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Optimum Design for Nonlinear Problems Using Modified Ant Colony Optimization

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Abstract. A modified ant colony optimization algorithm is suggested for geometrically nonlinear problems. The objective of this study is to obtain a stable and robust optimal topology since ant colony optimization (ACO) algorithm might severely provide asymmetric stiffness matrix due to the characteristics of stochastic methods. In order to examine the applicability and effectiveness of the modified ACO, examples are compared with the solid isotropic material with penalization (SIMP) and bi-directional evolutionary structural optimization (BESO).

Keywords: Ant Colony Algorithm (ACO), Topology optimization, Geometrically nonlinear.

1. Introduction

Topology optimization has been applied for various linear structural problems so far [1-9]. However, when a very large load is applied or structural deformation is very large, materially nonlinearity or geometrically nonlinearity or both geometrically and materially nonlinearity may be occurred due to mechanical conditions. In order to obtain more useful and valuable optimal topology of a structure satisfying the given constraints, the above nonlinearities should be considered in analysis and design.

Recently, structural topology optimizations using ACO algorithm has been published by Kaveh [10]. The algorithm suggested a topology optimization technique for structural models to find the stiffest structure with a certain amount of material, based on the element's contribution to the strain energy.

In this paper, a modified algorithm based on ACO algorithm is suggested in topology optimization for geometrically nonlinear structural problems implemented with a filter scheme [11], and then the optimal topologies are compared with that obtained from the SIMP [12] and the BESO methods [13] to examine the effectiveness and applicability of the proposed algorithm.

2. Nonlinear Topology Optimization

2.1. Objective function for nonlinear topology optimization

Nonlinear topology optimization used complementary work as an objective function can be formulated as follows [14];

$$\begin{aligned} &\text{Minimize} \;:\; f(x) = W^{C} \\ &\text{Subjected to} \;:\; \text{equilibrium and } V_s \le \bar{V}_s \end{aligned} \tag{1}$$

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where, $\bar{V}_s$ is the target volume, V_s is a volume for the present topology. Complementary work can be expressed as the following;

$$W^C = \lim_{n\to\infty}\frac{1}{2}\sum_{i=1}^{n}\left(F_i^T - F_{i-1}^T\right)\left(U_i - U_{i-1}\right) \tag{2}$$

where, F_i and F_{i-1} are incremental load between i and $i-1$, respectively. U is the displacement vector, i is the incremental number of the load vector and n is the total number of load increments.

2.2. Sensitivity analysis for load constraint

Sensitivity for load constraint in nonlinear topology optimization [13] can be expressed as the following equation.

$$\frac{\partial f(x)}{\partial x_e} = \lim_{n\to\infty}\frac{1}{2}\sum_{i=1}^{n}\left[\left(F_i^T - F_{i-1}^T\right)\times\left(\frac{\partial U_i}{\partial x_e} - \frac{\partial U_{i-1}}{\partial x_e}\right)\right] \tag{3}$$

where, x_e means the design variable as a density variable for the *e*-th element. Sensitivity for the modified objective function can be expressed as follows;

$$\frac{\partial f(x)}{\partial x_e} = \lim_{n\to\infty}\frac{1}{2}\sum_{i=1}^{n}\left[\left(F_i^T - F_{i-1}^T\right)\times\left(\frac{\partial U_i}{\partial x_e} - \frac{\partial U_{i-1}}{\partial x_e}\right) + \lambda_i\left(\frac{\partial R_i}{\partial U_i}\frac{\partial U_i}{\partial x_e} + \frac{\partial R_{i-1}}{\partial U_{i-1}}\frac{\partial U_{i-1}}{\partial x_e} + \frac{\partial (R_i + R_{i-1})}{\partial x_e}\right)\right] \tag{4}$$

where, R_i and R_{i-1} are residual forces at the increment between i and $i-1$, respectively. λ_i is a Lagrangian multiplier.

3. Modified Ant Colony Optimization Algorithms

The main difference of ACO and modified ACO is to use pheromone as a continuous design variable instead of the positions of ants previously as a discrete design variable [10]. In nonlinear topology optimization, a quantity of pheromone $\Delta\tau_i^k$ can be written as;

$$\Delta\tau_i^k = \frac{\left(\Delta W_i^{C,k}\right)^\lambda}{\sum_{j=1}^{N}\left(\Delta W_i^{C,k}\right)^\lambda} \tag{5}$$

where, the exponent λ is a tuning parameter for improvement of performance of the algorithm and its convergence. In addition, reducing computation time for nonlinear finite element analysis is very important. The resized $\Delta\tau_i$ provides the improved effect of acceleration rate on convergence, and overcome numerical singularity occurred on the low-density region. A suggested rule can be expressed as follows;

$$\Delta\tau_i = \left(1 - \Delta\tau_{min}^{new}\right)\frac{\Delta\tau_i^{new}}{\Delta\tau_{max}^{new}} + \Delta\tau_{min}^{new} \tag{6}$$

where, $\Delta\tau_i^{new} = \sum_{k=1}^{m}\Delta\tau_i^k$, $\Delta\tau_{min}^{new}$ is 0.0001 and $\Delta\tau_{max}^{new}$ is The maximum value of pheromone trail at each iteration.

4. Numerical Examples

4.1. A clamped beam

A clamped beam having dimensions of 1.6 m × 0.2 m × 0.01 m is subjected to 30 N at the center of the bottom surface as shown in Fig. 1. The material is assumed to have Young's modulus of 30 MPa and

Poisson’s ratio of 0.3. The modified ACO algorithm is applied for linear and geometrically nonlinear topology optimization. The coefficients of modified ACO are defined as $\lambda = 2$. The objective is to obtain a stiffest structure under a volume constraint of 20% of the original volume.

Optimal topologies for linear and geometrically nonlinear cases of the modified ACO algorithm are shown in Fig. 2, respectively. Optimal topologies for the both cases of the SIMP method are shown in Fig. 3. The complementary works are calculated as 0.0639 J for the linear case, 0.345 J for the geometrically nonlinear case. The evolutionary history of iteration is shown in Fig. 4. It can be found that the objective function converges very stably.

4.2. A rectangular plate

A rectangular plate having dimensions of 2 m × 2 m × 0.01 m is subjected to 20 kN at the center of the plate as shown in Fig. 5. The material is assumed to have Young’s modulus of 20 GPa and Poisson’s ratio of 0.3. The coefficients of modified ACO are defined as $\lambda = 2$. The objective is to obtain a stiffest structure under a volume constraint of 20% of the original volume.

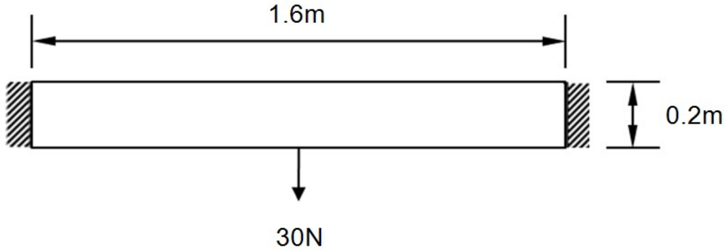

Fig. 1: Design domain of a clamped long beam

(a) Linear case (b) Geometrically nonlinear case

Fig. 2: Optimal topology using the modified ACO algorithm

(a) Linear case (b) Geometrically nonlinear case

Fig. 3: Optimal topology using the SIMP method

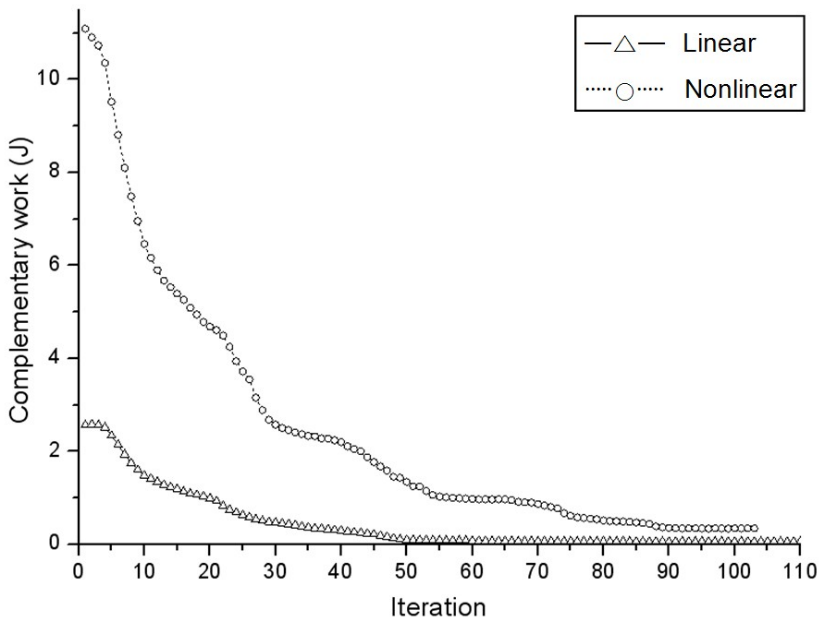

Fig. 4: Iteration histories of the complementary work of a clamped beam

Optimal topologies for linear and geometrically nonlinear cases of the modified ACO are shown in Fig. 6, respectively. Optimal topologies for the both cases of the BESO method are shown in Fig. 7. From comparisons of the results, the optimal topologies are quite similar each other. The complementary works are calculated as 15.35 J for the linear case, 66.344 J for the geometrically nonlinear case. The evolutionary history of iteration is shown in Fig. 8. It can be found that the objective function converges very stably.

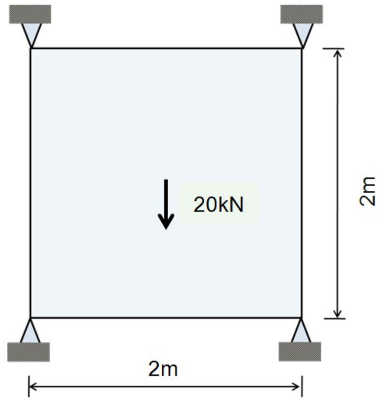

Fig. 5: Design domain of a rectangular plate


(a) Linear case (b) Geometrically nonlinear case

Fig. 6: Optimal topology using the modified ACO


(a) Linear case (b) Geometrically nonlinear case

Fig. 7: Optimal topology using the BESO method

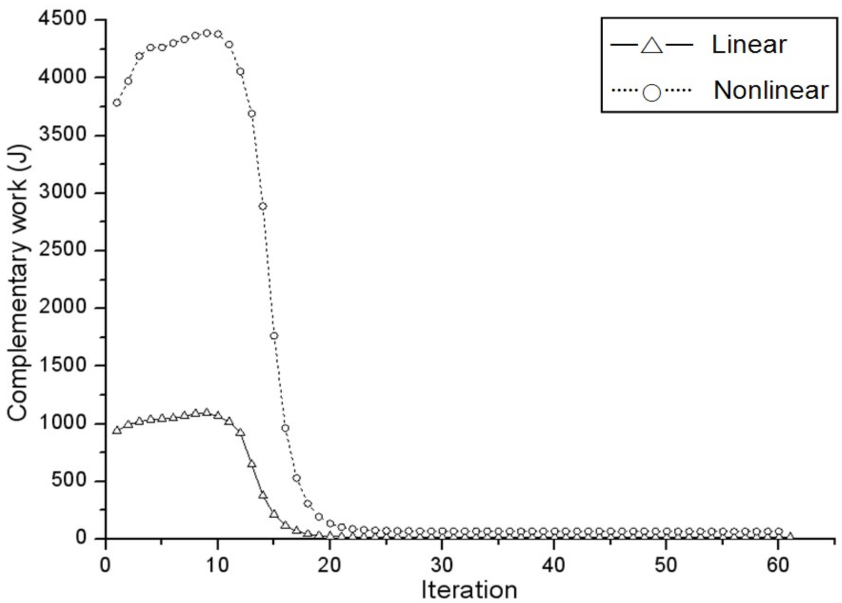

Fig. 8: Iteration histories of the complementary work of a rectangular plate

5. Conclusions

In this study, the modified ACO algorithm has been suggested for linear and geometrically nonlinear structural problems. From the results of examples, the following conclusions are obtained.

(1) It is verified that the modified ACO algorithm can successfully be applied for linear, geometrically nonlinear structures, and provides stable and robust optimal topology.

(2) The modified ACO algorithm is suggested for applying it for linear, geometrically nonlinear structures in order to obtain a stable topology since ACO algorithm might severely provide asymmetric stiffness matrix due to the characteristics of stochastic methods.

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