The periodic structure topology optimization using improved genetic algorithm

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Abstract. This paper combine improved genetic algorithm with bi-directional evolutionary structural optimization algorithm to optimize structure in dual coding way. The new algorithm not only has solved the genetic algorithm (GA) problem which is easy to appear premature, but also has solved the bi-directional evolutionary structural optimization algorithm (BESO) problem which is easy to get a local optimal solution. In order to satisfy the constraints of the periodic structure, the design area is divided into the form of unit cells, and optimize the representative unit cell, other cells content repeat constraints. This paper optimize the typical periodic structure with the new method of topology optimization, and the optimization results show that the presented method is reliability and validity.

Introduction

Since the BESO method proposed [1], topology optimization of continuum structure has got rapid development. In practical engineering, Because of the lightweight and manufacturing simplicity requirements, periodic structure topology optimization is widely used in aviation, construction and other fields, so it has higher used value and more practical significance to study periodic structure topology optimization. Huang and Xie [2] used the method of BESO to optimize the periodic structure, based on it, this paper proposed the algorithm which is combining improved genetic algorithm with bi-directional evolutionary structural optimization algorithm (IGA-BESO) for topology optimization, which overcame the local optimal solution may occur in the BESO algorithm [3], but also overcome the GA premature problems in the optimization process. Examples prove that the proposed method has the reliability and validity.

The sensitivity analysis

In order to satisfy the periodic constraint conditions, this paper divide the design area into unit cells according to the number of constraints in all directions, and the whole design area is divided into m= m1×m2 same unit cells, as shown in figure 1.
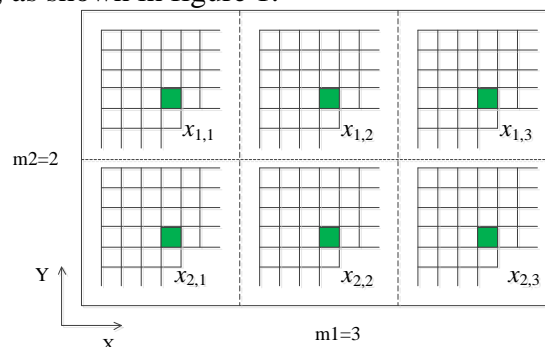

Figure. 1 The diagram of the unit cells in the periodic structure

This paper use the IGA - BESO method to minimize the structure compliance, and the structure topology optimization model building as shown in the formula (1).

In formula (1), C is the even compliance of the structure, F and U is the load and displacement

$$Minimize: C = \frac{1}{2} F^T U = \frac{1}{2} U^T K U = \frac{1}{2} \sum_{i=1}^{N} x_i^p u_i^T k_0 u_i$$

$$Subject\ to: V^* - \sum_{i=1}^{m} \sum_{j=1}^{n} V_{i,j} x_{i,j} = 0$$

$$x_{1,j} = x_{2,j} = x_{3,j} = \ldots = x_{m,j}$$

$$x_{i,j} = x_{\min}\ or\ 1$$

(1)

vector in the structure respectively, V^* is the target volume, $V_{i,j}$ is the volume of the jth element in the ith cell, $x_{i,j}$ is the density values of the jth element in the ith cell.

The periodic structure is optimized by the dual coding way in this paper, but only encode the element in the representative unit cell. On the macroscopic, 0 represent the absence of the element and 1 represent presence. On the microscopic,this paper endows individuals in representative unit cell with a certain string length of gene, according to the sensitivity of the element in representative unit cell, divide the element in different classes, then individual implement crossover and mutation in inter classes to update gene, add or delete material. In order to satisfy the constraints of periodic structure, different unit cell in corresponding location of unit cells should have the same sensitivity value and the density value. according to the formula (1), it can deduce the sensitivity of the elements in the representative unit cell, as shown in the formula (2). The sensitivity of element in representative unit cell should be assigned to other cells elements in corresponding location.

$$\alpha_j = \frac{dC}{dx_j} = \sum_{i=1}^{m} \frac{1}{2} x_{i,j}^{p-1} u_{i,j}^T K_{i,j} u_{i,j}$$

(2)

α_j is the sensitivity of the jth element in the representative unit cell, m is the number of the unit cells, p is the penalty factor, and its general values is more than 2.

Topology Optimization Process of IGA-BESO

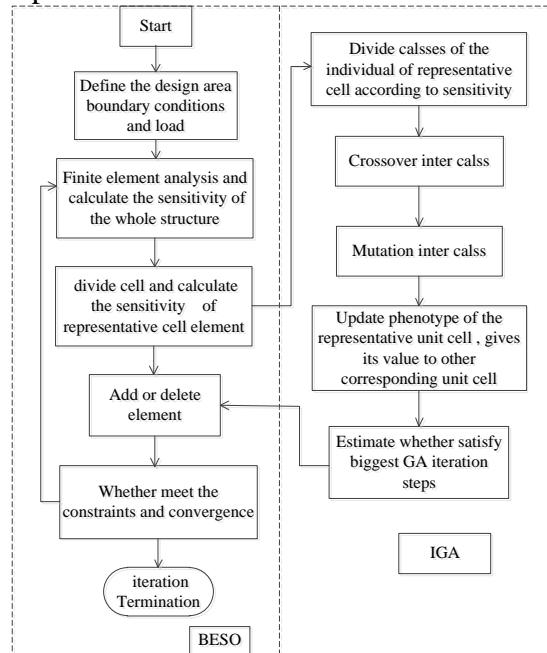The topology optimization process of the IGA-BESO method as follow figure 2.

Figure. 2 The topology optimization process of the IGA-BESO method

Calculation and result analysis
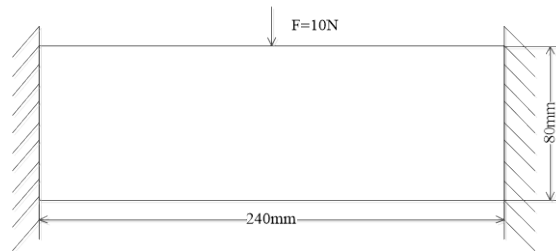
（1） 2D double side fixed beam

Figure. 3 Load and constraints of the double side fixed beam

As shown in the figure 3, the design area of the structure is a rectangular with 240mm×80mm, the degree freedom of X and Y directions is fixed at the left end and right end of the structure. A vertical concentrated load F=10N is applied at the center of the up face. The elastic modulus of materials is 100MPa. Poisson's ratio is 0.3. The volume constraint is 0.75. The filter radius is 10mm. Selected different unit cell numbers, optimization topology structure with the IGA-BESO method is shown in the table 1 below.

It can be seen from the table 1, the final optimization topology structure has a big difference when the cell number is different in the structure, and with the increase of the unit cell number, the topology structure is more and more complex. The number of unit cell is equal to the number of periodic constraint. Even compliance and total iteration steps of the two-dimensional double side fixed beam is shown in the following table 2.

As known form the table 2, with the increase of the unit cell number, the even compliance value of the structure is more and more large, because the more number of cell divided, the less element the representative unit cell contains, and it is more difficulty to search the optimal solution in the smaller range area, finally the optimal solution is worse.

Table 1 Optimal designs for 2D double side fixed beam under different constraints

$m_1=1$ $m_2=1$	$m_1=2$ $m_2=1$	$m_1=3$ $m_2=1$
$m_1=4$ $m_2=1$	$m_1=5$ $m_2=1$	$m_1=6$ $m_2=1$

The even compliance and the total iteration steps of the two-dimensional double side fixed beam is shown in the following table 2.

Table 2 The even compliance and the total iteration steps of the double side fixed beam

$m= m_1 \times m_2$	1×1	2×1	3×1	4×1	5×1	6×1
Even compliance(N·mm)	21.7663	22.1132	27.4181	27.2366	28.1845	28.4587
Total iteration steps	52	44	52	59	52	44

（2） two-dimensional sandwich structure
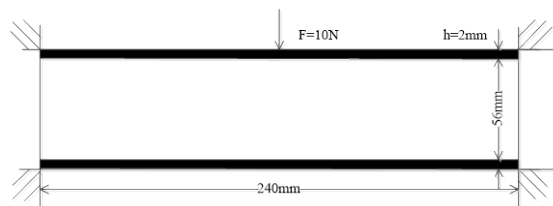
Fig. 4 Load and constraints of the two-dimensional sandwich structure

The load and constraints of the two-dimensional sandwich structure is shown in figure 4. The design area is 240mm×56mm, and the non-design area is 240mm×2mm. the design area is tied with

the non-design area, and both of them have the same material properties. The sandwich structure is fixed at the both ends of skins. A vertical concentrated load F =10N is applied at the center of the up face. The elastic modulus of structure is100MPa. Poisson's ratio is 0.3. The volume constraint is 0.45. Filter radius is 3mm. The design area is divided into different unit cells, and its final optimization structure is shown in the table 3 below.

Table 3 Optimal design for 2D sandwich structure under different constraints

$m_1=1$ $m_2=1$	$m_1=2$ $m_2=1$	$m_1=4$ $m_2=1$	$m_1=8$ $m_2=1$
$m_1=1$ $m_2=2$	$m_1=2$ $m_2=2$	$m_1=4$ $m_2=2$	$m_1=8$ $m_2=2$

It can be seen from the above table 3, when the number of unit cell is equal, the divided way is different at the same time, the optimization structure has a obvious difference. The even compliance and the total iteration steps with the IGA-BESO method of the two-dimensional sandwich structure is shown in the following table.

Table 4 Even compliance and the total iteration steps of sandwich structure

m= $m_1 \times m_2$	1×1	2×1	4×1	8×1	1×2	2×2	4×2	8×2
Even(N·mm) compliance	57.5976	74.3671	77.6122	92.2867	60.1098	77.7376	89.1814	99.1893
Total iteration steps	65	81	86	57	64	57	77	57

It can be seen from table 4, m=m1×m2=1×8 and m=m1×m2=2×4 have the same unit cell number, but their compliance have a big difference, this suggests that the latter form of cell division have more advantage to search the optimal solution.

Summary

It can get the following conclusion through the above analysis.

(1) IGA-BESO method can effectively conduct periodic structure topology optimization.

(2) The number of the unit cell and the divided way is different, the same structure have big difference in topology optimization.

(3) With the increase number of unit cell, the topology of the structure is more complicated and have higher compliance.

References

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