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A TIMP Method for Topology Optimization with Displacement and Stress Constraints in Multiple Loading Cases

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Abstract

This paper proposes a method of transplanting ICM ideas into material with penalization for the continuum structural topology optimization. The abbreviation of the method is TIMP, where TI represents Transplanting ICM (Independent Continuous and Mapping) Ideas, and MP is the latter half part of Solid Isotropic Material with Penalization (SIMP). It is well-known that the SIMP method is widely studied and used by internal and overseas researches. Since the filter function in ICM and the penalty function in SIMP are observed regarding to their similar formulations, the mathematical connection between the two methods yields analogies. Thus, several progresses in ICM are transplanted into SIMP for further developments, which yield to the TIMP method. There are two basic perspectives in TIMP: (1) weight and allowable stress penalty functions are added into SIMP besides the Young's modulus penalty function, and (2) design variables in TIMP are confined to the artificial material densities in SIMP. Therefore, TIMP method inherits all of the characteristics of SIMP method, and develops its theoretic system by analogizing ICM method.

In order to demonstrate the effectiveness and validity of TIMP, three concrete tasks are conducted. Firstly, an optimization model of minimizing weight with displacement constraints under multiple loading cases is constructed based on TIMP. The sensitivities of displacement constraints are obtained directly from the approximations by utilizing the unit virtual loading method. Secondly, an optimization model with stress constraints under multiple loading cases is constructed and converted into a model with global structural distortion energy density constraints by employing the stress constraints globalization approach. Based on the von Mises yield criterion, local stress constraints in a loading case are replaced with a single global distortion energy constraint. This addresses the difficulty of dealing with enormous constraints at once. Structural distortion energy and allowable distortion energy are identified and approximated with the element Young's modulus penalty function and allowable stress penalty function. Therefore, sensitivities of constraints are calculated for free. Thirdly, topology optimization models with displacement constraints and stress constraints are unified, and the nonlinear programming algorithm is used for solutions. The whole solution process is implemented automatically on ABAQUS software with Python scripts, and made into secondary development software.

Fours numerical examples are conducted on the secondary development software and the effects of linear and nonlinear element weight penalty functions on the convergence speed are studied and discussed. Fine results are obtained based on the proposed method. It is indicated that, TIMP method is efficient and valid for addressing topology optimization problems with displacement/stress constraints, and a nonlinear element weight penalty function yields higher convergence speed than a linear function.