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A Review on Optimization of Truss Structure Using Genetic Algorithms

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Abstract: Optimization of truss structure is major beneficial in the field of mechanical and civil engineering. There are several methods existing for the optimal design of structures which have been developed in past few years. However, Genetic Algorithm is proven method for truss structure optimization due to its probabilistic nature. This paper presents a review on implementation of genetic algorithms to optimization of10-bar truss structure. Result of this technique is also compared with other optimization technique to present it is best method than other.

Keyword: Structural optimization (SO); Truss Topology optimization (TTO); Genetic algorithms (GAs)

I. INTRODUCTION

An engineering structure is a body or assemblage of bodies in space to design a system capable of supporting all loads. Physically structure includes artificial and natural arrangements. There are two types of structures which are continuum structuresand discrete structures. Buildings, skeletons, beaver dams, truss and frame are all examples of physical structures. However structural optimization is defined as to get optimal structure that gives best function without changing input condition applied.[A]

There are lots of methods have been developed in past few years. But, most of the methods developedon linear programming techniques which have a common problem that they are tend to treat structural optimization as a problem in which the search space is continuous, though it is discrete. While in the other side, some recent structural optimization techniques are based on discrete search spaces, but they have an initial lack of generality and therefore they cannot be readily extended to other kind of structures.[B]

This paper focuses on the use of advance optimization technique called Genetic Algorithm (GA) to optimize the designof 10-bar truss. This technique considers a discrete search space and probabilistic nature, having better realistic results thanlinear programming methods.

II. TRUSS STRUCTURES

A truss is a structure having one or more than one triangular element constructed with straight members whose ends are connected at joints referred to as nodes. There are three categories of structural optimization problems depending upon geometric feature of it. Which are as following.[c]

2.1 Sizing optimization:
Size optimization is process to find the optimal design by considering the size of the cross-sectional dimensions of trusses as variable.

2.2 Shape optimization:

Shapeoptimization is process to find optimal designs by modifying the predeterminedboundaries of truss structure.

2.3 Topology optimization

Topology optimization is process to find the optimal design for the optimal spatial order and connectivity of the bars of truss structure.

Size (Nodes)	**Shape (Elements)**	**Topology (Connectivity)**

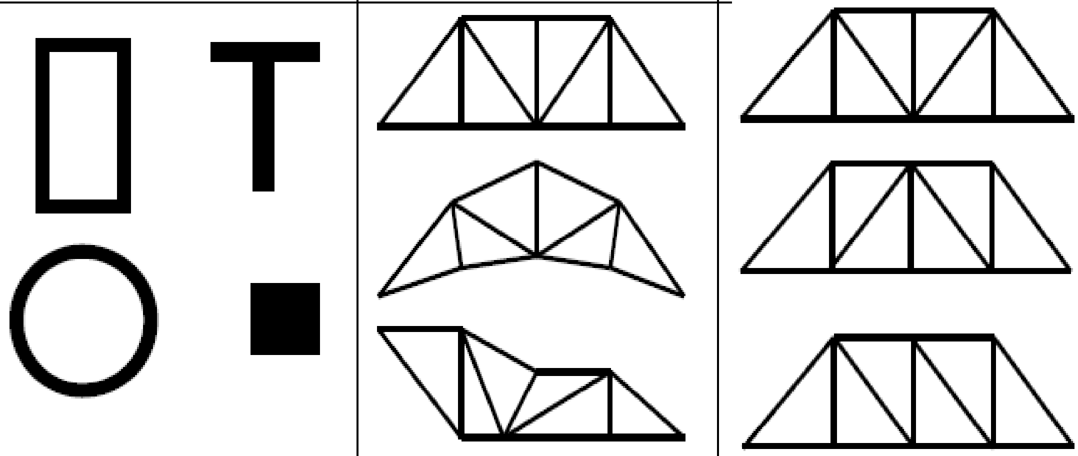

Figure 1 Size, Shape and Topology optimization of truss structure.

III. MATHEMATICAL MODEL

To make a perfect mathematical model for the optimization problem is very difficult task. There are so many constraints we have to consider for making objective function. In this problem formulation we have considered three most important constraints which are stress constraints, displacement constraints and area constraints. The objective function for truss topology optimization can be written in following manner as minimization of the mass of the entire truss structure within the boundary conditions.[dfg]

Minimize $\boldsymbol{f}(\mathbf{M}) = \sum_{i=1}^{n}(\boldsymbol{\rho_i l_i A_i})$

Subjected to

C1=$\sigma_{max} > \sigma_i$, i=1,2,…,n
C2= $\delta^{max} > \delta_i$, i=1,2,…,j
C2= $A_i^{min} < A_i < A_i^{max}$, i=1,2,…,n

Where,
M= total mass of truss structure,
L_i is length of the i^{th}element,
ρ_i is density ofelement material,

A_i is cross-sectional area of the same i^{th} element,
n is number of truss elements,
C1, C2, C3 are numbers of constraints,
σ_{max} is maximum allowable stress,
σ_i is stress of the i^{th} element,
j is number of nodes,
δ^{max} is maximum allowable deflection,
δ_j is deflection of j^{th} node,

IV. GENETIC ALGORITHMS

Genetic Algorithms are based on the principle of Darwinian survival of fittest. It ismainly applicable for global search procedures based on a stochastic approach of problem. [I]
Genetic algorithms are computerized search and optimization algorithms based on the mechanics of natural genetics and natural selection.

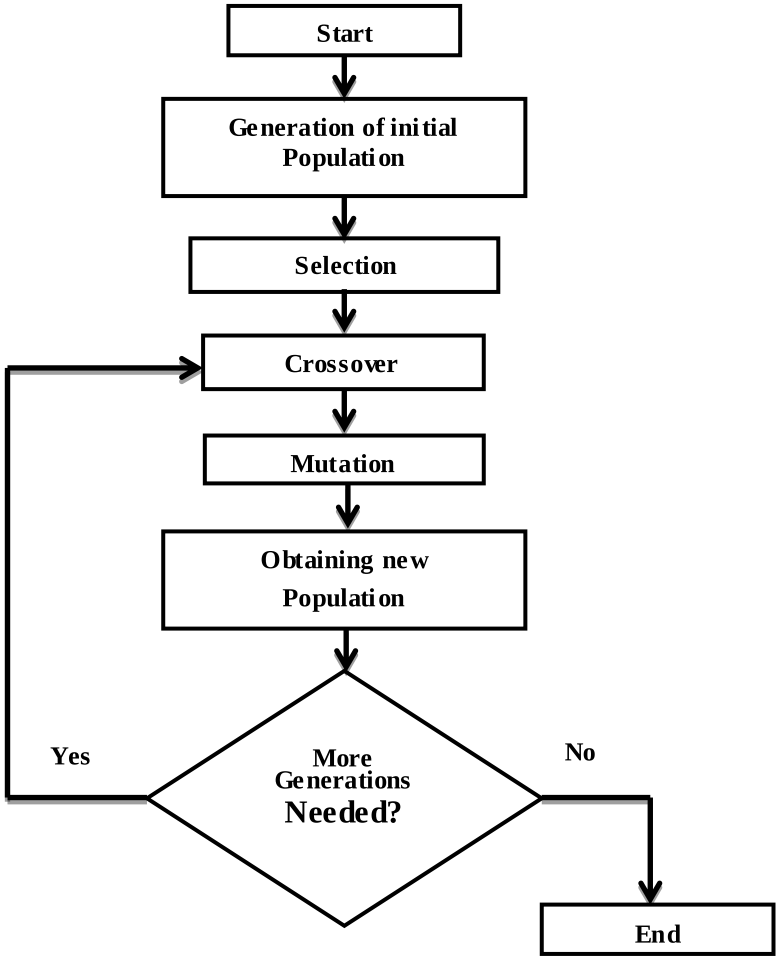

Figure 2 Block diagram of the classical genetic algorithm [D]

Genetic Algorithms have three main basic operators which are selection, cross over and mutation. At every iteration, these operators are applied on arandomly created populationor individualsinordertoimprovetheirfitness.Eachindividualis representedbyastring.[e]. Here detailed information is given in above flow chart.

4.1 Steps in the Genetic Algorithm Optimization

1. Choose a coding to represent problem parameters, a selection operator, a crossover operator, and a mutation operator. Choose population size n, crossover probability p_c, and mutation probability p_m. Initialize a random population of strings of size l. Choose a maximum allowable generation number t_{max}. Set t = 0.
2. Evaluate every string in the population.
3. If t_{max}or any other termination criteria are satisfied, terminate it.
4. Apply reproduction on the population.
5. Perform crossover with probability $p_c$on pair of the strings.
6. Perform mutation on strings with probability p_m.

Evaluate strings in the new population. Set t* = t +1 and go to Step 3

V. EXAMPLE: 10-BAR TRUSS

The 10-bar truss is a commonly used benchmark problem in most of the literature. The 10-bar truss is shown in the Figure3.

The first constraint C1 is that stress of each member may not exceed $172*10^4$ Mpa. This constraint isappliedfor both tension stress and compression stress.The second constraint C2 is that maximum deflection may not exceed 0.0508 m.The third constraint C3 is that the cross sectional areas may maximum 0.1 in^2 and minimum 10 in^2.

The stiffness of materials of truss or Young's Modulus is $6.895*10^4$ Mpa. [h]Parameters for 10-bar truss topology optimization are as following.

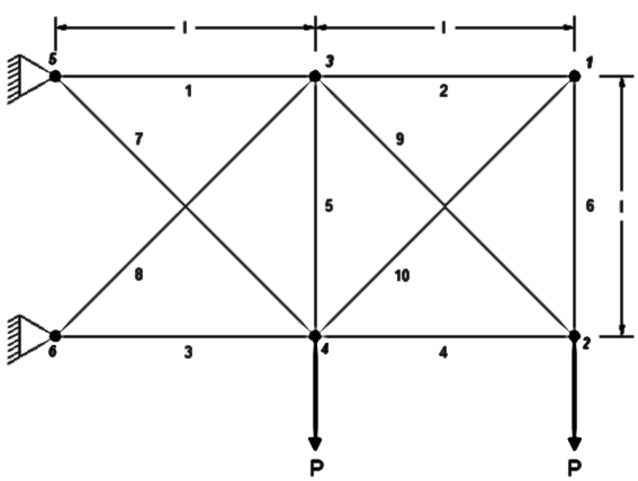

Figure 310-bar truss structure

5.1 Implementation of Genetic Algorithm

As the genetic algorithm is being used for theminimization of objective function for total mass of structure, let us shortly describe it. Genetic Algorithm for 10-bar truss works with a population whose elements are different in cross sectional area. Each chromosome in the population is represented as a string sequence of member crosssectional areas which are randomly generated.Then mutation is applied to change the diversity. During the last step, individuals from the old population are killed and replaced by the new ones. Our objective functionis based on thestructural responses for a given load condition and constraints, as defined above. Those elements that do not meet with given constraints are assigned a cost penalty and process is repeated until the best solution obtained.

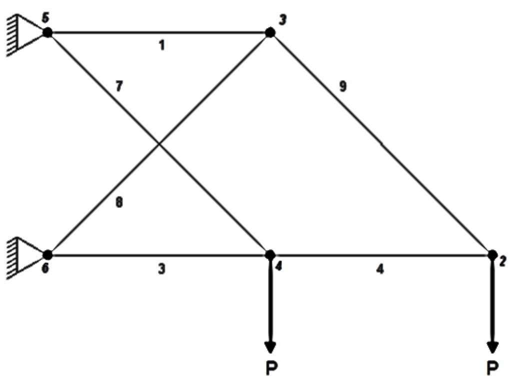

Figure 4 Topology optimizedstructure of 10-bar truss

Genetic algorithm for 10-bar truss compares with the results published in [h].

Table 1. 10-bar Truss Resuls

Element	Deb and Gulati Area m^2[B]	Hajela et al. Area m^2[J]	SOGA Area m^2[H]	KSR Area m^2[H]
1	0.019355	0.01806	0.019355	0.019355
3	0.015480	0.01548	0.015480	0.015480
4	0.010300	0.01030	0.009677	0.010300
7	0.003870	0.00387	0.003870	0.003870
8	0.012900	0.01355	0.012258	0.012900
9	0.013550	0.01420	0.014840	0.013550
Optimal mass (kg)	2,228.44	2,241.97	2,235.2	2,228.44

VI. CONCLUSIONS AND FUTURE WORK

As genetic algorithm has ability to deal with discrete search spaces, it is good choice for solving discrete structural optimization like truss structural.Also, the genetic algorithm runs with several partial solutionssimultaneously against the traditional sequential search of all othermethods. As results show that genetic algorithm gives best solution than other methods in table 1. However, genetic algorithm is complex process to implement because of common sense for software use is still requiredin such a complex task. Although, genetic algorithm is expected to play a main role in the structural design software in the future.

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