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COMPUTER PROGRAM FOR DIRECTED STRUCTURE TOPOLOGY OPTIMIZATION**

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ABSTRACT To compensate for the imperfection of traditional bi-directional evolutionary structural optimization, material interpolation scheme and sensitivity filter functions are introduced. A suitable filter can overcome the checkerboard and mesh-dependency. And the historical information on accurate elemental sensitivity numbers are used to keep the objective function converging steadily. Apart from rational intervals of the relevant important parameters, the concept of distinguishing between active and non-active elements design is proposed, which can be widely used for improving the function and artistry of structures directly, especially for a one whose accurate size is not given. Furthermore, user-friendly software packages are developed to enhance its accessibility for practicing engineers and architects. And to reduce the time cost for large time-consuming complex structure optimization, parallel computing is built-in in the MATLAB codes. The program is easy to use for engineers who may not be familiar with either FEA or structure optimization. And developers can make a deep research on the algorithm by changing the MATLAB codes. Several classical examples are given to show that the improved BESO method is superior for its handy and utility computer program software.

KEY WORDS bi-directional evolutionary structural optimization (BESO), continuum structures, computer program development, improved algorithm, directed structure topology optimization, portion construction design

I. INTRODUCTION

Topology optimization seeks to find a suitable layout for a structure while satisfying various constraints such as a given amount of material. It has attracted considerable attention in the last three decades for its limited material resources, environmental impact and technological competition. Various techniques have been developed for topology optimization, for example, the homogenization method[1], the solid isotropic material with penalization (SIMP) method[2] and the evolutionary structural optimization (ESO) method[3].

Of these, the bi-directional evolutionary optimization (BESO) method is one of the most popular techniques for topology optimization. This simple approach is based on the concept of slowly removing inefficient materials from structure and adding efficient materials at the same time so that the residual structure will evolve towards the optimum[4].

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However, mesh dependence and non-convergent solution are obvious drawbacks in the early versions of BESO. And some inefficient elements or key units might be needed for the aesthetic reasons or functions in practice. So, more robust and efficient evolutionary criteria are badly needed for complex and specific applications.

To overcome these problems, an improved BESO algorithm has been developed and implemented in a user-friendly software package for directed structure optimization and portion construction design of both 2D and 3D structures.

II. THE IMPROVED BESO

2.1. Stiffness Optimization Problems

Stiffness is one of the key factors which must be taken into account in the design of buildings or bridges. In fact, the mean compliance C is an inverse measure of the overall stiffness of a structure. So searching for the minimum mean compliance structure with a given volume of material is often considered in topology optimization. In BESO methods, the structure is optimized by removing and adding elements step by step to get the objective volume. Thus, the optimization problem with the volume constraint can be stated as

$$\begin{cases} \min \quad C = \dfrac{1}{2} F^{\mathrm{T}} U \\ \text{s.t.} \quad V^* - \sum\limits_{i=1}^{N} V_i X_i = 0, \quad X_i = X_{\min} \quad \text{or} \quad 1 \end{cases} \tag{1}$$

where F and U are known as the applied load and displacement vectors and C is the mean compliance. V^* and V_i are the prescribed total structural volume and the volume of an individual element. N is the total number of solid elements. The design variable X_i represents the soft element for $X_i = X_{\min}$ and the solid element for $X_i = 1$ in the system.

2.2. The Material Interpolation Scheme

In the troditional BESO method, the inefficient elements were directly delected ($X_i = 0$). However, the complete removal of a solid element from the design domain could result in numerical analysis difficulties in topology optimization. In fact, the way of irrational 0-1 alternative may cause stiffness matrix singularity, which will lead to inefficient or incorrect optimization. In steering the solution to nearly solid-void designs, material interpolation schemes have been widely used in the SIMP method[1]. To achieve a solid-soft design, an approximate function is given as

$$\begin{cases} E_i = E_0 + X_i^p (E_1 - E_0) \\ \rho_i = \rho_0 + X_i^p (\rho_1 - \rho_0) \end{cases} \quad X_i = X_{\min} \quad \text{or} \quad 1 \tag{2}$$

where E_i and ρ_i are known as the Young's modulus and density of the material. Young's modulus (E_0) and the density of soft elements (ρ_0) are much smaller than these (E_1,ρ_1) of solid elements and p is the penalty exponent. Since $X_{\min}$ is usually very small (e.g. 1×10^{-9}), the soft elements are structurally negligible and the topologies obtained are equivalent to the virtually 0-1 design. But, it is the soft elements that are able to effectively avoid the stiffness matrix singularity occurring in the process of topology optimization provided no change will take place in the global property.

2.3. The Improved Sensitivity Number

When a solid element is removed from a structure, the change in total strain energy is equal to the elemental strain energy[5]. So when the Poisson's ratios of materials are the same, the strain energy of the ith element ΔC_i can be defined as

$$\Delta C_i = \begin{cases} \dfrac{1}{2} \left(1 - \dfrac{E_0}{E_1} \right) U_i^{\mathrm{T}} K_i^1 U_i \quad \text{for solid material} \\ \dfrac{1}{2} \left[\dfrac{X_{\min}^{p-1} (E_1 - E_0)}{X_{\min}^{p-1} (E_1 - E_0) + E_0} \right] U_i^{\mathrm{T}} K_i^0 U_i \quad \text{for soft material} \end{cases} \tag{3}$$