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Geometric nonlinear sensitivity analysis for nonparametric shape optimization under non-zero prescribed displacements

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ABSTRACT

Large number of design variables in nonparametric shape optimization brings a challenging demand for efficient and accurate sensitivity analysis methods. It is even more critical when nonlinearity is taken into account. The ultimate future goal is to use these methods for various large scale industrial shape optimization problems with different nonlinear analysis types.

This paper investigates geometric nonlinear sensitivity analysis under non-zero prescribed displacement loads which is a common setup for many industrial structural nonlinear problems. Firstly, the analytical sensitivity formula is derived in discrete form, where no further discretization steps are needed in implementation. Since the number of design variables is larger than the number of responses, adjoint method is utilized in the deduction. The sensitivity is finally expressed as the multiplication of adjoint variables, partial derivative of secant stiffness matrix with respect to design variables and equilibrium displacement vector.

Secondly, a straightforward procedure is designed to calculate sensitivities based on in-house finite element code, where a semi-analytical approximation of partial derivative of secant stiffness matrix is used. The procedure is verified with a cantilever beam example.

In commercial FEA code, the stiffness matrix information may not be accessible. To replace the finite difference of stiffness matrix in semi-analytical approximation, internal force results of nonlinear analyses of the structure under special designed load cases are used instead. The nonlinear analyses only need to be carried out on element level, which significantly reduce the computational efforts. This method is validated in a commercial FEA solver with the same

cantilever beam example.

Lastly, source of errors in the procedure is investigated. It is shown that, similar as in linear sensitivity analysis, a major error comes from the semi-analytical approximation due to the rigid “rotation” of elements. The technique to correct the error is also discussed.