Evolutionary Topology Optimization of Geometrically Nonlinear Continuum Structures

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Abstract
Using the method BESO (Bidirectional Evolutionary Structural Optimization), stiffness was maximized for geometrically nonlinear structures. A GUI (Graphical User Interface) was created to allow a quick setup of the optimization parameters. The usual linear formulation was extended to a more general case, where a linear-elastic material undergoes small strains but great displacements. A series of optimal structures were obtained and validated.

Key words: Topology Optimization, Nonlinear, BESO

Introduction
The optimization method BESO, together with FEM (Finite Element Method), was used to find optimal topologies for a chosen family of nonlinear problems. More specifically, continuum structures with linear-elastic material behavior, undergoing small strains but great displacements (geometric nonlinearity). For a given volume fraction of a set domain, the optimized topology defines a structure with maximized stiffness for the established loads and boundary conditions.

Results and Discussion
The main codes were developed in MATLAB but some computationally expensive sections may be executed by compiled files for better efficiency. The quality of results was evaluated with the simulation software ANSYS. A GUI was created to provide a friendlier way to define the domain, discretized mesh, boundary conditions and applied loads. This interface was initially developed to solve simpler problems, so that the methods' implementation could be easily validated. Therefore, stiffness maximization was firstly approached for Hookian structures undergoing small displacements and strains (linear problem). Subsequently, each method was extended to work in geometrically nonlinear conditions.

In order to take great displacements effects into account, higher order terms of the strain tensor must not be disregarded. By doing so, in the FEM implementation, strain measures no longer have a linear relation with nodal displacements. Thus, the matrix system has to be solved by an iterative procedure, such as the Newton-Raphson method.

New considerations are necessary for implementing the BESO method for nonlinear problems. The objective function has to be slightly altered, structures under force control and displacement control may behave differently so they should be treated separately. Computational cost is increased and convergence is harder to achieve. Because of those challenges when treating nonlinear problems, it was a sensible decision to focus this work only in two-dimensional structures in plane state of stress or strain.

An optimization domain defined and discretized on the GUI is shown on Figure 1. It corresponds to a simply supported beam with a vertical load applied on the top-central position. Here, the final volume is set to 40% of the domain's volume and the initial mesh has 6144 elements. Figure 2 shows the obtained optimized structure for those settings.

Conclusions
Many challenges arise when considering nonlinearities in structural analysis and topology optimization itself. A fair level of theoretical knowledge was needed to develop proper algorithms from general formulations. A GUI was created to facilitate user's interactions and the BESO method was implemented successfully. A number of particular cases were studied and different optimal structures were obtained. The results were validated by qualitative comparison with literature data and by quantitative comparison with results generated from ANSYS simulations.

Acknowledgement
I gratefully acknowledge the support of CNPq for promoting this work through a PIBIC scholarship.