AM5450 - Project
Plane Truss Optimization using Genetic Algorithm

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1 Introduction

Trusses are common structures in construction due to their outstanding advantages in material saving and maximum utilization of structure load capacity. A truss is an assembly of bar elements when combined creates a rigid structure. For this study we try to analyze a simple planar truss which has all the members and the nodes lie in a single plane. All the members in truss take only tensile and compressive axial loads. Optimization of the truss structure is a problem of seeking best solution in preliminary design stage. Depending on the design variables, optimization problems are of three types: size optimization, shape optimization and topology optimization. In this study our focus is towards reducing the weight of the truss. In order to optimize the truss, we need to incorporate mathematical and mechanical analysis. This uses general Genetic Algorithm and finite elements method to evaluate behavior of the members. Both Finite element and Genetic Algorithm is implemented in MATLAB.

2 Problem Definition

Every structure should have to fulfill the structural and economic requirement. Hence there needs to be optimization of truss design to obtain minimum weight which leads to maximum structural efficiency. Redundancy is also major problem in trusses. In a redundant truss the number of members in it are more than that required in a perfect truss. Such trusses are also statistically indeterminate. The optimum design of a structure should satisfy various constraint limits such as displacement limits, stress and local stability conditions. As it is well known that the optimum shape of a truss depends not only upon its topology, but also upon the distribution of element cross-sectional areas. The support conditions and connection of members (bolting/welding) also affect the structural behavior. Although purlins are provided on truss joints but due to maximum purlin spacing limitations/field constraints, there may be a situation when purlins are provided on truss members

3 Approach

For this particular study, a 10-element planar truss is chosen which is shown in the figure 1. The construction and the study of stresses induced and nodal displacements are carried out by Direct stiffness method which is the most common implementation of the Finite element method. In applying the method, the system must be modeled as a set of simpler, idealized elements interconnected at the nodes. By implementing the above study stiffness matrix for the element can be calculated, and by doing matrix operations the global stiffness matrix can be obtained which helps us to find the elemental stresses and the nodal displacements.

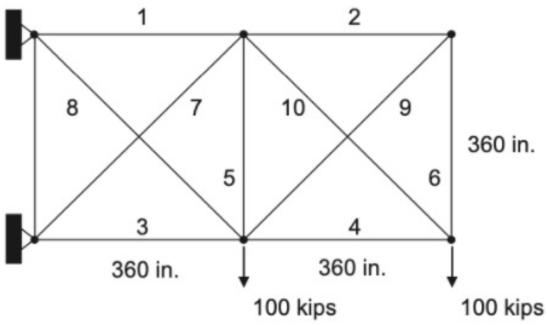


Figure 1: 6 Node 10 Element Truss

To optimize the weight of the truss, the cross-sectional area of the members needed to be adjusted based on the constraints that are going to be applied on the truss. Various constraints include nodal displacement, allowable stress in members and local stability constraints. In order to optimize the cross-sectional areas of the elements, we incorporate Genetic Algorithm.

3.1 Formulation of Objective and Constraints

The objective in our study is to minimize the weight, subject to the material properties/design constraints. They are formulated as follows:

Minimize F(A) where

$$F(A) = \sum_{i=1}^{n} A_i \rho_i L_i$$

Subjected to constraints,

$$\text{Stress Constraint - } |\sigma_i| - \sigma_i^{max} \leq 0$$

$$\text{Displacement Constraint - } |\delta_i| - \delta_i^{max} \leq 0$$

$$\text{Area Constraint - } A^{min} \leq A_i \leq A^{max}$$

3.2 Application of Genetic Algorithm

In this particular problem, there are a wide range of algorithms available for optimization and Genetic Algorithm is one among the few. The feasibility of genetic algorithm for this problem can be understood by the variation which is being randomly performed on the cross-sectional area of elements present in the truss. This algorithm starts with population generation which can be defined as set of chromosomes. The initial population which is the first generation is usually created randomly. Once the population generated then we calculate the fitness value of the population where it evaluates the weight of the truss in this case. The algorithm checks how far it has improved and proceeds with off-springs if the criteria for convergence is not met. For forming the off-springs, a set of the population is selected and crossed. The process of crossing in this case can be assumed to swap of element cross sectional area between two different entities. During the process of crossover, a random tweak in the chromosomes called mutation occurs. The final off-springs are passed back as new generation for the next iteration. A violation in the constraints are accounted in the form of penalty in the system using the input non-linear genetic algorithm solver in MATLAB. For each of the offspring the truss analysis is performed and the constraints are checked along with the fitness calculation. A flow chart of the algorithm is attached:

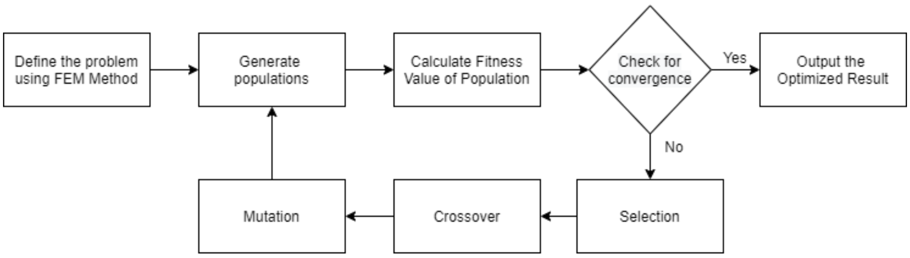
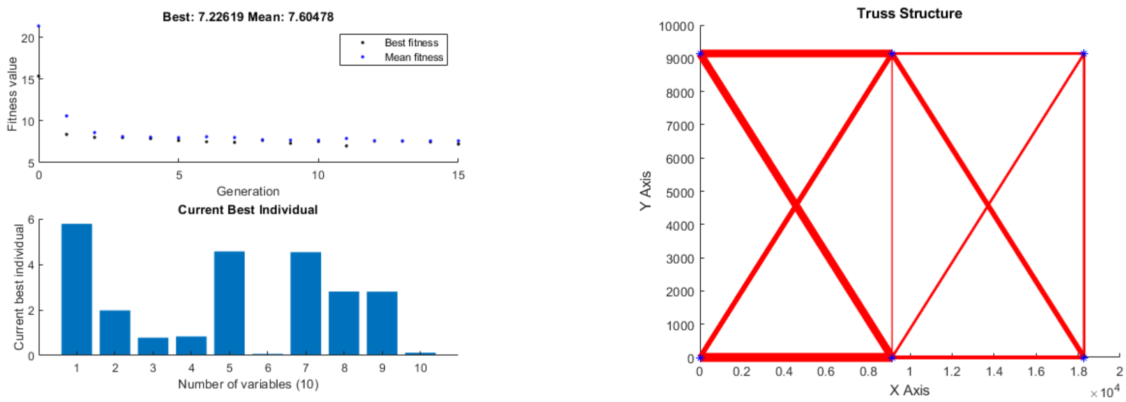


Figure 2: Flowchart for Genetic Algorithm implementation

4 Results and discussion

For the material properties, E = 69 GPa, σ^{max} = 172 MPa, δ^{max} = 50.8mm , $\rho = 2.77 * 10^{-5} N/mm^2$ the following results are obtained:



(a) Best vs. mean fitness over generations

(b) Final optimal truss

Figure 3: Truss optimized using Genetic Algorithm

The optimal solution obtained in the final generation is 7.22 units which is approximately 0.5 times the original value. From the below figures the area of 4 of the elements are not comparable to the other members. The area of the elements has been optimized and total weight of the truss is reduced to 7.22619 kg.

Summary

The benchmark truss problem with 6-noded and 10 element problem is analyzed for elemental stresses and nodal displacements using Direct stiffness method. By applying some constraints on stress and displacement, objective function(weight) is optimized(minimized) using Genetic Algorithm. The observations show the area leading to very less values maybe removed without causing any effects on the Truss.

References

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