6th European Conference on Computational Mechanics (ECCM 6)
7th European Conference on Computational Fluid Dynamics (ECFD 7)
11-15 June 2018, Glasgow, UK

REDUCED-ORDER MODEL AND ADJOINT SENSITIVITY ANALYSIS FOR GEOMETRICALLY NONLINEAR TOPOLOGY OPTIMIZATION PROBLEMS

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Keywords: *Reduced-Order Model, Adjoint Sensitivity Analysis, Geometrically Nonlinear Topology Optimization*

In structural topology optimization (TopOpt) the computational burden is mainly found in the finite element analysis (FEA) of the physics of the problem, conducted in each design iteration. Reduced-order models (ROMs) have been employed in linear settings to reduce the computational cost [1, 2]. In the linear setting, the generation of a basis for the ROM commonly relies on design perturbations generated as a consequence of the (iterative) optimization procedure. Moreover, a consistent formulation for adjoint sensitivity analysis is required to reduce the computational cost. If geometrically nonlinear behaviour is taken into account, the numerical solution of the equilibrium equations typically requires an incremental-iterative procedure [3, 4]. In fact, reduced-order modelling was initially used to alleviate the computational burden in the incremental-iterative nonlinear analysis [5]. However, ROM concepts have not been extended to either the analysis or the optimization algorithms in geometric nonlinear topology optimization problems.
In this research, an effective ROM and four adjoint sensitivity analysis options are proposed and investigated for geometrically nonlinear TopOpt problems. In the analysis stage, we use the solution vectors of the first few load increments to construct the ROM basis. Thereafter, the full-order model (FOM) is projected onto the subspace spanned by the basis, and the incremental-iterative procedure is continued with a reduced set of degrees of freedom and the corresponding reduced tangent stiffness matrix. Moreover, the basis can be updated adaptively based on a non-projected error criterion. For topology optimization, we present four options for calculating the sensitivities. The first option corrects the ROM with the FOM, and performs a standard full-order adjoint sensitivity analysis. The second option formulates the adjoint sensitivities based on the ROM in a consistent manner. The third option directly uses the approximate solution in the standard full-order adjoint sensitivity analysis, assuming that the equilibrium of the FOM is achieved. The last option ignores the derivatives of the reduced basis vectors in the consistent formulation and calculates approximate adjoint sensitivities. The implementation is tested on two geometric nonlinear TopOpt examples, and the accuracy and efficiency of the ROM and the sensitivity analysis options are compared with the standard FOM

procedure. The numerical tests demonstrate the flexibility of the ROM and four adjoint sensitivity analysis options in the balance between accuracy and efficiency.

REFERENCES

[1] O. Amir, M.P. Bendsøe, O. Sigmund, Approximate reanalysis in topology optimization, *Int. J. Numer. Meth. Engng*, Vol. **78**, pp. 1474–1491, 2009.

[2] C. Gogu, Improving the efficiency of large scale topology optimization through on-the-fly reduced order model construction, *Int. J. Numer. Meth. Engng*, Vol. **101**, pp. 281–304, 2015.

[3] T. Buhl, C.B.W. Pedersen, O. Sigmund, Stiffness design of geometrically nonlinear structures using topology optimization, *Struct Multidisc Optim*, Vol. **19**, pp. 93–104, 2000.

[4] N.P. van Dijk, M. Langelaar, F. van Keulen, Element deformation scaling for robust geometrically nonlinear analyses in topology optimization, *Struct Multidisc Optim*, Vol. **50**, pp. 537–560, 2014.

[5] B.O. Almroth, P. Stern, F.A. Brogan, Automatic Choice of Global Shape Functions in Structural Analysis, *AIAA Journal*, Vol. **16**, pp. 525–528, 1978.