movement of the top edge is provided. Three lamination schemes are studied, namely: cross-ply  $(90/0)_{2s}$ , quasi-isotropic  $(90/\pm 45/0)_s$  and angle-ply  $(\pm 45)_{2s}$ .

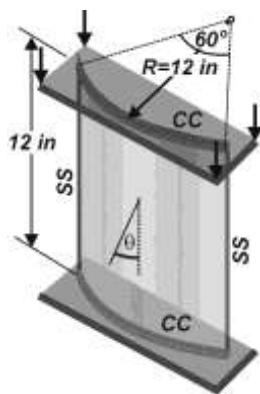


Fig. 1 Geometry of the shell.

Figure 2 presents the equilibrium paths (axial displacement vs. compression load) obtained for quasi-isotropic and angle-ply shells together. The load is normalized according to the formula  $P=P_{act} \cdot L / (t^3 \cdot E_1)$ , where  $L$  stays for the length of the panel and  $P_{act}$  is the actual load. For comparison purposes, the lowest critical load as calculated with linear eigenvalue problem is displayed in Fig. 2. The lay-up changes remarkably the behaviour of the structure even in the pre-buckling range. The quasi-isotropic shell behaves linear up to the critical point, thus the maximum load level obtained in nonlinear static agrees with

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the first critical force (LEP). This cannot be observed in the case of angle-ply shell. Some quantity differences between nonlinear solutions, especially in post-buckling range, given by NX-Nastran and SHELL can be explained by using of different finite elements in two programs. It is worth noticing, that the 8-node element is more suitable for modelling the curved geometry of cylindrical panel.

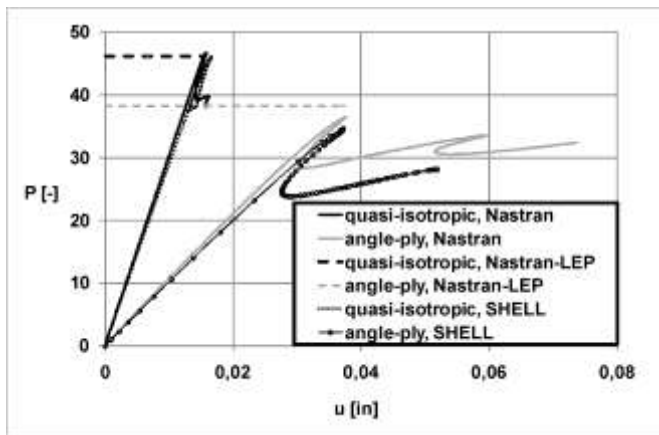


Fig. 2 Present results.

The influence of boundary conditions on the structure response for the cross-ply shell is illustrated in the Figure 3, where additionally the experiment results are provided for a comparison purposes. The acronym BC1 indicates the original boundary conditions, as shown in Figure 1, while BC2 are almost the same conditions as BC1 but in this case the rotation about the tangent to the top curved edge is restrained. There are big discrepancies between the experimental path and numerical solutions calculated with NX-Nastran and STAGS-C [2] with BC1 conditions. It should be mentioned, that the algorithm of STAGS-C was not able to analyse the perfect shell, thus the geometrical imperfection was introduced to the model, what explains the difference between critical loads evaluated numerically. It is very surprisingly that the discrepancy between the experiment and numerical solutions occurs just at the beginning of the path. One can suppose that there are some errors in input data for numerical models. According to the detailed report of a very similar experiment described in [3], some rotation of the top plate during the test was possible, i.e. the parallelism of the top and bottom plate was not provided. To check the influence of this phenomenon, the BC2 conditions were assumed in the model in NX-Nastran. This changed the path rapidly and in the authors' opinion the BC1 conditions, assumed in [2], were 'too perfect'. However, it is obvious that in reality the rotation of the top plate was not completely free, as assumed in the BC2 case, but it was rather partially constrained. This can explain why the critical load level observed during the experiment was higher than that calculated for the BC2.

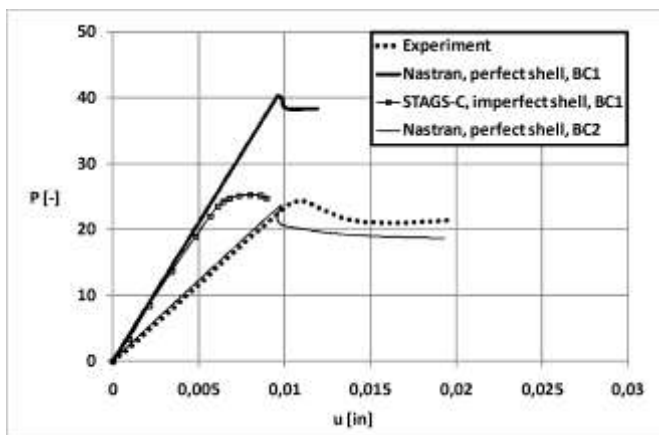


Fig. 3 Influence of boundary conditions - cross-ply shell.

## References

- [1] I. Kreja, R. Schmidt, and J. N. Reddy, *Int. Journal Non-Linear Mechanics* **32**, 1123-1142 (1997).
- [2] M. L. Becker, A. N. Palazotto, and N.S. Khot, *AIAA* **18**, 739-744 (1981).
- [3] N. L. Bauld and N.S. Khot, *Compt.&Struct.* **15**, 393-403 (1982).