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A formulation for multiple loading cases in plastic topology design of continua

Une formulation pour la conception topologique des milieux plastiques sous cas de chargement multiples

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A B S T R A C T

In the real life, most industrial structures are subject to multiple load cases. The present paper proposes a topology optimization formulation for multiple loading cases. It is based on the recently developed Direct Method of Limit Analysis for plastic topology Design (LADM). In this formulation, a single mathematical problem is considered to optimize structures under multiple loading cases; each case acts independently at a different time. For the continuous design problem, as in LADM, a unique iteration is considered. For the discrete, i.e. black and white, topology optimization problem, the same approach used in LADM is conserved with the use of a sequence of conic programming problems of the same form as the continuous design problem. The proposed method is illustrated with continuous and discrete example design problems. Examples with multiple loading cases confirm the conservation of the LADM features.

R É S U M É

Dans la vie réelle, la majorité des structures industrielles sont soumises à des cas de charges multiples. Le présent article propose une formulation pour l'optimisation de la topologie des structures soumises à plusieurs cas de chargement. Il est basé sur une technique récente développée en utilisant une méthode directe d'analyse limite pour la conception topologique des structures plastiques (LADM). Dans cette formulation, un seul problème mathématique est généré pour optimiser les structures soumises à des cas de chargements multiples, chaque cas agissant indépendamment à différents moments. Pour le problème continu, comme dans la LADM, une seule itération est nécessaire. Pour le problème discret, l'approche utilisée dans la méthode LADM est conservée, avec l'utilisation d'une séquence de problèmes de programmation de coniques de même forme que le problème de conception continue. La méthode proposée est illustrée par des problèmes

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continus et discrets. Les exemples de topologie avec plusieurs cas de chargement montrent la conservation des caractéristiques de la méthode LADM.

1. Introduction

Today, topology optimization techniques are highly demanded and used in the industry [1], and powerful dedicated software have emerged [2]. However, most of the work on the topology optimization of continuum structures was traditionally treated with elastic structures [2–6].

If the Solid Isotropic Microstructure with Penalization for intermediate densities (SIMP) [7] method is the most popular among the numerical FE-based topology optimization methods applied in industrial softwares [2], several other methods have been developed. Among the latter, stress-based topology optimization [8,9] represents a great interest for real applications.

According to Kiyono et al. [10], the topology optimization problem for stress design is still an open problem due to a number of difficulties.

One of these difficulties is the nonzero stresses in “void” regions; many solutions have been proposed to prevent this issue, such as the e-relaxation method, the qp-relaxation method, and the relaxed stress indicator method. Another difficulty is related to the high computational cost that reduces the efficiency of the optimization solver, and a third difficulty is related to the high nonlinear behavior of this problem, requesting an efficient and accurate optimizer. Another problematic issue is the presence of some intermediate material which requests a post-processing step, after which the stress value may increase.

In many industrial applications, the structure is loaded by Multiple Loading Cases (MLCs). Each of these loading cases acts independently at a different time. Frequently, these loading cases are completely independent of each other. And each case, when considered separately, can induce a totally different topology.

In the recent years, a great deal of research is carried out to extend topology optimization for elastic materials to the structures subject to multiple load cases (as in [11]). A review of those works is given in [12]. We can cite, for example, the work of Diaz and Bendse [13], who have extended the homogenization algorithm to MLCs. The majority of the algorithms for multiple loading cases can be solved by considering a weighted function on each load case as an objective function. Xie and Steven [14] extend the Evolutionary Structural Optimization to the MLC by considering a step-by-step optimization process. They took into account two different criteria for optimization: the extreme stress criterion and the weighted average criterion. Different results may be obtained by using one or the other.

On the other hand, as their maturity has been reached, an extension of the elastic approaches of topology optimization to elastoplastic analyses is expected. However, the high computational demands prevent this extension.

On the contrary, when only the information about the limit stress field is of interest, direct methods of limit analysis present an adequate alternative for plastic collapse analysis. Indeed, lower computational efforts are required to determine limit states in terms of stress field solutions.

Direct Method of Limit Analysis for plastic topology Design (LADM) is proposed and formulated in [15] and [16] for the minimum weight of continuum structures subject to a specified admissible loading.

The continuous topology design presented in [16] associates the optimization problem with direct limit analysis and treats them in a single mathematical programming problem. This allows the same order of magnitude of computational demand as a single static limit analysis problem. The microscopic approach [16] is used to formulate the design problem, and continuous material densities represent the design variables. The generated mathematical problem is a conic programming problem that presents interesting convergence properties, and prevents the difficulties that are commonly encountered in nonconvex elastic and elastoplastic topology design problems. Therefore, big problems can be treated in a relatively acceptable CPU time. Another consequence of convexity is the uniqueness of the optimum value and the fact that any optimum solution obtained is a global one. Moreover, by combining variable material densities with direct limit analysis, no numerical difficulties arise when densities vanish. So, we do not need to impose a finite lower bound on the density, as in continuum elastic design, to avoid singularities.

The presented work in [17] extends this method to the discrete, or black and white, topology design problem by applying a penalization scheme to the continuous one. The generated problem becomes non-convex, so it is treated by solving a sequence of continuous design problems. For the illustrative considered examples (taken from the literature), a comparison of the results of this method with those obtained by the elastic design methods shows (for the examples treated until now) a good agreement among the generated topologies, although there are large differences in the material behavior and the type of analysis. Moreover, it is shown that no checkerboard patterns appear with the direct methods of limit analysis for plastic topology design.

Throughout this work, based on [16] and [17], we will exploit the features of the LADM method to write a formulation that can give optimum topologies for a domain subject to multiple loading cases.