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STRUCTURAL ANALYSIS OF A GENETIC ALGORITHM OPTIMIZED STEEL TRUSS STRUCTURE ACCORDING TO BS 5950

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ABSTRACT

A modern technique in structural optimization known as genetic algorithm was implemented in this paper to optimize a plane steel truss structure under point loadings and is subject to stress and displacement and buckling constraints. The genetic algorithm was developed in the MATLAB software. The genetic algorithm was run thrice on the plane truss structure and the run with the best result was picked as the final optimized truss structure. For each run a minimum of 500 initial population was set. The optimized truss structure gotten from the algorithm were analyzed and designed under dead and imposed loadings to compare and determine the percentage weight reduction and check the feasibility of the optimized truss structure. The software used to analyze and design according to British standard for steel design, BS 5950 was the SAP 2000 software. The results of the analysis and design in the SAP 2000 software showed the feasibility of the optimized truss as it passed all stress and displacement checks. The weight of the original truss problem in the SAP model gave a total weight of 5970.723496 Kg, while the weight of the optimized truss gave a total weight of 3147.1994 Kg showing a weight reduction of about 52%.

Key words: Structural Optimization, Genetic Algorithm, Steel Truss.

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1. INTRODUCTION

Design engineers over the years have been tasked with the responsibility of providing engineering projects that meet specific needs in the society while using as little resources as possible. The major principles that guide designs in engineering are functionality, economy, safety and aesthetics, and an engineer is required to use resources available to him optimally to achieve all these aspects of a design [1]. This has posed engineers with the challenge of developing ways to achieve this optimality in design without compromising the other aspects of the design. This process of finding the best design under certain constraints of time and resources is referred to as Engineering optimization. Engineering optimization can be seen applied in many fields of engineering, for example, civil engineering, mechanical engineering and aeronautic engineering [2].

The process of optimization that deals with finding the best configuration or arrangement for an engineering structure under any given circumstance is called structural optimization. Structural optimization is simply searching for the most efficient way or ways of achieving a defined set of objectives. In other words, structural optimization is the process of using mathematical representations to seek an optimal solution for engineering design problems with or without constraints [3]. Some common engineering structures that are optimized are trusses, concrete structures, subsea platforms and so on. Engineers have developed different techniques over the years for structural optimization, they can be classified into classical optimization techniques and modern optimization techniques. This paper deals with the optimization of trusses using a type of modern optimization technique called genetic algorithm. The size, shape and topology of the trusses are considered during the optimization

1.1. Structural Optimization

Structural optimization can be categorized into topology, size and shape optimization. Shape optimization deals with the geometrical presentation of a structure, size optimization deals with the area of the members of a structure and topology optimization deals with the connectivity of a structure's members. A common structural optimization objective is to find the optimum weight of a truss structure by considering either or all of size, shape and topology optimization, often times the optimization is subject to one or two structural constraints [4]. Design variables are numerical inputs of the objective function of an optimization problem that are able to change to provide the desired results. Design variables can either be continuous or discrete. Continuous variables are variables that are continuously varied between practical extremes while discrete variables represent a selection form a set of parts [5]. The type of design variables used for truss optimization are discussed below [6]. For size optimization, the design variable considered is the cross-sectional area of the members of the truss structure. the variable can either be continuous or discrete in nature, for continuous variables an upper and lower limit is set, and the cross-sectional area is allowed to be chosen from this range. The discrete variable on the other hand is chosen from a cross-sectional profile table where the areas have been determined [7]. For shape optimization, the design variables used are the coordinate of the nodes. The coordinates are allowed to change for a better and optimal structure to surface. This type of variable is usually continuous in nature. For topology optimization the connectivity and the number of the nodes are the design variables. The nature of these variables is discrete as the number if nodes are usually pre-determined. Common techniques in topology optimization are ground structure method, reduced method, SIMP (Solid isotropic material with penalization) technique, ESO (evolutionary structure optimization) technique [8].

1.2. Genetic Algorithm in Structural Optimization

Genetic algorithm is a modern optimization technique which adopts the concept of biological evolution developed by Charles Darwin. The search technique influenced by evolutionary concept was first developed by professor John Holland in the year 1975. He's known to be the father of the optimization technique, genetic algorithm. Some of the general concepts adapted from genetic evolution are genes, chromosomes, mutation, cross-over and allele [9].

[10] used a hybrid genetic algorithm for the optimization of a pitched truss structure with aluminum members. They considered shape, size and topology for the truss structure in the

optimization process. A binary encoding technique and a real-valued encoding technique were adopted for the algorithm in the MATLAB software, thus making it a hybrid genetic algorithm. The binary coded algorithm was used for the size and topology optimizations while the real-value encoding was applied for the shape optimization. The truss was subject to constraints such as displacements, stress and slenderness [11]. The variable used during optimization were node coordinates and cross-sectional areas. The algorithm was used to optimize an 8-node truss subject to a total of 800 Kg applied at the truss nodes. The resulting optimized truss gave an optimal weight of 206.2781Kg. This was after their algorithm had been tested on a benchmark problem that gave reasonable answers.

[13,14,15,16] used a slightly different approach with the genetic algorithm technique in their optimization process with the aim of reducing run time of the genetic algorithm. The aim of the research was to treat a major drawback in the norms of using genetic algorithm by changing and reducing design variables and implementing equations in the process to help obtain other variables. The chosen variables were nodal coordinates and displacements but they excluded cross sectional areas. This led to the reduction of the chromosome length and eventually the run time of the algorithm. The genetic algorithm was tested on a benchmark problem, a 6-node cantilever truss and produced reasonable results in comparison with other research results. The genetic algorithm didn’t obtain optimized results till like after the 100th generation a bit more than how other algorithms work.

2. MATERIALS AND METHODS

The primary tool used in the encoding of the genetic algorithm used in this research paper is the MATLAB software [12].

2.2. Procedures of Setting up the Genetic Algorithm

2.2.1. Initialization of population

The encoding technique for the genetic algorithm implemented in this research is the binary encoding technique. The variables considered were number of nodes, coordinates of nodes and the cross-sectional areas. The cross-sectional areas variables are discrete variables. They are obtained from areas of square hollow sections available in the British steel design code BS 5950.

2.2.2. Fitness Function

The objective function of the optimization is the minimization of the weight of a plane steel truss. This can be expressed with a mathematical expression:

Where,

W= truss weight

ρ – material density

A – area of truss bars

L – length of truss bars

2.2.3. Constraints Considered

The objective function for optimal weight of truss structure was subject to tension limits, compression limits and buckling stability according to BS 5950. The constraints were implemented into the algorithm by the technique of a penalty function.

2.2.4. Selection of Individuals

The selection method in this paper was the tournament selection. The mutation rate was 0.05 and the cross-over probability was 0.9. the techniques used for the crossover was uniform cross-over technique and the technique use in the mutation is the uniform mutation technique.

2.3. SAP Model

The resulting optimized truss was modelled in a design and analysis software called SAP 2000. The software uses Finite element method to analyze the structures. The truss structure modelled in the software were subjected to dead load and point load acting as imposed loadings.

3. RESULTS AND DISCUSSION

3.1. Cantilevered Truss with 6 Nodes (Benchmark Problem)

The genetic algorithm implemented in this paper was tested on a benchmark problem; a cantilevered truss with 6 nodes, 2-point loads at the bottom chords and 2 support nodes located at the left sides of the truss. Figure 1 represents the benchmark truss.

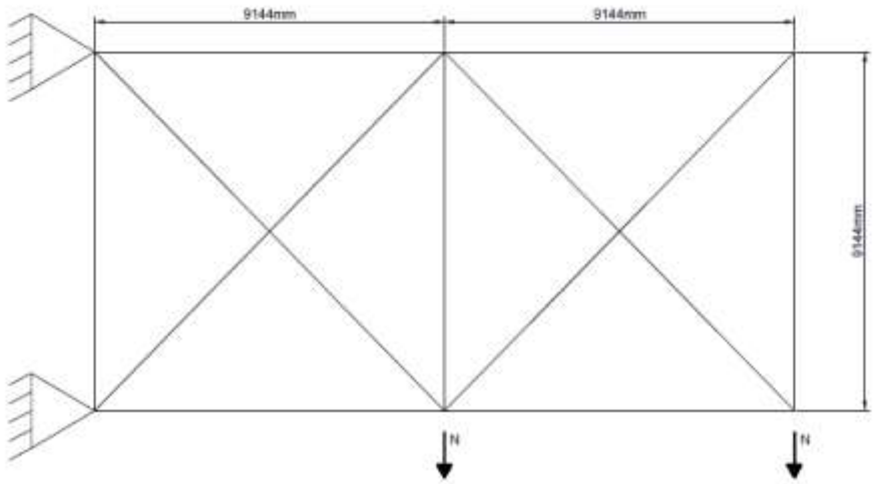

Figure 1 Cantilevered Truss with 6 nodes and 2-Point loads

The genetic algorithm was run three times. The first run had an initial population of 500 while the mutation and probability rates were 0.05 and 0.9 respectively, the second run had an initial population of 700 with mutation and crossover technique similar to the first run. The third run however was determined by the result of the previous two runs. After the optimization process of the first two runs as seen in table 2, the resulting node and element numbers were used in creating the truss structure in the third run. The optimized truss in the first run gave a truss with 5 nodes and 6 truss members, so the truss in the third run had the same parameters, and a population size of 600 was used. The final optimized truss structure after the third run gave a truss with 4 nodes and 4 members but produced a much heavier weight than the previous runs as shown in Figure 2. This led to choosing the optimized truss in the first run as the best optimized truss structure as seen in Figure 1.

The resulting shape, size and topology optimized truss was then modelled in the SAP 2000 software to run a real-life load analysis and determine the feasibility of the optimized structure in real life. SAP 2000 uses finite element method in the analysis of structures making it essentially good in determining stress and displacements in every section of a structure. After analysis the truss passed all stress and displacement checks. The total weight of the truss in its original form in comparison with the optimized truss showed a significant reduction in the weight of the optimized truss. The weight of the truss under dead and imposed loading gave a truss weight of 5970.7 Kg but the weight of the optimized truss gave a value of 3147.20Kg, as seen in Table 4 and Table 5.

Table 2 Result of optimized cantilever 6-node truss (Run 1)

	Cross-Sectional Profile	Weight (Kg)	Start Coordinates (x1, y1)	End Coordinates (x2, y2)	% of allowable stress	Stress (N/mm2)
2	300x300x6.3	528.5232	0, 0	9.144, 0	97.2612	-180.5268
3	150x150x6.3	363.3771	0, 9.144	9.144, 0	90.283	248.2783
4	160x160x5	425.7522	0, 9.144	16.6, 3.1	87.4321	240.4383
5	200x200x5	245.4731	9.144, 0	16.6, 3.1	84.6533	-127.1448
8	120x120x4	61.7711	16.6, 3.1	18.288, 0	99.3574	273.2328
10	160x160x5	220.9704	18.288, 0	9.144, 0	92.5886	-78.2301

Total	**1849.9258kg**
Displacements:	Horizontally 11.267 mm, 30.8044% of the limit Vertically 71.3408 mm, 97.5241% of the limit

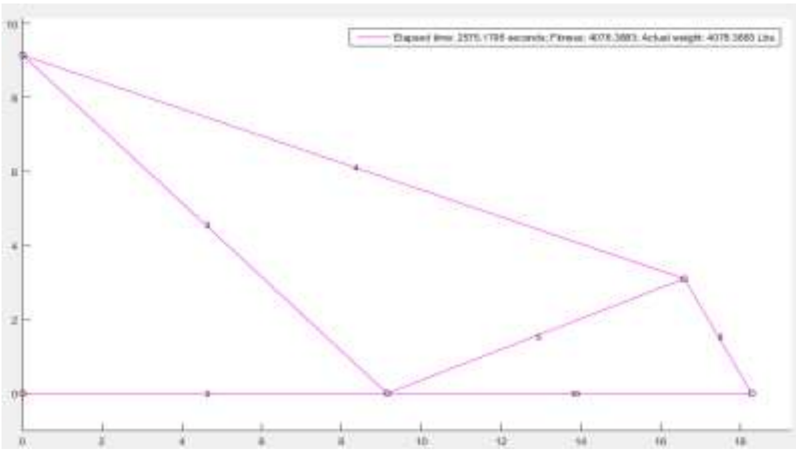

Figure 2 A weight optimized truss structure (First run and second run)

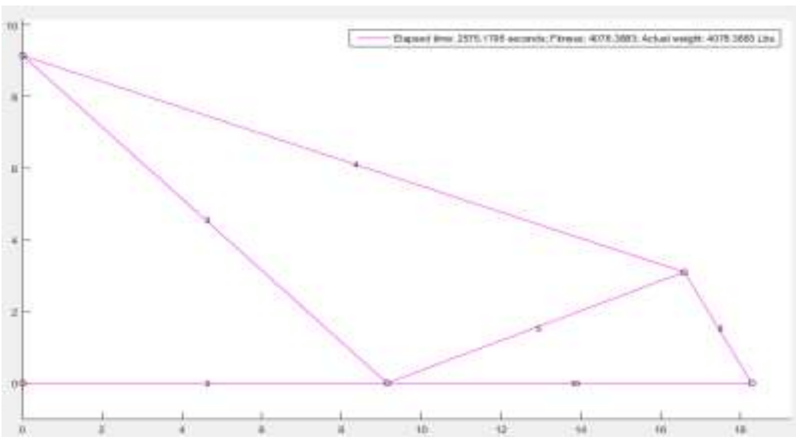

Figure 3 A weight optimized truss structure (Third run)

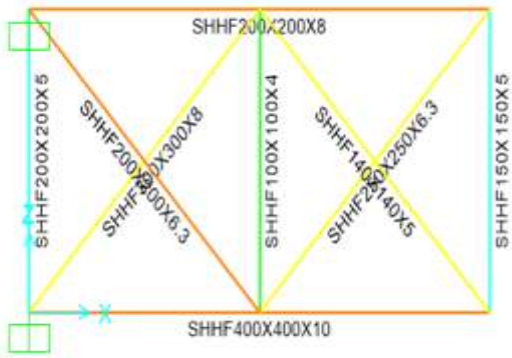

Figure 3 SAP 2000 model of the original truss

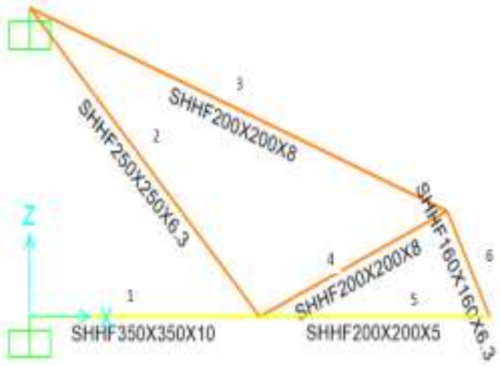

Figure 3 SAP 2000 model of the optimized truss

Table 3 Sap 2000 design result for the original 6 node truss

	Cross-sectional profile	Length	weight	stress
1	400X400X10	18.288	2231.136	-147.416
2	150X150X5	9.144	206.6544	114.576
3	200X200X8	18.288	872.3376	256.576
4	200X200X5	9.144	277.976	0.492
5	100X100X4	9.144	108.8136	-122.206
6	300X300X8	12.93157	941.418296	160.037
7	250X250X6.3	12.93157	619.4222	-85.804
8	200X200X6.3	12.93157	491.3997	263.567
9	140X140X5	12.93157	271.5657	244.275
	Total weight	**5970.723496**		
	Max displacement	Vertica; = 53.916mm Horizontal = 12.21mm		

Table 4 Sap 2000 design result for the optimized 6 node truss

Member	Cross-sectional profile	Length	weight	stress
1	350X350X10	9.144	969.264	-122.945
2	250X250X6.3	12.93157	619.44	152.684
4	200X200X8	17.66607	842.6715	125.359
5	200X200X8	8.07477	381.6	-81.612
6	160X160X6.3	3.52978	106.2463	135.073
7	200X200X5	9.144	227.9776	-63.862
	Total weight	3147.1994		
	Max displacement	Vertical = 38.82mm Horizontal = 7.02mm		

4. CONCLUSIONS

The genetic algorithm used in this paper for the optimization of the truss structure gave optimized weight results which in comparison to previous researches gives similar but better results. The optimized structures were then modelled in SAP 2000 to subject them to some real-life loadings (dead and imposed) to determine the feasibility of the optimized truss in practice. The result of the analysis showed the stress and displacement check in accordance to BS 5950 passed. The weight reduction was about 52% in the optimized truss structure. The research therefore leads to show that works on optimization in the research fields can be of immense benefit to engineering practice, if the two parties work together and transfer information effectively.

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