A heuristic approach to optimization of structural topology including self-weight

Katarzyna Tajs-Zielińska and Bogdan Bochenek

Institute of Applied Mechanics, Cracow University of Technology
Jana Pawła II 37, 31-864 Kraków, Poland
e-mail: Katarzyna.Tajs-Zielinska@pk.edu.pl
Bogdan.Bochenek@pk.edu.pl

Abstract

Topology optimization of structures under design-dependent self-weight load is investigated in this paper. This problem deserves attention because of its significant importance in engineering, especially nowadays when topology optimization is more often applied to design large engineering constructions like for example carrying systems of tall buildings. It is worth noting that well known approaches of topology optimization successfully applied to structures under fixed loads cannot be directly adapted to the case of design-dependent loads, so that this issue can be a challenge also for numerical algorithms. The paper presents the application of a simple but efficient non-gradient method to topology optimization of elastic structures under self-weight loading. The algorithm is based on Cellular Automata concept, application of which can produce effective solutions with low computational cost.

Keywords: topology optimization, self-weight, Cellular Automata

1. Introduction

The idea of topology optimization introduced by Bendsoe and Kikuchi [2] has been for a few decades one of the most intensively and thoroughly investigated fields of structural optimization. The nature of that approach is to find the optimal distribution of material within a design domain. The most common approach is the minimization of compliance of a structure subject to a total volume constraint while the structure loads are fixed. Much less common problem is topology optimization with design-dependent loads like for example thermo-elastic loads, surface pressure loads, centrifugal loads, and finally structural self-weight. Topology optimization of structures under design-dependent loads is very challenging because it cannot be treated as an extension of standard formulation of topology optimization under fixed load and therefore requires modification of known and well recognized approaches.

One of the first applications of topology optimization to structures under self-weight loading is discussed in [6]. There are two main issues observed and reported by the authors. First one is a non-monotonous behavior of the compliance. The second one is called parasitic effect which can be observed for low density regions when using a standard SIMP approach [1]. This effect enforces application of a new element stiffness update function (see e.g. [6] and [9]) or redefinition of the element density update model [7]. It is worth noting that in [6] another very interesting effect has been reported, namely unconstrained character of the optimum, what means that the volume constraint can be inactive for optimal topology. As far as the effect of self-weight impact on topological optimization is concerned the recently published paper [8] should also be mentioned.

This paper presents the application of a simple but efficient non-gradient method to topology optimization of elastic structures under self-weight loading. The algorithm is based on Cellular Automata concept, application of which can produce effective solutions with low computational cost.

2. Formulation of topology optimization problem

As already mentioned, the classical topology optimization problem is the minimization of structure compliance:

$$U(d_i) = d_i^p \mathbf{u}_i^T \mathbf{k}_i \mathbf{u}_i \tag{1}$$

where $\boldsymbol{u}_i$ is the element displacement vector and $\boldsymbol{k}_i$ is the element stiffness matrix. The objective is usually subject to a total volume constraint $V=\kappa V_0$, where κ is a prescribed volume fraction and V_0 is a design domain volume. The most effective, and the most common material interpolation scheme implemented in topology optimization problems is the power law approach known as SIMP - solid isotropic material with penalization

$$E_i = d_i^p E_0, \quad \rho_i = d_i \, \rho_0 \tag{2}$$

In (2) the elastic modulus E_i of each element is represented as a function of design variables being relative densities d_i of material ($0 \leq d_{min} \leq d_i \leq 1$), p is a penalization power, whereas E_0 and ρ_0 are the elastic modulus and density of a solid material, respectively. To avoid a parasitic effect reported in [6] the modification of standard SIMP method is necessary so that the material density ρ_i of each element is defined according to:

$$\rho_i = d_i^p \rho_0 \, . \tag{3}$$

3. Cellular Automata basics

The gradient-based mathematical programming algorithms are nowadays more often replaced by heuristic techniques like Cellular Automata (CA). The concept of CA is based on modelling behaviour of a complex systems by simple rules. The application of CA to structural optimization requires decomposition of a considered domain into lattice of cells states of which are represented by design variables d_i. The iterative process of evaluation of design variables values is governed by the local update rule defined as:

$$d_i^{(t+1)} = d_i^{(t)} + \left(\alpha_0 + \sum_{k=1}^{N} \alpha_k \right) m \tag{4}$$

In (4) quantities α_0 and α_k are components associated with a central cell and cells forming its neighbourhood. Their values are calculated based on comparison of values of compliance found for particular cells with the selected threshold value. The quantity m stands for a move limit. Numerous applications of proposed CA rule to optimization of structural topology of both plain and spatial elastic structures under fixed loads can be found in [3], [4] and [5].

4. Numerical example

Plane, elastic structure presented in Figure 1 is chosen to demonstrate the efficiency of the applied algorithm. Rectangular domain of width 16*a* and height 4*a* (where a = 1m) is discretized with regular mesh of 6400 elements. Applied material properties are as follows: Young modulus E = 1000 Pa, Poisson ratio ν=0.3, material density ρ = 1 kg/m^3. The volume fraction is set to be equal 0.5. The gravitational acceleration equals 9.81 m/s^2. First, the topology optimization procedure has been performed for a structure under self-weight only. The final topology is presented in Figure 2. The resulting compliance equals 121 Nm. For comparison, the same task has been solved using ANSYS topology optimization procedure, resulting in compliance of final topology equals 125 Nm. The next topology generation has been performed for a structure under both self-weight load and additional concentrated load which equals 100% of the self-weight. The final topology is presented in Figure 3. The resulting compliance equals 9536 Nm while the compliance of final topology obtained by ANSYS topology optimization procedure for the same structure equals 9635 Nm.

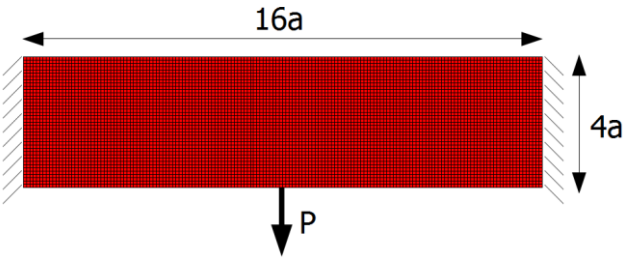

Figure 1: Initial structure. Loading and supports

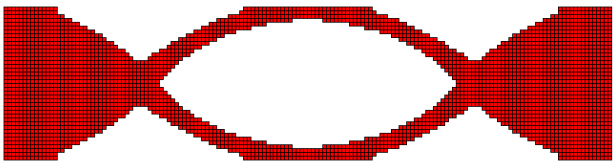

Figure 2: Final topology. No applied load, only self-weight

5. Concluding remarks

This paper presents application of heuristic method based on Cellular Automata concept to topology optimization of structures including self-weight loading. Obtained results validated by ANSYS topology optimization procedure demonstrate the efficiency and effectivness of the proposed approach. By adapting the modified element density update model so called parasitic effect has been avoided. Finally, one can observe that the obtained topologies are free from intermediate densities, so-called grey areas, without using any additional filtering.

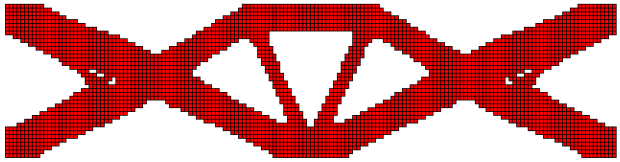

Figure 3: Final topology. P = 627.84 N, self-weight included

For comparison, the calculations for a concentrated external force without self-weight loading were performed and the final topology is presented in Figure 4.

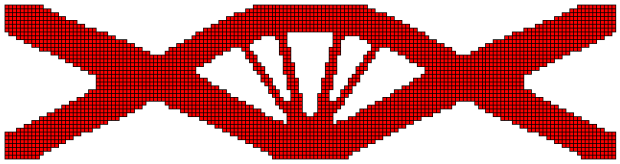

Figure 4: Final topology. P = 627.84 N, no self-weight

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