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Efficient adjoint sensitivity analysis of isotropic hardening elastoplasticity via load steps reduction approximation

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Abstract:

Sensitivity analysis plays a key role in gradient-based shape optimization. In this paper, a highly efficient procedure for design sensitivity analysis of elastoplastic material with isotropic hardening rule is presented. Here, an adjoint variable method is employed, where the adjoint sensitivity formulation is derived from the discrete master equation, yield condition, and consistency condition. Due to history dependence of plasticity, adjoint variables must be solved via a stepwise backward procedure. Therefore, the computational cost increases in proportion to the number of load steps. To address this cost and improve efficiency, condensation rules are proposed to reduce the number of load steps in the sensitivity analysis based on properties of adjoint variables. The properties of adjoint variables and proposed condensation rules are all theoretically proven in this paper. The accuracy and efficiency of the proposed techniques are demonstrated using bar truss structures and solid structures in various complex load cases. The results show that the techniques significantly reduce the number of load steps required in the sensitivity analysis while keeping satisfying accuracy.

Keywords: sensitivity analysis, adjoint variable method, elastoplasticity, isotropic hardening, load steps reduction, gradient-based shape optimization

1. Introduction

Methods employed to solve shape optimization problems fall into two categories, i.e., gradient-based and non-gradient-based methods. Starting from an initial point, gradient-based algorithms iteratively search for an optimal solution according to sensitivity information, i.e. derivatives of responses with respect to design variables. While design parameters naturally translate to design variables in the parametric shape optimization approach, non-parametric shape optimization instead typically employs nodal coordinates in a finite element model as its design variables. This provides a detailed description of structural shape, thus significantly enlarging the design space much more so than in parametric optimization.

Sensitivity analysis for linear structural systems has been widely investigated, with numerous relevant successes in industrial applications. However, in practice, nonlinear structural behaviors occur equally if not more often than linear problems. The three types of nonlinearities are: geometric, material, and boundary condition nonlinearities. These nonlinearities may be encountered simultaneously or individually in large-scale engineering problems. Among the challenges in nonlinear sensitivity analysis, efficiency cannot be over emphasized. Firstly, given the characteristics of nonlinear problems, each sensitivity analysis maybe more complicated than corresponding linear cases, thus requiring more computation time and storage space. Secondly, the total number of sensitivity analysis in a nonlinear optimization procedure is greater than that in a linear optimization due to the increase in the number of iterations and possible need for