EVOLUTIONARY PARALLEL SAP2000 FOR TRUSS STRUCTURE OPTIMIZATION

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ABSTRACT

An approach is presented for the optimization of steel truss by combining evolutionary algorithms and commercial structure analysis program. Genetic algorithms (GA) have been shown to be effective optimization tools for practical optimization problems. The use of nonlinear finite element can assist greatly in achieving a safe design. However, commercially available finite element programs are not designed for optimization tools. 'Home-written' structure analysis program can be designed to achieve this task, but it may suffer from serious drawbacks such as bugs, lack of user friendliness, lack of generality, and unproven reliability. The purpose of this paper is to discuss combining SAP2000 structure analysis program with genetic algorithm for optimizing steel truss structure. The implemented method is tested on 10 members of 2D steel structure, 25 members of 3D steel structures and 72 members of 3D steel structure, where the results are compared with previous researches. It is concluded that this method can serve as a useful tool in engineering design and optimization.

Key words: Optimization, Genetic algorithm, Steel structure, SAP2000

1. INTRODUCTION

The use of finite element method (FEM) which used by commercial FEM program can assist in achieving a safe design. However, commercially finite element programs are not commonly designed for optimization. Design feature which included in commercial structure analysis program usually used to check if the member and applied inner force pass the corresponded code or not. 'Home-written' structure analysis program can be designed to achieve this task; however it may suffer from serious drawbacks such as bugs, lack of user friendliness, lack of generality, and unproven reliability [10].

The application of genetic and evolutionary computation to the automated design of structures has followed several avenues. The first is topology and shape optimization, in which the applications have included elastic truss structures subjected to static loading [4][6]. There have also been research efforts devoted to developing algorithms for optimized structure topologies to satisfy user-determined natural frequencies. The second major area of automated design using genetic algorithms has been their application for optimal member sizing for truss structures using linear elastic analysis with U.S. design specifications [1].

The final major application of genetic algorithms has been the automated design of steel frame structures. The vast majority of these efforts have been restricted to the optimized design of planar structures using linear elastic analysis. However, recent research efforts have begun to utilize genetic algorithms to guide the design of steel framed structures where the structural analysis includes nonlinear geometric behavior and nonlinear material behavior with semi rigid connections. One excellent method was combining commercial FEM program with iteration method to find required area of steel reinforced concrete plate [10].

SAP2000 structure analysis program is a well known Finite Element Analysis tool which already used for analyzing and modeling structure based on the relevant code such as AISC-LRFD99. SAP2000 could process or import the file input with extension MDB, XLS, TXT and SDB. SAP2000 also could export analysis result and design to files with extension XLS, TXT and SDB. After input file being opened, SAP2000 will run analysis, save result and design all members. In the output file, we can get required data such as frame stress and joint displacements as design criteria [2][3]

Genetic algorithm (GA), a member of Evolutionary Algorithm (EA), is a population-based global search technique based on the Darwinian evolutionary theory [7][9]. Common operators used in GA are initialization of population, evaluate population, selection, mating, crossover, mutation, stopping criterion and get results. The preliminary approach of GAs is Simple Genetic Algorithm (SGA). SGA guides the evolutionary search by a single population Pi. The size of Pi is denoted by SP. Individuals are encoded in a string scheme associated with one of the codes of the binary, integer, and real. In the evolutionary search, the promising individuals Pi−*sel* and Pi+1−*sel* are chosen from the population by a selection operation (roulette wheel, stochastic universal sampling, ranking, truncation, etc.). Then, the individuals chosen are applied to recombination and mutation operation (one point or multipoints crossover and mutation, uniform crossover, etc.). These evolutionary operations (mutation *mut*, crossover *cr*, and selection *sel*) are governed by their related evolutionary parameters Par (mutation and recombination probability rates, selection pressure, etc.). The population *Pnew* evolved by the application of these evolutionary operators is decoded. Then, the fitness values are computed by use of this population. The evolutionary search is executed to transmit (migration) the individuals (emigrant and immigrants) to the next populations until satisfying a predetermined stopping criteria (e.g., completion of a generation number NG).

Evaluation function was a base step for selection process [7][9]. In this phase, strings were converted to function parameter, evaluate the objective function and then convert the objective function to fitness. One big weakness in genetic algorithm is that solving problem need a lot of generations and this can take time.

As a matter of influence the GA robustness, many researchers develop methods for fastening GA runtime. One of famous method used for parallel GA is distributed optimization for GA [11].

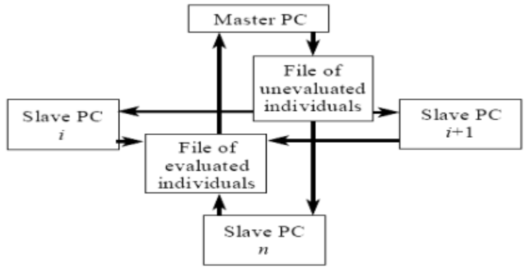

Fig. 1. *Parallel GA for distributed optimization [11].*

GA procedures are processed in Master PC and Slave PC's take the remaining fitness evaluation task. In this method numbers of PC are used as Slave PC's (see Figure 1).

2. MATERIALS AND METHODS

There are three models which will be optimized in this research. The first model as shown in Figure 2 is 2D 10-bar truss optimization problem. This model also has been analyzed by other researchers [4][5][6][12]. Two Dead loads applied at joint 2 and 4. The 10 design variables were chosen among 32 available cross section areas (see [5] for more details).

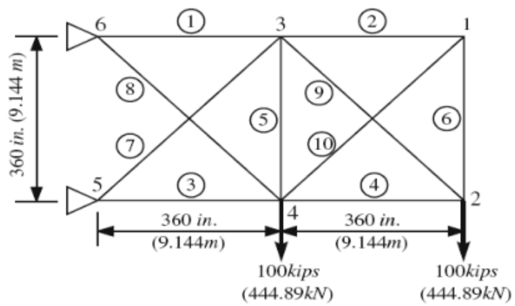

Fig. 2. *The first model 10 elements truss [7].*

The second model of steel structure considers the weight minimization of a 25-bar transmission tower as shown on Figure 3. This type also has been researched with different methods [4][5][6][12]. The design variables are the cross-sectional area for the truss members, which are linked in eight member groups. Details of the structure are presented on reference [12].

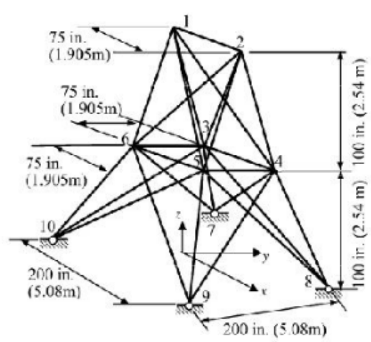

Fig. 3. *Second model 25 elements truss (7).*

The third model as shown in Figure 4 is a 4-story regular truss space frame structure [1].

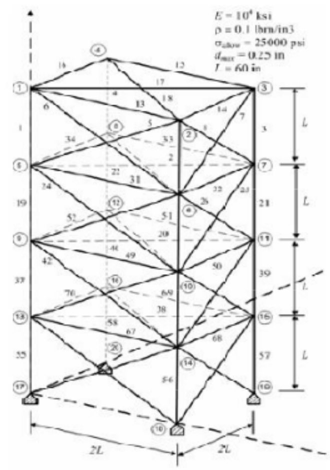

***Fig. 4**. Third model 72 elements truss (1).*

This model is subjected to two loading conditions. In the first loading condition, node 17 is subjected to 22.24 kN (5.0 kips), 22.24 kN (5.0 kips), and −22.24kN (−4kips), along the x, y and z directions, respectively. In the second loading condition, nodes 17, 18, 19, and 20 are subjected to −22.24kN (−4.0 kips) loads along the z axis. The allowable stresses for both tension and compression are 172.4 MPa (25 ksi). The displacement constraints are applied at the four upper nodes 17, 18, 19, and 20 with limiting displacements as ±0.635cm (0.25 in.) in both the x and y directions. The 72 members of the truss are linked to 16 design variables with a lower bound 0.0645cm^2 (0.01 in^2) on the cross-sectional area [1].

The parallel computing uses the *beowulf* cluster computing method (Figure 6). Next, the GA processes are continued until the stopping criteria reached and finally the result is found.

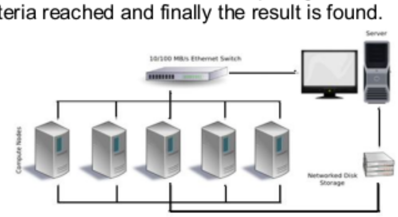

***Fig. 6**. Beowulf concept for parallel computing*

Problems in this paper are solved by combining SAP2000-GA, making the parallel computing module, and running the program. Steps of this research described in Figure 5 below.

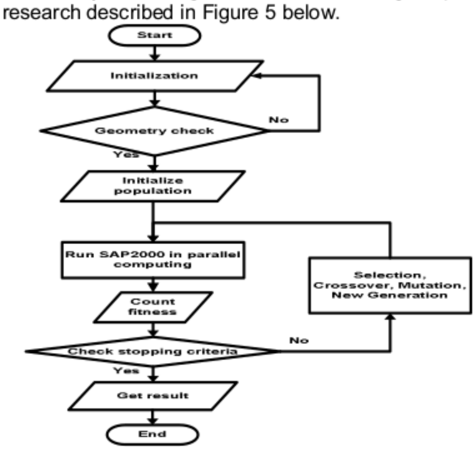

***Fig.5.** Flowchart combining genetic algorithm and SAP2000 [8].*

The steps for optimizing steel structures are initialized by creating SAP2000 input file and then rechecking the geometry. Population is generated by creating more SAP2000 input files randomly. Randomly means the selected members defined randomly based on the provided materials. These populations are automatically analyzed by SAP2000 in single and parallel computing way.

3. RESULTS AND DISCUSSION

Main objective optimization of three model steel structures are minimizing structure's weight subjected dead load with constrained in member's stress and node displacement. Objective Function defined as describe below.

$$f_{(x)} = \sum_{i}^{n} \rho A_i L_i + C1 \sum_{i}^{n} g_{1i} + C2 \sum_{i}^{n} g_{2i} \quad (1)$$

where : ρ is material's density, A_i is member's cross section Area, L_i is member's length, C1 & C2 are coefficient of constraint. g_{1i} and g_{2i} are penalty function due to following constraints : if allowable stress > actual stress, then $g_{1i} = 0$, otherwise $g_{1i} = 1$. If allowable node displacement > actual displacement, then $g_{2i} = 0$, otherwise $g_{2i} = 1$.

Analysis process of SAP2000 results frame forces and node displacements. Two types data above are can be found in the output file of SAP2000. Data will be processed to produce fitness value as part of GA procedure. The program is to optimize the 2D 10 elements, 3D 25 elements model, and 3D 72 elements model, and constrained on the member stress and node displacements. Figure 7 shows the flowchart of those programs.

After experimental study, it is found that the objective function is:

$$f_{(x)} = \sum_{i}^{n} \rho A_i L_i + 10000 \sum_{i}^{n} g_{1i} + 10000 \sum_{i}^{n} g_{2i} \quad (2)$$

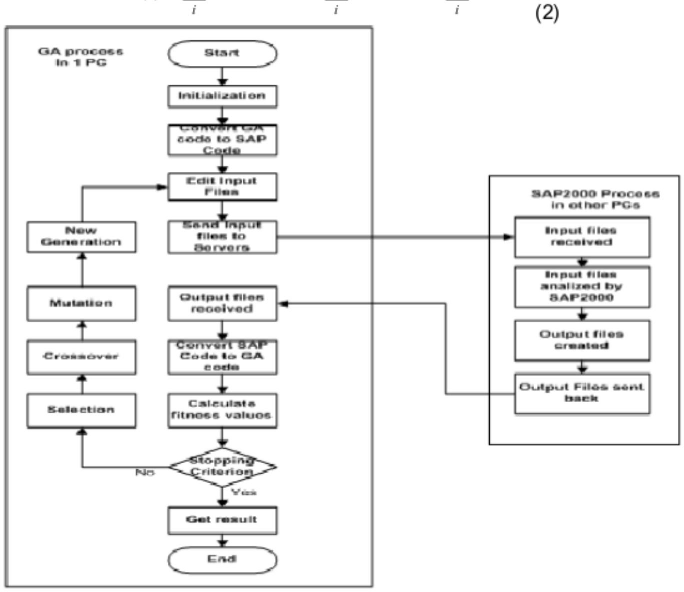

Fig. 7. *Flowchart for Parallel SAP2000-GA [8].*

The next step is to run the program with GA parameters showed in Table 1.

Table 1. Parameters used in SAP2K-GA method

	The first Model	The second Model	The Third Model
Population	100	100	100
Generation	100	200	200
Cross over	0,8	0,8	0,8
Mutation	0,005	0,005	0,005
Member's constraint	25 Ksi	40 Ksi	25 Ksi
Node's constraint	2 inches	0,35 inches	0.25 inches
Number of variables	10	8	16
Number of Constraints	22	55	264
Material Density (lbs/in^3)	0.1	0.1	0.1
Modulus of Elasticity (ksi)	10.000	10.000	10.000

All optimizations are executed in single computing method with one PC and parallel computing method with 6 PCs in Beowulf cluster configuration (see figure 3). All PCs use E2160 Dual Core processor, 1GB RAM and 1 wireless LAN-router 10 MBps.

Optimization results of the first model are compared with other techniques without any violation on member's stress and node displacements specified. This could be seen that the result of SAP2000-GA method (5584 lbs weight) is at the third place if compared with the other methods (See Table 2).

Table 2. Comparison of (SAP2K-GA) with other techniques for the first truss model

	Method		
	Coello	Rajeev	SAP2000-GA
Weight (lbs)	5586.4	5613.5	5584.3
A1 (inch^2)	NA	33.5	33.5
A2(inch^2)	NA	1.00	1.00
A3(inch^2)	NA	22.00	23.20
A4(inch^2)	NA	15.50	18.20
A5(inch^2)	NA	1.620	1.00
A6(inch^2)	NA	1.620	1.00
A7(inch^2)	NA	14.20	18.20
A8(inch^2)	NA	19.90	21.39
A9(inch^2)	NA	19.90	21.50
A10(inch^2)	NA	2.60	2.20

The optimization result for the second model are compared with some others structural optimization methods in Table 3. It shows that result of SAP2000-GA method is at the third place with the total weight of structure 533.45 lbs and maximum deformation 0.159 inch. Rajeev use a GA as explained before and get a better solution, but with SAP2000-GA method there is no doubt about the accuracy of structure analysis result.

Table 3. Comparison of (SAP2K-GA) with other techniques for the second truss model

	Method		
	Rajeev	Der Shin Juang	SAP2000-GA
Weight (lbs)	545.86	485.17	533.45
A1(inch^2)	0.10	0.10	0.10
A2(inch^2)	1.80	0.30	0.80
A3(inch^2)	2.30	3.40	3.00
A4(inch^2)	0.10	0.10	0.10
A5(inch^2)	0.10	2.40	0.90
A6(inch^2)	0.80	1.00	0.90
A7(inch^2)	1.80	0.30	0.80
A8(inch^2)	3.00	3.40	0.34
Displ. max(inch)	0.14	0.15	0.159

The optimization result for the third model in Table 4 shows that SAP2000-GA is at the third place with the total weight of structure 20922.8 KN. Whereas we look at work above, their cpu times can't be compared because Adeli's method used split FEM and SAP2K-GA used SAP2000 as FEM [1][8].

Table 4. Optimum structure weight obtained for the third model

No	Type of Method	Weight of Structure
1	Adeli & Kamal (1986)	1687 KN (379lbs)
2	Adeli & Park (1998)	1675KN(376,5lbs)
3	SAP2K-GA (2010)	1696KN(381,2lbs)

Table 5. CPU Time and saved data size for optimizing models

Method	CPU Time (hours)		
	First model	Second model	Third model
Single Computing	106 hours 24 minutes	128 hours 20 minutes	326 hours 12 minutes
Parallel computing (with 6 PCs)	15 hours 12 minutes	18 hours 20 minutes	46 hours 36 minutes
Saved Data	6.20Gb, 10000 files	17.84Gb, 20000 files	19.44Gb, 20000 files

All computation results can be saved or not, depend on requirement and the capacity of disc storage. Otherwise the data may be useful for another method like Neural Network. It can be seen in Table 5, optimization with parallel method can solve problem 7 times faster than with single computing method. However the result displayed in Table 5 may vary based on bandwith capacity of Local Area Network, size of transferred files, GA parameters, and PC's specifications.

The GA process for three optimization problems can be summarized as graphic plot of objective function, fitness, weight or the pareto set [7]. In this paper the result of optimization are taken from objective function plot at every 5 generation as shown in figure 9 below and they are look good as commonly GA plot results.

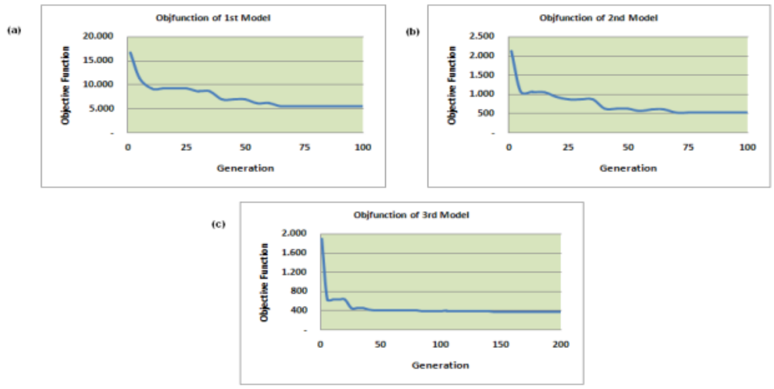

***Fig. 9**. Objective function plots (a) optimization result of first truss, (b) optimization result of second truss, (c) optimization result of third truss.*

4. CONCLUSION

Program to optimize the steel structures has been created by combining SAP2000 and Genetic algorithm in single and parallel computing method. Models analyzed by this program are 10 elements truss as first model, 25 elements truss as second model and 72 elements truss as the third model. All model analysis and optimization based on member stress and node displacement criterion. Result of this method compared by other research. With this method, optimization of truss steel structure has been solved successfully. Continued research are allowed for fastening running time and combining with other FEM program and other method.

ACKNOWLEDGEMENTS

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