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Discrete Size Optimization of Indeterminate Truss Using HyperWork

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Abstract: **Cost and stability of any structure is an issue concerned to all structural designers. Cost of structure predominatelydepends on weight of the structure.This paper presents a procedure to optimize weight of plane indeterminate truss. The objective of optimization is to minimize total weight of the structure, subjected to stress and displacement constraints with cross sectional area of members as design variables. These design variables are discrete in nature, spread in a range with regular interval. In indeterminate truss, the optimization procedure becomes nonlinear because displacements are implicit function of design variables.And thus iterations are required to reach the best solution. Analysis toachieve optimal cross-sectional size of component members to attain minimum weight has been carried out using HyperWork software.The truss is modeled with two noded bar elements. In this paper, discrete size optimization of ten bar indeterminate truss having ten design variables is done and results are discussed.**

Keywords: **Size Optimization, Indeterminate Truss structure, Discrete variables.**

1. INTRODUCTION

Optimization is the act of obtaining the best result under given circumstances. In design, construction, and maintenances of any engineering system, engineers have to take many technological and managerial decisions at several stages. Optimization can be defined as the process of finding the conditions that gives the maximum or minimum value of a function. In other words optimization is the selection of a best element from set of available alternatives which satisfied certain criteria.

In the past decades, optimization has become a remarkable part of the structural design process, especially in the preliminary parts of the procedure [1]. From a number of different types of engineering structures, trusses are probably the most frequent one, which have been applied to test different optimization techniques since the early 1960.Structural engineers and designers, in the daily engineering praxis, require to design the cheapest possible structures with the minimum amount of material and technical equipment. The use of modern optimization methods thus becomes a great opportunity in the area of structural engineering.

Using genetic algorithm certain research work is carried out on discrete optimization of truss structure [2]. Comparison between genetic algorithm and classical technique of 3D trusses has been carried out [3]. The size, shape and topology of plane trusses have been optimized using genetic algorithm and finite element analysis in MATLAB [4]. For discrete member sizing optimization of steel truss structures, fully constrained design method has been developed [5]. The present work deal with sizing optimization of indeterminate truss has been carried out using software.

1.1 Optimization of truss

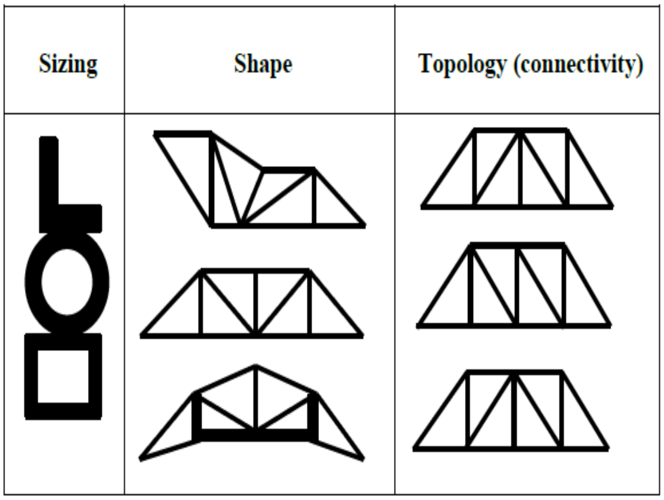

Fig. 1. Example of truss optimization [6]

The optimization of truss structures can be classified into three categories depending on which component of the structure is used as a design variable: 1) Sizing, 2) Shape and 3) Topology. The three variety of optimization[6] as shown in Figure 1. In sizing optimization cross-sectional area of the members are the design variables and the coordinates of the nodes and the connectivity of various members are fixed. However, in truss design problems, cross sections are considered discrete variables such that member cross-sectional areas are specific predefined values. In Shape optimization the design variables are the nodal coordinates, and in topological optimization the number of nodes and the connectivity between nodes are the design variables while nodal coordinates are assumed to be known. However, the most efficient design will be obtained by considering all three categories simultaneously.

As a result, traditional methods of optimization have not been appropriate for such problems and the use of nature inspired optimization techniques such as genetic algorithm (GA) is gaining popularity in the field of structural optimization. Although it becomes difficult to optimize in complex structures where variable interactions increase. Classical optimization methods can produce sub-optimal results because of these interactions [7]. In determinate truss, member forces are independent upon cross section area of the bar, i.e it is independent upon design variable. Therefore it is easy to optimize to optimize determinate truss. But in case of indeterminate truss, member forces are function of cross section area, also displacements are implicit function of design variable. Hence optimization procedure becomes nonlinear in case of indeterminate truss. To overcome this problem HyperWork software is useful. The complexity in indeterminate structure becomes quite easier in this software.

2. MATHEMATICAL FORMULATION OF TRUSS OPTIMIZATION

Weight optimization of truss structures involves optimizing cross sections A_i of the members such that weight of the structure W is minimized and certain design constraints are satisfied. The fitness function is given by expression

$$W = \sum_{i=0}^{n} \rho A_i L_i \quad (1)$$

Where L_i is the length of the i^{th} member, ρ is the specific weight of the material and A_i is the cross section area of the i^{th} member [8].

The problem is subjected to stress constrains

$$\frac{|\sigma_i|}{\sigma_{max}} - 1 \le 0 \quad (2)$$

And the upper limit of the nodal displacement in any direction

$$\frac{|u_j|}{u_{max}} - 1 \le 0 \quad (3)$$

Where σ_i stress in the i^{th} member is, σ_{max} is the permissible stress in member, u_j is displacement at j^{th} node and u_{max} is the displacement limit at joint.

2.1 Finite element analysis (FEA)

To obtain the constraints equation(stresses and displacements in the member) as function of design variable finite element analysis is required. Displacements in equation (3) have been carried out using finite element analysis.

$$[S]_s\{d\}_s = \{f\}_s \quad (4)$$

Where $\{d\}_s$ is displacement matrix of structure, $[S]_s$ is the global stiffness matrix, $\{f\}_S$ is force matrix. Global stiffness matrix in equation (4) is generated by assembling of all element stiffness matrix of truss element. After getting the displacement vector $\{d\}_S$, stresses in equation (2) can be carried out by using,

$$\sigma_i = E\varepsilon_i \quad (5)$$

Where ε_i is strain in the i^{th} member. Routine FEA procedure [8] is used here to find displacement and internalforces in structure.

2.2 Modeling in HyperWorks 13.0

HyperWorks solver technology includes finite-element-based linear and non-linear structural analysis and simulation capabilities (RADIOSS), thermal and fluid analysis (AcuSolve) as well as multi-body simulation (MotionSolve). Combined with design optimization technology and multi-physics capabilities, HyperWorks enables users to drive the product-development process and make reliable decisions based on high-quality results. With the HyperWorks 13.0 release, Altair continues a successful mix by adding new functionality to accommodate customer needs and latest research results, combined with usability enhancements and performance improvements by leveraging the latest computing technology.

In this software, truss is modeled with assemblage of two noded bar elements. At each node, degree of freedom is two and these are translation along x and y axis. Therefore there is no issue regarding connectivity between members. All joints are pin connected. The cross sections of all members of truss are independent upon each other.

3. NUMERICAL APPROACH

In Figure 2, the optimization problem of the 10 bar truss is depicted. The problem input data and constraints limits are given as follows, the weight density $\rho = 2.77 \times 10^3$ kg/m^3, Young's modulus E = 6.9×10^{10} N/m^2, allowable stress for all members $\sigma = \pm 1.72 \times 10^8$ N/m^2 the displacement limit of each joint in the vertical direction d= ± 60 mm, and truss loading condition is considered as $P_{2y} = P_{4y} = -4.45 \times 10^5$ N. Cross-sectional areas of members are to be adopted among the numbers in the range from 6.45×10^{-5} m^2 to 2.26×10^{-2} m^2 with an increment equal to 5×10^{-7} m^2.

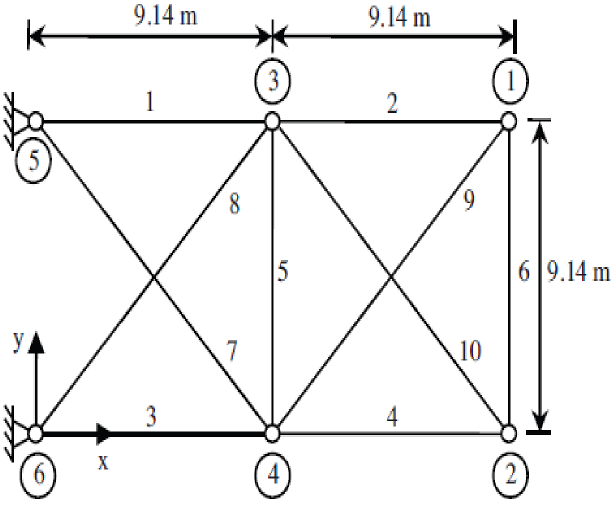

Fig. 2. The 10 bar truss problem structure

This problem is modeled in HyperWork software as shown in Figure 3. Initially the cross sections of all members are considered assame with the value of to 11309 mm^2. This will be the initial solution for size optimization. The cross section of each member is not related with each other. The lower bound and upper bound of design variable are 64.5 mm^2 and 22600 mm^2 respectively with increment of 0.5 mm^2. The axial stress constraints limits equal to $\pm 1.72 \times 10^8$ N/m^2 and displacement constraints limits equal to $\pm$ 60 mm in downward direction.

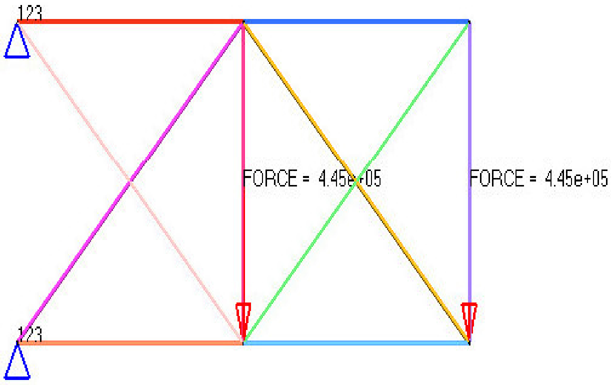

Fig. 3.The 10 bar truss in HyperWork software

The contour plot of axial stress at the end of iteration 0 and iteration 9 are shown in Figure 4. and Figure 5. respectively.

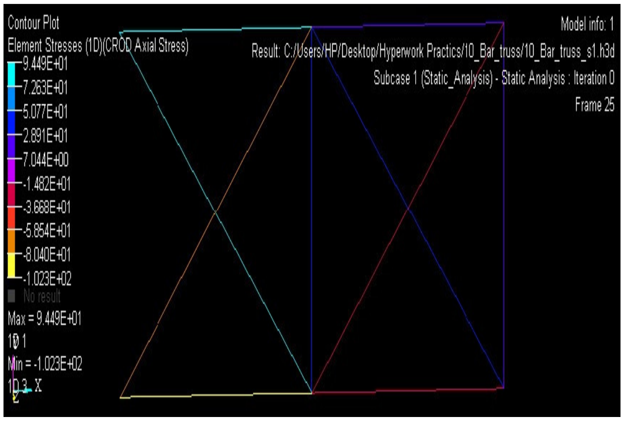

Fig. 4. Axial Stresses at iteration 0

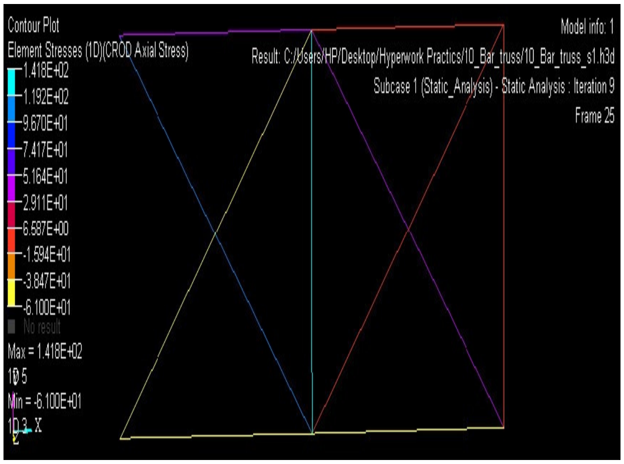

Fig. 5. Axial Stress at iteration 9

Also contour plot of displacement at the end of iteration 0 and iteration 0 are shown in Figure 6. and Figure 7 respectively.

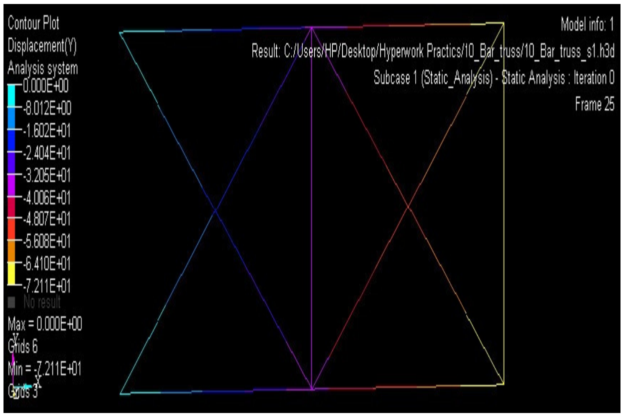

Fig. 6. Displacement at iteration 0

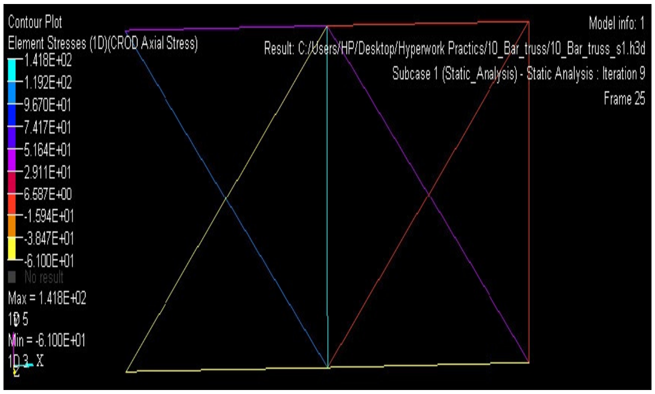

Fig. 7. Displacement at Iteration 9

At the end of 9th iteration, Optimization has converged and all constraints are satisfied. The optimum weight and displacement are carried out after ninth iteration and it is same as eighthiteration. It is shown in Figure 8. and Figure 9. Also convergence history is shown in Figure 10.

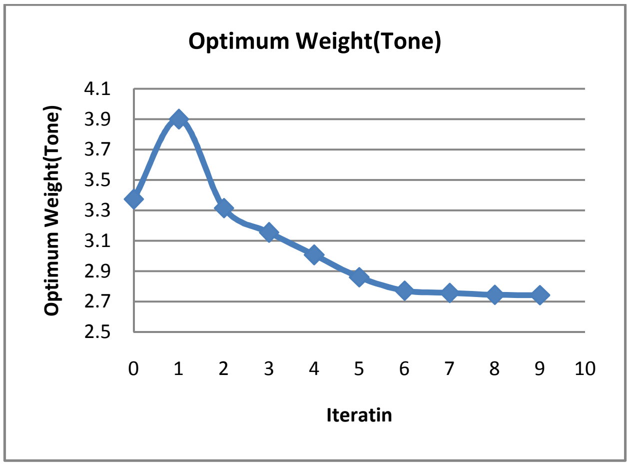

Fig. 8. Optimum weight in 10 bar truss

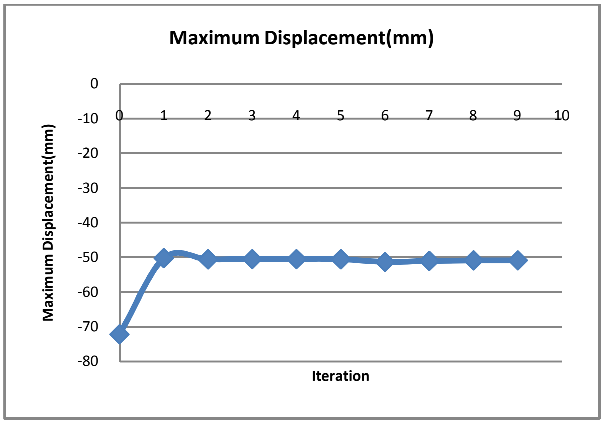

Fig. 9.Y Displacement (mm)

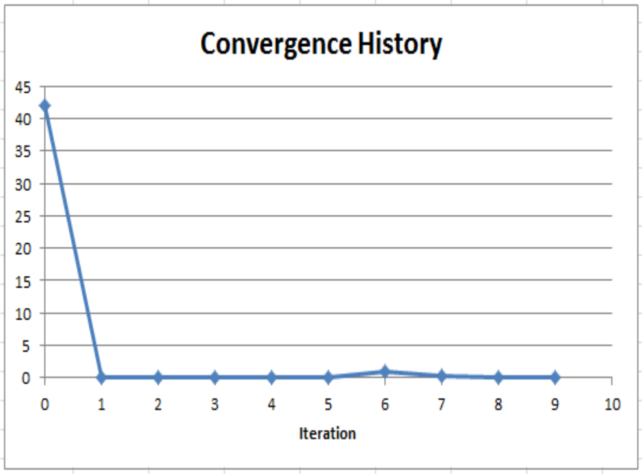

Fig. 10. Convergence history

Comparison between cross section area at the end of Iteration 0 and Iteration 9 is shown in Figure 11. The cross section areas of member 1 and member 3 have been increasedwhereas cross section areas of all other member have been decreased.

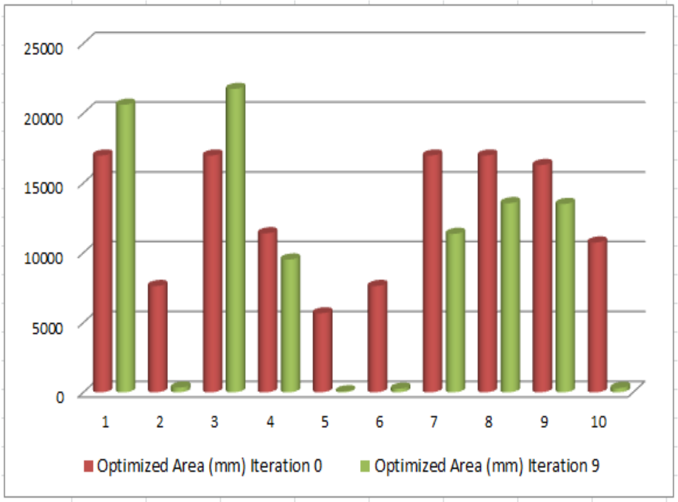

Fig. 11. Comparison between cross section area at the end of Iteration 0 and Iteration 9

4. CONCLUSIONS

In the present study, optimization technics for indeterminate truss has been studied using HyperWork software.An approach is proposed based on using cross section of the member as design variable and nodal displacements and stresses are constraints. The following conclusions are made.

1. Objective function for minimizing the weight is depends upon various parameters such as choice of design variable.

2. Appropriate optimization has to be selected depending upon optimization problem and number of design variable.

3. Result from last iteration optimization analysis has been saved by 18.6% compared to first iteration analysis.

4. Figure 8. Shows random selection of initial values of design variable has led in fluctuating convergence of weight. In the further iteration software has predicted the trend of convergence leading to monotonic test convergence ending at 9th iteration.

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