Paper

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Using Genetic Algorithm as An Automatic Structural Design Tool

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1. Abstract

The focus of this paper is on the development and implementation of a methodology for automated design of discrete structural systems. The research is aimed at utilizing Genetic Algorithms (GAs) as an automated design tool. Several key enhancements are made to the simple GA in order to increase the efficiency, reliability and accuracy of the GA methodology for code-based frame design. Simultaneous sizing, shape and topology optimal designs of structural framed systems are considered. Comparisons with results from prior publications and solution to new examples show that the enhancements made to the GA do indeed make the design system more efficient and robust than a simple GA.

2. Keywords

Genetic algorithm, optimal design, AISC, frame design, design automation.

3. Formulation of the Design Problem

The sizing, shaping and topology optimization of three-dimensional frames can be stated as follows.

$$\begin{array}{lll}
\text{Find} & \mathrm{x} = \left\lfloor {}^{b}x_1,\ldots,{}^{b}x_{nb};\, {}^{i}x_1,\ldots,{}^{i}x_{nd};\, {}^{s}x_1,\ldots,{}^{s}x_{ns} \right\rfloor & \\
\text{to minimize} & f(\mathbf{x}) & \\
\text{subject to} & g_i(\mathbf{x}) \le 0 & i = 1,\ldots,ni \\
 & h_j(\mathbf{x}) = 0 & j = 1,\ldots,ne \\
 & {}^{b}x_p \in \{0,1\} & p = 1,\ldots,nb \\
 & {}^{i}x_q \in \{x_q^1, x_q^2, \ldots\ldots\ldots, x_q^{nq}\} & q = 1,\ldots,nd \\
 & {}^{s}x_r^L \le {}^{s}x_r \le {}^{s}x_r^U & r = 1,\ldots,ns
\end{array} \tag{1}$$

4. The Improved GA Optimizer

Selective improvement can be made to obtain a more robust solution methodology for a class of problems. Table 1 shows the proposed improvements.

	Traditional GA	**Proposed GA**
Penalty Function	ad hoc	Automatic and Adaptive
Schema	ad hoc	Ordered (Using Assoication String)
Cross-over Probability	ad hoc	Automatic and Adaptive
Population/Max Generation Size	ad hoc	Suggested as 2n

Table 1 Differences Between Traditional and Proposed GA

A total of 21 combinations of the options have been proposed for testing in the previous publication[1,2]. The results show that the proposed algorithm performance better than all others in efficiency, accuracy and reliability.

5. Design Variable Linking

Table 2 shows the design variables linking for sizing, shaping and topology structural optimization problems.

Optimization	**Physical Meaning**	**DV Type in GA**	**Note**
Topology	Element Existence	Boolean	
Sizing	Cross-sectional selection	Integer	Search through a given table
Shape	Nodal Coordinates	Real	Varies between upper and lower bounds

Table 2 Linking of Design Variables and the Physical Meaning

6. Numerical Examples

This example is taken from Grierson and Lee 's paper[3]. The structure is shown in Figure 1. The dead, live and wind load intensities define the service load level. The material properties and other design data of the original publication are listed in Table **3**. Figure 2 through Figure 4 show the layout of the five different load cases considered in the design. Table 4 lists the load values for the five load cases. In addition to the stress constraint, displacements in the Y-direction at node 8 and 11 are limited to 4 inches.

	Grierson and Lee		Current Research	
	Rafter and Chord	**Web**	**Rafter and Chord**	**Web**
Density	0.283 lb/in3	0.283 lb/in3	0.283 lb/in3	0.283 lb/in3
Young's Modulus	30,000 ksi	30,000 ksi	30,000 ksi	30,000 ksi
Yield Stress	44 ksi	36 ksi	44 ksi	36 ksi
Ultimate Stress	N/A	N/A	60 ksi	58 ksi
Allowable Stress	26.4 ksi	21.5 ksi	AISC	AISC
Kl/r	Assumed	Assumed	Buckling Analysis	Buckling Analysis

Table 3 Material Properties and Design Data

Units = k/in			
W1	0.04783	W6	0.01179
W2	0.02873	W7	0.03586
W3	0.00783	W8	0.01344
W4	0.01792	W9	0.00698
W5	0.00931		

Table 4 Load Values for the Five Load Cases

	Grierson and Lee (1984)		TEST1		TEST2		
	Sizing DV	**Section**	**Sizing DV**	**Section**	**Sizing DV**	**Topology**	**Section**
Rafter	1	CISC W	1	AISC W	1	N/A	AISC W
Top Chord	1	CISC WT	2	AISC W	2	N/A	AISC W
Bottom Chord	1	CISC WT	2	AISC W	2	N/A	AISC W
Vertical Web	2	CISC DL	3	AISC W	3	1~4	AISC W
Inclined Web	3	CISC DL	4	AISC W	4	5~8	AISC W

Table 5 Design Variables Linking

	Grierson	TEST1-F	TEST1-D	TEST2-F		TEST2-D	
	Section	**Section**	**Section**	**Section**	**Exist**	**Section**	**Exist**
Rafter	W460x61	W6X25	W8X24	W8X24	ALL	W8X24	ALL
Top Chord	WT230x30.5	W12X14	W12X14	W12X14	ALL	W12X14	ALL
Bottom Chord	WT230x30.5	W12X14	W12X14	W12X14	ALL	W12X14	ALL
Vertical Web	DL100x90x6	W12X14	W6X9	W6X9	25~29	W6X9	25~29
Inclined Web	DL 55x35x4	W6X9	W6X9	W14X74	NONE	W18X50	NONE
Weight (lb)	2918.5	2445.2	2319.6	1818.1		1818.1	
CPU Time (sec)		669	865	1147		1309	
Function Evals.	N/A	3279	4326	6145		7101	

Table 6 Final Design Results

With only sizing design variables, the final weight is about 20% less than those reported in the earlier publication. With the addition of topology design variables the savings are even greater – about 40%. It should also be noted that in TEST2 the proposed GA (operator F) uses much less computation time and function evaluation (about 13% less) than the traditional GA (operator D), with similar results. The final topology of TEST2 is shown on Figure 5.

6. Concluding Remarks

Enhancements have been made in making the GA robust and efficient. New stopping criteria, penalty function, crossover operator and schema representation have been developed and implemented. Particular attention is paid to reducing the number of user-input optimization parameters. As evidenced by the results from several numerical experiments the developed methodologies show promise in terms of efficiency, reliability and accuracy.

7. Acknowledgements

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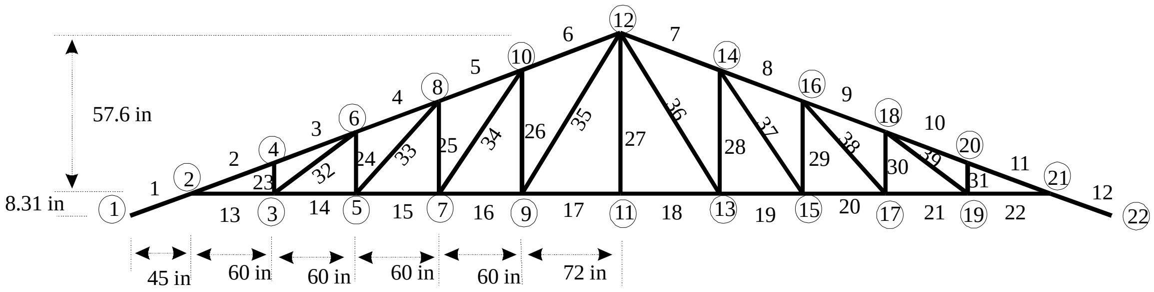

Figure 1 Structural Model

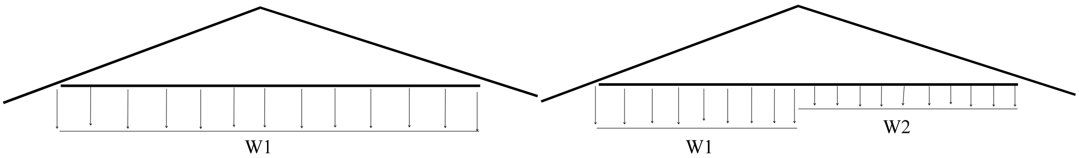

Figure 2 Load Case 1 (Left) and Load Case 2 (Right)

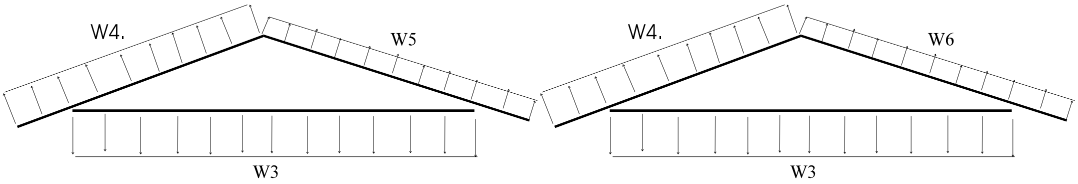

Figure 3 Load Case 3 (Left) and Load Case 4 (Right)

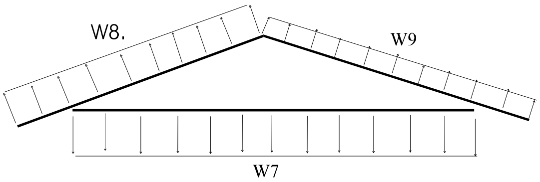

Figure 4 Load Case 5

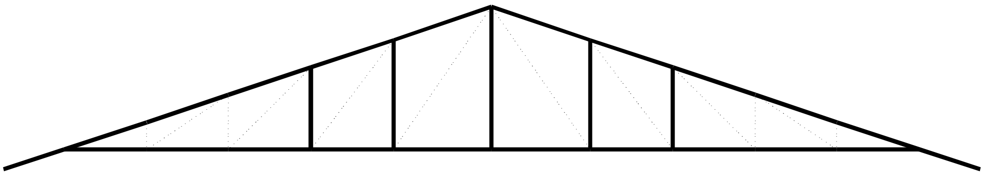

Figure 5 Final Topology for Both Operators

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8. Reference

[1] S-Y. Chen and S.D. Rajan, 1998, Improving the Efficiency of Genetic Algorithms for Frame Designs, *Engineering Optimization*, Vol. 30, pp281-307.

[2] S-Y. Chen, December 1997, *Using Genetic Algorithms for the Optimal Design of Structural Systems*, Dissertation for Doctor of Philosophy, Department of Civil Engineering, Arizona State University.

[3] D. E. Grierson and W. H. Lee (1984), Optimal Synthesis of Frameworks Using Standard Sections, *Journal of Structural Mechanics*, Vol. 12, No. 3, pp.335-370.

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