10th World Congress on Structural and Multidisciplinary Optimization
May 19 -24, 2013, Orlando, Florida, USA

Topology optimization using the material density as a level set function.

L. F. Fernandez[1], P. Guarneri[1], G. Fadel[1]

[1]Clemson University, Clemson, South Carolina, USA, {luisf, pguarne, fgeorge}@clemson.edu

1. Abstract
Topology optimization has been applied to structural design problems for finding the best material distribution in a given domain. As it is accepted, the topology optimization problem is ill-posed because optimal designs tend to have infinite number of holes. In order to regularize the topology optimization problem geometrical constraint (e.g., perimeter), or topological constraint (e.g., number of holes) must be imposed. This paper present a methodology for optimal topologies with an imposed number of holes.
Level sets model material/void distribution through a level set function $\phi(\mathbf{x})$ assuming a value of a constant C, i.e., $\phi(\mathbf{x})=C$, at the boundary between the material ($\phi(\mathbf{x})>C$) and the void ($\phi(\mathbf{x})<C$). In this paper, finite element discretization is used and material densities in each element are considered as the design variables. Using the sensitivities and the characteristic function $\chi(\mathbf{x})$ of the current design configuration, a temporary density function $\phi^{NEW}(\mathbf{x})$ is updated through the steepest descent direction. The level set concept is applied to the updated density function $\phi^{NEW}(\mathbf{x})$ to define the material/void boundary, the characteristic function $\chi^{NEW}(\mathbf{x})$, for the next iteration. With this procedure, small densities are penalized, holes are easily created, material is conveniently added/removed, and every updated design has a 0/1 distribution.
If the design space is reduced to the elements in the boundary, this method results in a shape optimization procedure. Thus, shape optimization allows the movement of the boundaries towards optimal configurations. Combining topology and shape optimization, the number of holes in the optimal designs can be controlled. The number of holes can be obtained by the topology optimizer and the shape optimizer maintains the number of holes in the optimization process.
With these mathematical and physical concepts, structural topology optimization problems have been studied to show the effectiveness of the proposed method. 2D minimum compliance problems with volume constraints have been addressed and numerical tests have been performed. Optimal configurations for different number of holes were obtained. The proposed method is more efficient than traditional level set methods in terms of computational cost due to the use of a simple evolution equation. It can handle very general objective functions and the sensitivities with respect to the design variables can be conveniently computed.