Designing of the optimal topology and nodes of truss using evolution strategy

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Abstract

The subject is a truss with any topology and any static external load. The aim of the paper is to design the optimal truss topology and determine the optimal stiffness of the nodal connections. The criterion of optimization is to minimize the use of material of the truss within the limits of strength and displacement. This will be achieved through an evolution strategy. The general way to solve the problem is illustrated in several examples.

Keywords: topology optimization, finite element method, evolution strategy.

1. Introduction

The problem of optimization of topology design of structures is an important issue from an engineering point of view. Allows for the most economical use of the material, in order to meet the endurance limits. In the case of truss structures, this problem was considered in the work of Burczyński and others [1].

In this paper, we search optimized distribution of rods and their cross-sections and we would like to define the optimum stiffness of nodes of the truss.

The study assumes a model of the truss nodes with a spring stiffness which is subject to optimization. Through this approach it is possible to more realistic and more engineering modelling of the steel truss, and also the more precise optimization.

2. Analysis of the problem

In this paper we confine ourselves to the analysis of truss structures made of isotropic and linear elastic material. We assume that the load is only in the plane of the truss. We assume also, that the displacements of material points of the truss will be small in relation to the dimensions of the truss.

At each point of the body we have to deal with the three components of stress (σ_x, σ_y, τ_{xy}). Other components of stress tensor do not lie in the plane of the truss, i.e. (σ_z, τ_{xz}, τ_{yz}) are in this case equal to zero. This situation is related to the plane stress assumption.

This problem will be impossible to solve by using exact analytical methods. The finite element method (FEM) will be used to find the displacements and stresses in the truss.

The issue of optimization of the structure is a numerically complicated. Therefore, to solve it, we use an evolution strategy. It allows us to find the global minimum objective function which is the aggregate amount of material of the truss.

3. Finite element method

For FEM calculations we will use rectangular finite element with 4-nodes (Figure 1). In every node we have 2 degrees of freedom: the two displacements (u, v) in directions perpendicular to each other. For this reason, a finite element stiffness matrix will have a size of 8x8.

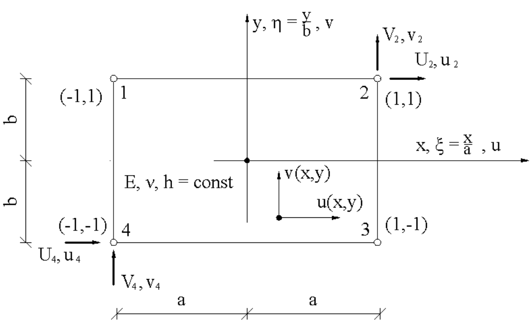

Figure 1: The finite element used in considerations

The derivation of stiffness matrix of finite element models we cite from the book [2].

Such acceptance finite element modelling will allow us to modelling elastic nodes of a truss as a structure in plane stress.

4. Evolutionary strategy

In this paper, it was decided to use one of the methods of artificial intelligence that is an evolutionary strategy [3]. The primary feature distinguishing evolutionary strategy from other evolutionary algorithms is a floating-point encoding genotype. In this paper we use the basic type of evolutionary strategy, i.e. strategy type (1,1). In this case we have only one individual and its mutations. Mutation can be variable in time, however, never occurs here crossing operator.

This method has many advantages when applied to the optimization problem which we analyzed. Primarily due to the presence of only one individual instead of the whole population is much faster than the simply genetic algorithm (SGA). In the analysis problem, where this algorithm will be linked to time-consuming FEM algorithm, it is a very important advantage. In addition, the lack of crossing operator allows us to further improve the algorithm. All these characteristics suggest an evolution strategy for its choice as the useful tool to optimize the topology of the truss.

In the current task a single individual will be an entire truss, and its genotype - the array of stiffness of individual finite elements of the rectangular area occupied by the truss. The objective function is the sum of the material from all the finite elements in the analyzed area (weight of the structure).

Optimization constraints arise from the need to fulfil strength condition anywhere in the truss, namely, that reduced stresses must be lower than the strength of the material.

In every generation we have a mutation consisting of decreasing or increasing the stiffness of selected number of finite elements (increase or decrease the value of one or more genes). Then, the resulting individual is evaluated for compliance to the stress limits and compared with the individual parent. An individual with a lower value of the objective function moves to the next generation.

5. The computer program

In order to solve the given problem, we made the computer program in development environment of MS Visual C++ 2008 Express Edition. It is designed to work in operating systems such as Windows XP, Vista and 7 (all versions).

After a specific external loads and support conditions, the program makes an automatic optimization of the topology of the truss and compute the state of displacement, strain and stress for analyzed structure. Data are entered into the program from the interface in a standard Windows dialog. During and after the process of computing, the results are presented in graphical and numerical way. It is also possible to write / read from the file of the results. The example of some results obtained from this program is presented on figure 2 and 3:

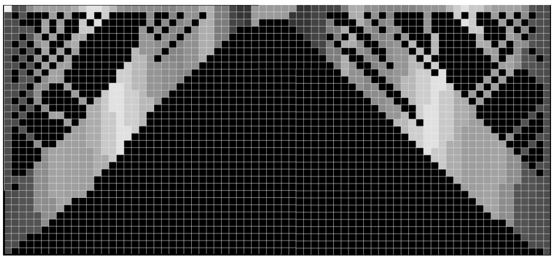

Figure 2: The example of the optimized topology of the truss: free support on left and right sides, homogenous load from top

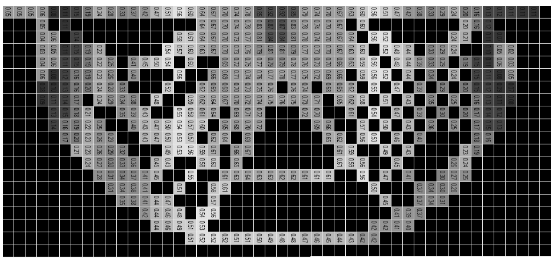

Figure 3: The example of the optimized topology of the truss: free support on left top and right top corner, concentrated force in the middle of the upper edge

6. Results and conclusions.

Using this program we resolved a few examples of optimization of trusses with various methods of support and with various external loading. The results were analyzed correctness, by using of engineering program Autodesk Robot Structural Analysis 2011.

As a result we made the following proposals:

1. The proposed method of artificial intelligence: an evolutionary strategy is suitable for the given considered optimization problem.

2. Obtained results allow to significantly reduce the use of the material in many engineering cases in relation to the current methodology.

3. The use of truss-reinforced nodes, in particular, the support nodes, allows for better optimization of the structure as a whole.

4. Numerical results of stresses and strains obtained by the program were comparable with those obtained using engineering program.

5. It is worth noting that the relatively easy to change the criterion of optimization (objective function). It's possible to use the same program to optimize a different problem (eg finding the maximum rigidity with minimum weight truss and many others). This will be the subject of further research work.

References

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