Nonlinear buckling analysis of structures using a novel reduced order model

†*Ke Liang, Qin Sun

School of Aeronautics, Northwestern Polytechnical University, Xi'an 710072, PR China

*Presenting author: k.liang@nwpu.edu.cn
†Corresponding author: k.liang@nwpu.edu.cn

Abstract

Isogrid-stiffened structures have been extensively applied to aerospace engineering as lightweight and highly efficient structural component. In this work, the buckling behavior of isogrid-stiffened cylinder is analyzed by the smeared stiffener based reduced-order modeling method accurately and efficiently, considering both the geometrical and material nonlinearities.

The previous reduced-order modeling method, termed the original Koiter-Newton(KN) method, has been approved to be a numerically accurate and computationally efficient algorithm to trace the nonlinear equilibrium path in a stepwise manner, especially in the presence of buckling. In each step, this method works by combining a nonlinear predictor and a few Newton iteration-based corrections. Although the predictor is obtained from the reduced order model(ROM), corrections to the exact equilibrium path rely exclusively on the full model.

In this work, we firstly extend the method such that the reduced order model can be used also in the correction phase. This significantly reduces the computational cost of the method. As a side product, the method has better error control and more robust step size adaptation strategies, benefiting from the corrections applied in each solution step of the ROM. Then, the Koiter-Newton reduced-order modeling method, which was originally only applicable to geometrical nonlinear problem, is further extended for small scale yielding case. A computing strategy for a simplified elastic-plastic study is implemented into the predictor-corrector procedure in the path-tracing of structural response. Finally, the smeared stiffener method proposed based on mechanical characteristics of isogrid-stiffener cell is applied to facilitate the finite element modeling of structure. The reduced order model is constructed based on Koiter's asymptotic expansion and the smeared stiffener model. The material nonlinearities are considered both in construction of reduced order mode and in calculation of residuals.

Numerical results validate the good performance of the proposed method in buckling behavior study of isogrid-stiffened cylinder. We observe that the smeared stiffener model predicts the buckling load and mode very well, compared to the discrete stiffener model. We demonstrate that only 5 numerical steps are applied for the proposed method to trace the structural response satisfactorily up to the maximum load-carrying capability, compared to more than 100 steps used in full nonlinear analysis. We achieve almost the same values of lower bound of buckling loads in imperfection sensitivity analysis using three different geometric imperfection shapes. We notice that more numerical steps (8 steps) are needed for the proposed method, when the material yielding occurs near the buckling load. We conclude that the yield strength is not reached near the buckling load when the imperfection amplitude is less than a certain value. We stress that the material-nonlinearity effect which reduces the

buckling capacity of structure should be taken into account, when the material yields before buckling appears.

Keywords: Isogrid-stiffened cylinder; Reduced order model; Small scale yielding.

References

[1] Liang, K., Abdalla, M., Gurdal, Z. (2013) A Koiter-Newton approach for nonlinear structural analysis, *International Journal for Numerical Methods in Engineering* 96(12), 763-786.

[2] Liang, K., Ruess, M., Abdalla, M. (2014) The Koiter-Newton approach using von Karman kinematics for buckling analyses of imperfection sensitive structures, *Computer Methods in Applied Mechanics and Engineering* 279(1), 440-468.

[3] Liang, K., Abdalla, M., Sun, Q. (2018) A modified Newton-type Koiter-Newton method for tracing the geometrically nonlinear response of structures, *International Journal for Numerical Methods in Engineering*, 113(10), 1541-1560.