Design Optimization Of Free Standing Communication Tower Using Genetic Algorithm

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Abstract - *Towers have been utilized by humanity since ancient times. Steel towers are tall structures intended to support antenna for information transfers and television. The steel lattice is the most wide spread form of constriction. It gives great quality and economy in the utilization of materials. Such structures are typically triangular or square in plan. steel, being the suitable material which satisfies the structural and durability requirements, has a greater self weight. This leads to addition to the cost of material, transportation, erection and maintenance. Therefore, optimization of weight of tower becomes necessary.*

The weight of the tower is minimized using different optimization algorithms. In this work weight of the tower is optimized using genetic algorithm (GA). It depends on the fact that social sharing of data among individuals of a species offer an evolutionary benefit. Of late, GA has been quite helpful in diverse engineering design application. GA has also been applied in structural engineering in the Areas of Size, Shape and topology optimization with promising results. The present study aims at optimization of communication towers to arrive at an optimum weight, satisfying a set of specified constraints. GA has been devised and developed using 'MATLAB' code to optimize the communication tower. The program has been used to validate one benchmark problem and then applied to seven configurations of communication towers. It has been found that the developed GA yields better optimal results.

Key Words*: *optimization, optimal design, tower, genetic algorithm.

1. INTRODUCTION

With the growing contest to produce best design, engineering industry is in need of optimization of design that would lead to minimum cost and weight. Steel lattice towers are in extensive use in the communication as well as the power transmission industries.

Optimization, in general is to exploit the available limited resource to obtain maximum utility. The objective of optimal design is to achieve the best feasible design according to a required measure of performance and efficiency.

Optimization can be defined as a process of finding the condition that gives maximum or minimum value of a function.It can be applied to solve many enginee ringproblems including structural engineering design problems and has been attempted to many civil engineering structures such as buildings, steel trusses, bridge, towers etc. the objective of structural optimization is to either minimize the cost or weight or to maximize the safety or both.

Structural optimization has been defined as designing and developing a structure at minimum cost, with the goal of satisfying a well defined purpose. Costs must also include safety, service life, maintenance and future adaptability. Since all research and practice in structural engineering are presumably aimed towards such a goal, the activity known as structural optimization must be defined in a unique way, that is, the development and application of interactive or automated computer techniques for improving designs within well defined costs and constraints.

2. OBJECTIVES AND METHODOLOGY

Genetic algorithms are becoming progressively popular because of the availability and affordability of high speed computers. Design optimization of towers aims at size optimization. The purpose of the optimization problem is to achieve a minimum weight design for the tower. In the current study, a GA based methodology is adopted for the optimization. The present study is to develop a program using MATLAB for the optimization of communication towers.

3. DESIGN OPTIMIZATION

Structural optimization problems may be classified according to the type of design variables, loadings, and constraint. In practice, each class usually requires a different method or strategy for solution.

Based on loading constraints, problems are classified as static and dynamic. Static problems may include stress constraints as well as displacement and buckling constraints. Dynamic problems may be divided into problems with response and frequency constraints. Other categories are reliability based optimization dealing with probabilities of failure as variables or as the objective function.

Design of communication towers aims at Sizing optimization of the tower. The sizing design variables are areas of the members. The aim is to obtain a tower with minimum weight satisfying the set of constraints that arise under the loading imposed on it.

The main goal of designing efficient structures has made structural weight, the natural objective function to be minimized. Therefore, generally optimum design problems are dominantly minimum weight design problems. Other quantities such as reliability, stiffness, energy, frequency, and actual cost have also been taken as objective function as well.

3.1 Problem Formulation

The objective function for optimization of tower considered is the weight of the tower. The present routine incorporates the design criteria as per IS-802 (part 1/sec 2) and the stress constraints are calculated as per the code.

Objective function: weight of the Tower

Subjected to the following constraints:

a) **Stress Constraints**

$$\sigma i/\sigma_{allowable} \leq 1$$

b) **Displacement Constraints**

$$\delta i/\delta_{allowable} \leq 1$$

Displacement constraints are imposed on the displacement of the top nodes. The constraints are evaluated as per the recommendations in the TIA/EIA standards. As per the TIA/EIA specifications, the displacements of the top nodes of the tower under sway should not exceeded ± 0.5 degrees with respect to original alignment.

3.2 Member Grouping

As communication towers are large structural system, it is very difficult to optimize the area of individual members. Hence, some sort of member grouping should be done to reduce the design variables. In the current work, the member forming the leg members, the diagonal members are the horizontal members are grouped. Hence, the design variables got reduced and the time taken to run the program get is reduced. The member areas are also selected within an upper and a lower bound on their values.

That is

$$A^L \leq A \geq A^U$$

- Lower bound A^L= 0.1in^2
- Upper bound A^U= 35 in^2
- Design Variables = 10
- Crossover = Two point crossover
- Crossover % = Random
- Mutation = integer
- Mutation % = Random

3.3 Validation of Algorithm

To validate the developed GA, it has been tried out for a few benchmark problem given below.

Sizing optimization of a 10-bar truss

Figure-1 shows the 10-bar truss considered along with the loading details

Material Properties

- Young's Modulus of Elasticity, E = 10^4 ksi
- Density of steel, = 0.1 lb/in^3
- Cross sectional area varies between 0.1 to 35 in^2

Stress Constraints

- $\sigma_{allowable}$ = 25000 psi

Displacement Constraints

- $\delta_{allowable}$ = ±2 in

Parameter of GA

- Population Size = 10
- Number of Generation = 50

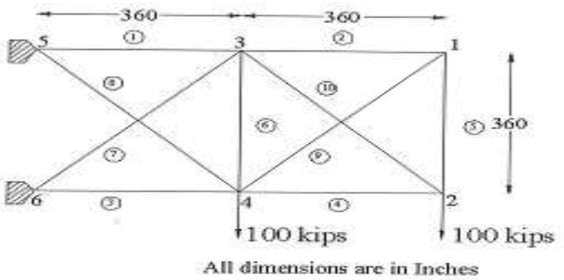


Figure-1: 10-bar Truss

3.4 Optimization results of the 10 bar truss

Table-1 demonstrates the GA best results of 10 bar truss problem. Other distributed results, for the same case, are summarized.

They are discovered utilizing different optimization approaches including slope based algorithms both unconstrained and constrained. We can see that the GA provides great results as compared with different techniques for the problem.

3.5 GA for Communication Towers

The developed GA was applied to communication towers. The developed GA was initially applied to the one benchmark problems namely 10 bar truss and compared the results published by different optimization methods done by different authors.

It was found that, the developed GA yield more optimal results than the other methods. Consequently, the developed GA was applied to seven different configurations of communication towers. Communication towers with X bracing, X bracing with horizontal panels and K bracing were optimized using GA.

Table-1. Optimization results of 10-bar Truss

Area group (in^2)	Present study (GA)	Rajeev and Krishnamoorty (GA) [1]	Gellatly and Berke (HAS) [8]	Ghasemi (GA) [9]	Schimit and Farshi (GA) [10]
1	32.1245	33.50	31.35	25.730	33.432
2	0.100	1.62	0.100	0.109	0.100
3	21.785	22.00	20.030	24.260	24.260
4	14.59	15.50	15.600	16.350	14.260
5	0.100	1.62	0.140	0.106	0.100
6	0.15	1.80	0.240	0.109	0.100
7	5.14	14.20	8.350	8.700	8.388
8	18.579	19.90	22./210	21.410	20.740
9	20.213	19.90	22.060	22.300	19.690
10	0.21	2.62	0.100	0.122	0.100
Weight (lb)	5031.13	5620.08	5112.00	5095.65	5089.00

4. PROBLEM DESCRIPTION

4.1 Details of Towers

Height of the Tower = 24 m, The tower is square in plan, Dimensions of the Tower

- 1.3 m x 1.3 m at the top,
- 3.2 m x 3.2 m at the base.

Angular Tower (i.e. tower is made up of angle sections only), Roof top Tower i.e. the tower rests on a building of 6m height, Tower is made up of 10 panels with top 4 panels 1.5m height and the rest 3m, Top 4 panels are straight while the remaining are at a slope of 3 degree with the vertical, The tower supports 8 GSM antennae, 2 at a height of 24m, 2 at a height of 22.5m, 2 at 21m and 2 at 19.5m respectively.

The size of the antenna is 2mx0.5m, Basic wind speed based on peak gust velocity averaged over a short time interval of around 3 seconds in open terrain is 55m/s, Tower is located at a site having terrain category 2, as per IS 875 (part 3), tower comes under class B structure, as per IS875 (part 3),

1. Modulus of Elasticity, E = 2 x 10^5 N/mm^2,
2. Density of the material, ρ = 7850 kg/m^3,
3. Solidity ratio is calculated as per IS875 (part 3).

Three configurations are considered for this tower.

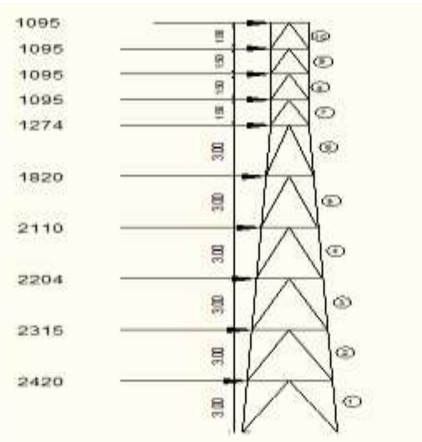
1. Configuration – 1 consists of K bracing in its panels and
2. Configuration – 2 consists of X bracing patterns in its panel.
3. Configuration – 3 consists of X bracing with horizontal panels.

4.2 Optimization Of Configuration – 1

Configuration – 1 consists of K bracing in its panels and the figure-2 shows the communication tower with K bracing.

Table-2: Wind Load Distribution for Configuration – 1

Panel numbers	Solidity Ratio	A=Projected Area (sq.m)	B = A * 1.5	Wind Load C = B * 1815(N)	Load Distribution In (N)	Load at Joints In (N)
10	38%	0.805	1.207	2190	1095	1095
					1095	2190
9	38%	0.805	1.207	2190	1095	
					1095	2190
8	38%	0.805	1.207	2190	1095	
					1095	2190
7	38%	0.805	1.207	2190	1095	
					1095	2548
6	16%	1.187	1.78	3230	1453	
					1777	3639
5	16%	1.52	2.28	4138	1862	
					2276	4219
4	16%	1.586	2.379	4317	1943	
					2374	4408
3	16%	1.661	2.49	4519	2034	
					2485	4629
2	16%	1.75	2.625	4764	2144	
					2620	4838
1	16%	1.81	2.715	4928	2218	
					2710	2710



All Dimensions are in m's

Figure-2: Tower with K bracing

4.3 Parameters of GA

- Population Size = 15
- Number of Generation = 50

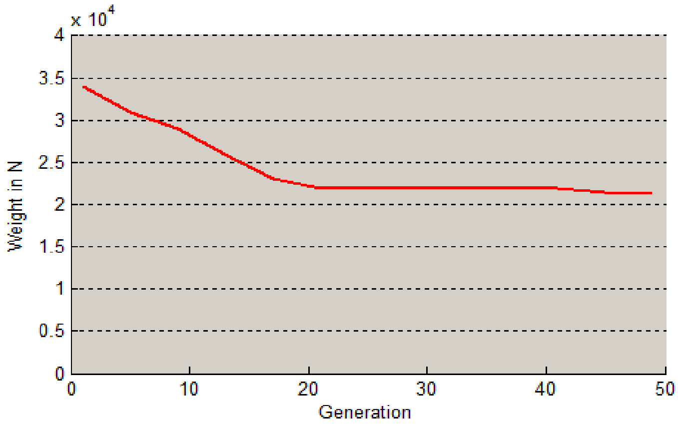


Figure-3: Weight Vs number of Generations for configuration – 1

In configuration – 1, the objective function, that is, the weight of the tower decreases as the generation increases and reaches an optimal value of 21208.473 N at 50th generation.

Table-3: Comparison between GA and PSO

Optimal Weight by PSO In (N)	Optimal Weight by GA In (N)	Percentage Reduction in optimal weight (%)
21490.99	21208.473	1.01 %
22930.06	22363.856	1.02 %
22550.06	21975.627	1.02 %

It may be observed that optimal weight by GA is 1.02% less than that obtained by PSO (13).

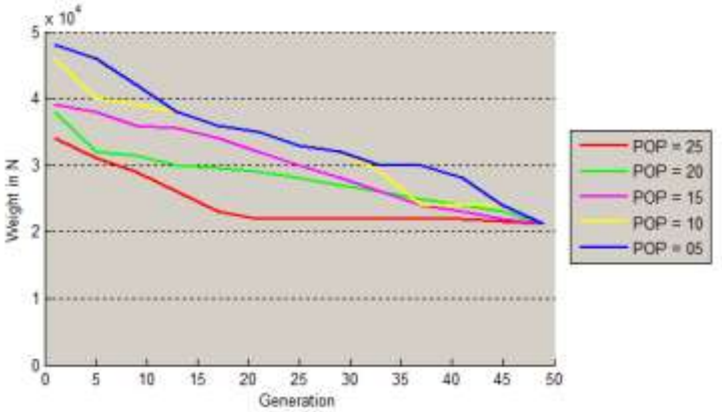


Figure-4: Variation of weight VS number of generations for Configuration – 1

For Different Population and a fixed convergence criteria, the number of Generation required is worked out and a plot of Population VS Generation as shown below for Configuration - 1

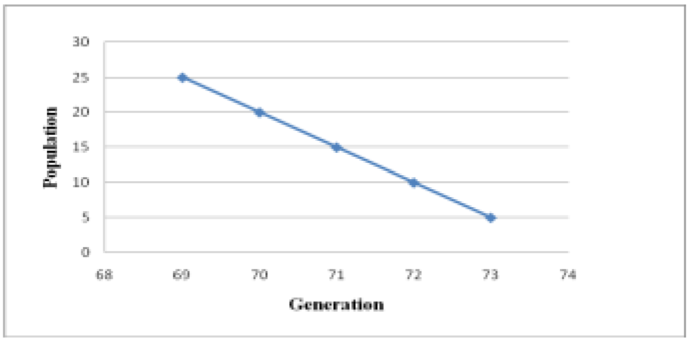


Figure-5: Population VS number of Generations for Configuration – 1

5. CONCLUSION

- The developed GA yielded satisfactory results for the benchmark problems. That is, the optimal weight obtained is less than the weights obtained other methods such as PSO and others
- It is found from the parametric study that as the population size increases, convergence reached faster.
- It can be seen that, GA are search methods that are more robust and effective to solve a wide variety of problems than most other optimization procedures.
- The results shows that optimal weight by GA is less than the that obtained by PSO

6. FUTURE SCOPE

- The present work considers towers, which are square in plan. It can be extended to other types such as rectangular, hexagonal or triangular towers.

- The present work incorporates analysis and design with angle sections. This can be extended for use with tubular sections and hybrid sections.
- The program can be extended for analysis and design of tower for seismic loading conditions.

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