유전알고리즘을 이용한 트러스 구조물의 이산최적설계

Discrete Optimal Design of Truss Structures Using Genetic Algorithm

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(논문접수일 : 1999년 12월 10일 ; 심사종료일 : 2001년 4월 19일)

요 지

본 연구에서는 트러스 구조물의 이산최적설계를 위해 유전알고리즘(GA)을 적용하였다. 확률론적인 절차를 통해 설계에 필요한 초기 집단을 생성시킨 후, 설계를 개선시키기 위해서 자연선택 및 적자생존의 원리를 적용하였다. 다하중조건 하에서 트러스 구조물의 중량 최소화를 위해 응력 및 변위 제약을 고려하였다. 먼저, 이미 잘 알려진 트러스 구조물에 대해서 GA를 이용하여 얻은 최적해와 기존 문헌들에서 제시하고 있는 값들을 비교함으로서 GA의 신뢰성 및 적용성을 검증하였고, 이러한 신뢰성 검증을 바탕으로 사용성 있는 트러스 구조물의 이산최적설계를 위해 현재 생산중인 강재제원표로부터 부재가 선택되도록 하였다. 강재의 단면으로는 L형강을 사용하였으며, L형강의 강종은 9개의 강종들(SS 400, SWS 400, SMA 41, SWS 490, SWS 490Y, SWS 520, SMA 50, SWS 570, SMA 58) 중에서 설계자에 의해 자유롭게 선택되도록 하였다.

핵심용어 : 유전알고리즘(GA), 이산최적설계, 트러스 구조물, L형

Abstract

This study describes the application of genetic algorithm(GA) in the discrete optimal design of truss structures. Stochastic processes generate an intial population of design and then apply principles of natural selection/survival of the fittest to improve the designs. To minimize the weight of trusses, stress and displacement constraints are considered under multiple loading conditions. First, optimum solutions obtained from GA are compared to verify the validity and applicability of GA with those of well-known truss structures which were referred by other authors. The optimum design problems with continuous and discrete design variables are solved by GA. Based on this validity, discrete optimal design is performed in satisfying service conditions of truss structures with commercially available fabricated sizes. Angle type is used for cross-sections of steel members and these are selected from structural steel types(SS 400, SWS 400, SMA 41, SWS 490, SWS 490Y, SWS 520, SMA 50, SWS 570, SMA 58) by users.

Keywords : *genetic algorithm(GA), discrete optimal design, truss structures, angle type*

1. Introduction

Recently, it is on an increasing trend to use the steel manufactures as the primary materials for construction structures. Especially truss structures which are the most general and representative steel structures have been settled in public structures because it is possible to

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• 이 논문에 대한 토론을 2001년 9월 29일까지 본 학회에 보내주시면 2001년 12월호에 그 결과를 게재하겠습니다.

analyze and design the complex and large sized truss structures by computer. Therefore, it must be accompanied with the economical design, namely optimal design, for promoting more demands of truss structures.

But, until now, optimal design of truss is limited to theoretical design or is only used in preliminary design for practical design. Because most of the conventional numerical optimization techniques treat the design variables as continuous variables, they are very inadequate in the presence of discrete design variables. Though they can solve the "relaxed problem"(i.e. all-continuous problems) by ignoring the discreteness constraints then employing the round-off technique, they may result in solutions far from optimum, or even result in infeasible values when the number of variables increase. Furthermore, optimization problem of truss is controlled by multiconstraints and also constraints themselves are changed by the cross-section and slenderness of selected steel members. Therefore, it is very difficult to solve these problems with conventional numerical optimization techniques.

In this study, usable optimal design of truss is performed using genetic algorithm(GA) which is one of the stochastic optimization techniques.

As GA is applied to optimal design of truss structures, it can be naturally considered the allowable compressive stress constraints which are changed by steel type, shape type and slenderness of members.

2. Genetic Algorithm(GA)

GA is a kind of search algorithms based on the principles of natural selection and survival of the fittest.[1] A new population is reproduced on the basis of fitness evaluations through genetic operators which are modeled on the process of evolution occurring in nature. Genetic operators contain reproduction, crossover, and mutation. The new population usually has higher fitness value and this means that the population improves the fitness values from generation to generation. A search can be terminated when it reaches the prescribed maximum generation, or when it converges to the desired fitness, or when it satisfies other stopping criteria.

2.1 Reproduction

Reproduction is a process in which individual strings are copied according to their objective function values. Copying strings according to their fitness values mean that strings with a higher score have a higher probability of contributing one or more offsprings in the next generation.

In this study, tournament selection method[2] is used to choose the appropriate individuals to contribute to the next generation. In this selection approach, two selected individuals are compared for fitness, and the individual with the better fitness of this pair survives for the crossover step, and this continues until the new population is filled. This method possesses several advantages over the more traditional roulette wheel or rank order selection methods. Compared with other selection methods which rely on the maximum numerical value for fitness to be considered the best fitness, the tournament selection method allows for a minimum fitness value to be considered the best fitness. Additionally, this tournament selection directly compares two individuals at a time, rather than comparing the relative fitness of one individual against the entire population. This avoids difficulties with fitness scaling.

2.2 Crossover

While reproduction represents an elitist selection which retains only the most fit members of a population for mating, it does not improve any single design in the population. It is the crossover transform that allows the characteristics of the designs in the population pool to be altered, with the intent of representing the best characteristics in the next generation.

Uniform crossover is adopted for crossover techniques. Uniform crossover is radically different from one or two points crossover. Each gene in the offspring is created by copying the corresponding gene from one or the other parent, chosen according to a randomly generated crossover mask. Where there is a 1 in the crossover mask, the gene is copied from the first parent, and where there is a 0 in the mask, the gene is copied from the second parent. The process is repeated with the parents exchanged to process the second offspring. A new crossover mask is randomly generated for each pair of parents.

2.3 Mutation

Mutation operator arbitrarily alters the gene value according to a predetermined probability. For binary digit string representation, the mutation operator flips the bit from 1 to 0 or vice versa on a bit-by-bit basis.

Even though mutation operator is regarded as a secondary operator, it actually makes a significant contribution to the search effectiveness. This is because of the following reason. Selection and crossover generate new strings, but they do not introduce any new genetic features into the population at the gene level. Mutation operators introduce diversity and reflect features which are not presented in the current population, and therefore can protect against such a harmful loss and prevent premature convergence.

2.4 Fitness function formulation

As genetic search needs only the fitness of the objective function, at first the constrained minimization problem is converted into an unconstrained maximization problem. General formulation of the constrained minimization problem as follows;

$$\text{Minimize} \quad F(X) = f(x_1,\ x_2, \ldots, x_n) \qquad (1)$$

$$\text{Subject to} \quad g_j(X) \le 0 \quad j = 1, \ldots, m \qquad (2)$$

$$X^L \le X \le X^U \qquad (3)$$

The constrained minimization problem above can be represented as the following problem using the exterior penalty function.

$$\text{Minimize} \quad F^* = F + \overline{P} \qquad (4)$$

where, $\overline{P}$ is the penalty term, and bounding strategy by Lin and Hajela[3] was adopted to decide this penalty term. If the average fitness of feasible design is F_{av}, then a limit value of the penalty $\overline{L}$ is selected as,

$$\overline{L} = kF_{av} \qquad (5)$$

where, k=2 and the penalty $\overline{P}$ appended to an infeasible design is obtained as;

$$\overline{P} = \begin{cases} G, & \text{if } G \le \overline{L} \\ \overline{L} + \alpha(G - \overline{L}), & \text{if } G > \overline{L} \end{cases} \qquad (6)$$

where

$$G = r \sum_{j=1}^{n} \langle g_j \rangle^2 \qquad (7)$$

Here r is a penalty parameter, and initial value of r is assigned a value of 100 and its value is increased every generation by 100 in this study. $\langle g_j \rangle$ represents only the violated constraints. α can be assigned a small value 0.0~1.0, α =0.2 is used.

To convert the minimization problem of Eq.(4) into a maximization problem required by GA, the following fitness function is used,

$$\text{Maximize} \quad Fitness = 1/F^{*} \tag{8}$$

3. Formulation of Optimization Problem

The objective function for optimal design of truss is the total weight of truss, and stresses (compressive and tensile stresses) and displacement constraints are considered. The stress constraints are formulated based on the Standard Specifications for Highway Bridges.[4] Formulation of optimization problem is as follows,

$$\text{Minimize} \quad W = \sum_{i=1}^{n} \gamma_i A_i L_i \tag{9}$$

$$\text{Subject to} \quad f_{tkl} \le \overline{f_t} \quad k=1,\cdots,n;\, l=1,\cdots,c \tag{10}$$

$$f_{ckl} \le \overline{f_c} \quad k=1,\cdots,n;\, l=1,\cdots,c \tag{11}$$

$$u_{jl} \le \overline{u_j} \quad j=1,\cdots,f;\, l=1,\cdots,c \tag{12}$$

$$\mathbf{a}_i \in \mathbf{a}_i \tag{13}$$

where, W=the total weight of truss, γ_i= specific weight of steels, A_i=cross-sectional area of members, L_i=the length of members, n=the total number of members, c=the number of loading conditions, and $\overline{u_j}$=allowable displacements at a joint, and $\mathbf{a}_i$ is set of the cross-sectional area of members. The allowable axial tensile stresses $\overline{f_t}$ in Eq.(10) is tabulated in Table 1 and the allowable axial compressive stesses $\overline{f_c}$ in Eq.(11) is presented;

$$\overline{f_c} = f_{cag} \cdot f_{cal} / f_{cao} \tag{14}$$

where,

f_{cag} : allowable axial compressive stresses without considering local buckling, prescribed in Table 2.

Table 1 Allowable axial tensile stresses for variable steels(kgf/cm²)

Steels	SS 400 SWS 400 SMA 41	SWS 490	SWS 490Y SWS 520 SMA 50	SWS 570 SMA 58
Axial tensile stresses	1,400	1,900	2,100	2,600

Table 2 Allowable axial compressive stresses without considering local buckling for variable steels(kgf/cm²)

Steels	SS 400 SWS 400 SMA 41	SWS 490	SWS 490Y SWS 520 SMA 50	SWS 570 SMA 58
Axial compressive stresses	(a) $\frac{l}{r} \le 20$ 1,400	(a) $\frac{l}{r} \le 15$ 1,900	(a) $\frac{l}{r} \le 14$ 2,100	(a) $\frac{l}{r} \le 18$ 2,600
	(b) $20 < \frac{l}{r} \le 93$ $1,400 - 8.4\left(\frac{l}{r} - 20\right)$	(b) $15 < \frac{l}{r} \le 80$ $1,900 - 13\left(\frac{l}{r} - 15\right)$	(b) $14 < \frac{l}{r} \le 76$ $2,100 - 15\left(\frac{l}{r} - 14\right)$	(b) $18 < \frac{l}{r} \le 67$ $2,600 - 22\left(\frac{l}{r} - 18\right)$
	(c) $93 < \frac{l}{r}$ $\frac{12,000,000}{6,700 + (l/r)^2}$	(c) $80 < \frac{l}{r}$ $\frac{12,000,000}{5,000 + (l/r)^2}$	(c) $76 < \frac{l}{r}$ $\frac{12,000,000}{4,500 + (l/r)^2}$	(c) $67 < \frac{l}{r}$ $\frac{12,000,000}{3,500 + (l/r)^2}$
	l : the effective length of member (cm) r : the radius of gyration of member (cm)			

Table 3 Allowable stresses for the local buckling of unstiffened elements for variable steels(kgf/cm²)

Steel	Allowable stresses for the local buckling	Steel	Allowable stresses for the local buckling
SS 400 SWS 400 SMA 41	1,400 $: \frac{b}{13.1} \leq t$ $240,000\left(\frac{t}{b}\right)^2 : \frac{b}{16} \leq t \leq \frac{b}{13.1}$	SWS 490Y SWS 520 SMA 50	2,100 $: \frac{b}{10.7} \leq t$ $240,000\left(\frac{t}{b}\right)^2 : \frac{b}{16} \leq t \leq \frac{b}{10.7}$
SWS 490	1,900 $: \frac{b}{11.2} \leq t$ $240,000\left(\frac{t}{b}\right)^2 : \frac{b}{16} \leq t \leq \frac{b}{11.2}$	SWS 570 SMA 58	2,600 $: \frac{b}{9.6} \leq t$ $240,000\left(\frac{t}{b}\right)^2 : \frac{b}{16} \leq t \leq \frac{b}{9.6}$

f_{cal} : allowable stresses for the local buckling of unstiffened elements, prescribed in Table 3.

f_{cao} : upper values of allowable axial compressive stresses without considering local buckling, prescribed in Table 2(a).

4. Verification the Validity of GA

To verify the validity and applicability of GA, optimal designs are performed with 25 and 72-bar space truss structures using GA, with the same design conditions to other literatures.[5)~8)] The optimum design problems with continuous and discrete design variables are solved by GA.

It is totally depended on the designer's experience to determine the value of GA parameters required in search process. For all examples, GA runs with the following values: population size=100, crossover probability p_c=0.8, and mutation probability p_m=0.01.

4.1 25-bar space truss

First, to verify the validity of GA, optimal design with continuous design variables is performed for 25-bar space truss shown in Fig. 1. The material properties, allowable stresses, allowable displacements and nodal load components are shown in Table 4~7, and the 25 members are linked to 8 variables.

As a result of comparing the solutions obtained by GA with those provided in literatures, we can

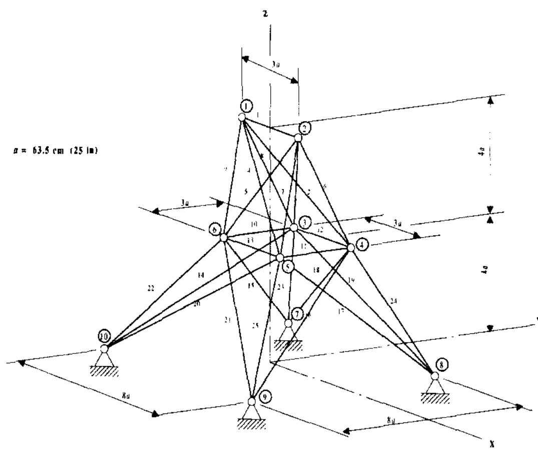


Fig. 1 25-bar space truss

Table 4 Data for 25-bar space truss

Modulus of elasticity	10^7psi
Specific weight	0.10lb/in³
Displacement limit	±0.35in
Minimum area	0.01in²
No. of design variables	8
No. of load cases	2

Table 5 Allowable stresses for 25-bar space truss(ksi)

Members	Tension	Compression	Members	Tension	Compression
1	40.0	-35.092	12,13	40.0	-35.092
2-5	40.0	-11.590	14-17	40.0	-6.759
6-9	40.0	-17.305	18-21	40.0	-6.959
10,11	40.0	-35.092	22-25	40.0	-11.082

Table 6 Allowable displacements for 25-bar space truss

Node	Displacement limits (in)		
	x	y	z
1	±0.35	±0.35	±0.35
2	±0.35	±0.35	±0.35

notice that GA obtains the almost same cross-sections and total weight, as shown in Table 8.

Fig. 2 shows the convergence history of 25-bar space truss. Objective value is rapidly converged until 50th generation, and the decreasing ratio of objective value is getting decreased after 50th generation. The objective value passing through the 158th generation retains constant value, and it can be called as converged value. In convergence history curve, the tendency of fitness curve is opposite to that of objective curve since they are in reciprocal proportion.

Table 7 Nodal load components(kips) for 25-bar space truss

Load case	Node	x	y	z
1	1	1.0	10.0	-5.0
	2	0.0	10.0	-5.0
	3	0.5	0.0	0.0
	6	0.5	0.0	0.0
2	1	0.0	20.0	-5.0
	2	0.0	-20.0	-5.0

Table 8 Optimum results for 25-bar space truss

Design variable	Member No.	Cross-sectional area (in^2)		
		Ref.[5] Haftka	Ref.[6] Arora	GA
1	1	0.010	0.010	0.010
2	2-5	1.987	2.048	1.981
3	6-9	2.991	2.997	2.989
4	10,11	0.010	0.010	0.010
5	12,13	0.012	0.010	0.010
6	14-17	0.683	0.685	0.714
7	18-21	1.679	1.622	1.682
8	22-25	2.664	2.671	2.626
Total weight(lb)		545.22	545.04	545.30

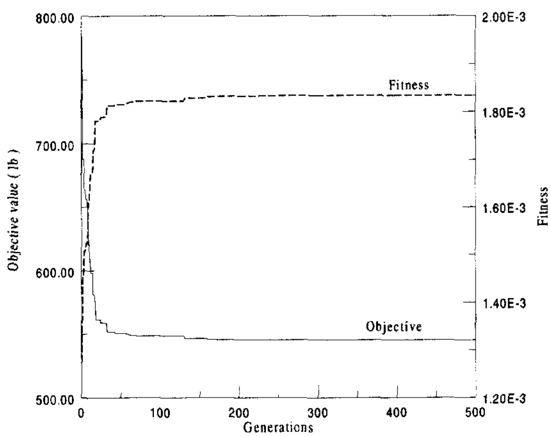


Fig. 2 Convergence history for 25-bar space truss

4.2 72-bar space truss

Fig. 3 is the space truss consisted of 72 members and those are linked to 16 design variables. The material properties and allowable displacements are shown in Table 9 and Table 10, respectively. This truss structure is subjected to two kinds of multiple loading conditions as shown in Table 11.

The final results of the optimal design problem are given in Table 12. As a result of comparing the optimum results by GA and literature, it is shown that GA obtains the almost same cross-sections and total weight.

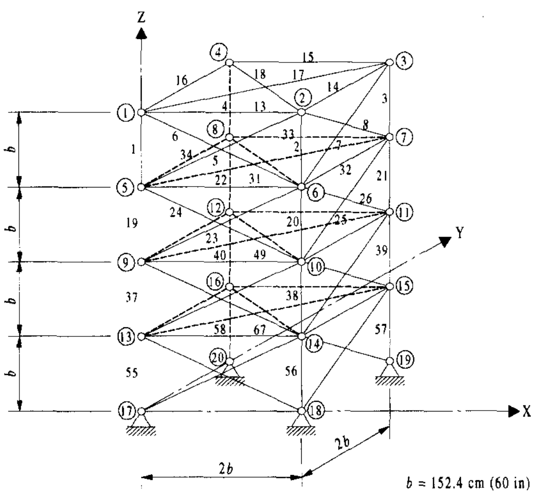


Fig. 3 72-bar space truss

Table 9 Data for 72-bar truss

Modulus of elasticity	107psi
Specific weight	0.10 lb/in^3
Allowable stress limits	±25.0ksi
Minimum area	0.1in^2
No. of design variables	16
No. of load cases	2

Table 10 Allowable displacements for 72-bar space truss

Node	Displacement limits (in)		
	x	y	z
1	±0.25	±0.25	-
2	±0.25	±0.25	-
3	±0.25	±0.25	-
4	±0.25	±0.25	-

Table 11 Nodal load components(kips) for 72-bar space truss

Load case	Node	x	y	z
1	1	5.0	5.0	-5.0
2	1	0	0	-5.0
	2	0	0	-5.0
	3	0	0	-5.0
	4	0	0	-5.0

Table 12 Optimum results for 72-bar space truss

Design variable	Member No.	Cross-sectional area(in^2)	
		Ref.[5] Haftka	GA
1	1-4	0.1571	0.1552
2	5-12	0.5356	0.5588
3	13-16	0.4099	0.3979
4	17-18	0.5690	0.5660
5	19-22	0.5067	0.4910
6	23-30	0.5200	0.5222
7	31-34	0.1000	0.1028
8	35-36	0.1000	0.1172
9	37-40	1.2800	1.1707
10	41-48	0.5148	0.5240
11	49-52	0.1000	0.1004
12	53-54	0.1000	0.1010
13	55-58	1.8970	1.9127
14	59-66	0.5158	0.5107
15	67-70	0.1000	0.1010
16	71-72	0.1000	0.1004
Total weight(lb)		379.66	380.33

4.3 Discrete optimal design for 25-bar space truss

To verify the validity of discrete optimal design of GA, discrete problems are optimized in this section. Since the design variables are discrete, it is necessary to supply a list of values that the design variables can take. The available sections assumed as design variables are given in the two lists A_1=(0.01, 0.1, 0.2, 0.3, 0.4, ...) (in^2) and A_2=(0.01, 0.4, 0.8, 1.2, 1.6, ...) (in^2), respectively.

Table 13 Optimum results for 25-bar space truss with discrete design variables

Design variable	A_1=(0.01, 0.1, 0.2, 0.3,...)(in^2)			A_2=(0.01, 0.4, 0.8, 1.2,...) (in^2)		
	Ref.[7] Schmit	Ref[8] Stander	GA	Ref.[7] Schmit	Ref.[8] Stander	GA
1	0.10	0.01	0.01	0.40	0.01	0.01
2	2.00	2.10	1.90	2.00	2.00	1.60
3	3.00	3.00	3.00	3.20	3.20	3.60
4	0.01	0.01	0.01	0.01	0.01	0.01
5	0.10	0.01	0.01	0.01	0.01	0.01
6	0.70	0.60	0.80	0.80	0.80	0.80
7	1.70	1.60	1.80	2.00	1.60	2.00
8	2.70	2.80	2.50	2.40	2.80	2.40
Total weight(lb)	553.00	547.04	549.57	575.41	564.86	568.69

The results are given in Table 13 compared with those given in the literatures. It is observed that GA also obtains very close results in discrete optimization.

5. Application of GA Based on Standard Specification for Highway Bridges

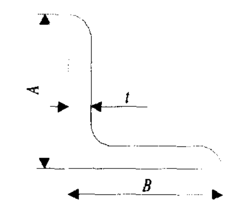
For performing the practical discrete optimal design of truss structures, members are taken from the list shown in Table 14 which is commercially available fabricated sizes. Angle type is used for cross-sections of steel members and these are selected from structural steel types (SS 400, SWS 400, SMA 41, SWS 490, SWS 490Y, SWS 520, SMA 50, SWS 570, SMA 58) by users. Material properties such as the modulus of elasticity and specific weight of steels are taken from Standard Specifications for Highway Bridges.[4]

5.1 25-bar space truss

At first example, discrete optimal design is performed with 25-bar space truss structure equal to the truss in section 4.1. The material

Table 14 Steel properties for the angle type

Dimension(mm)			Area (cm²)	Radius of gyration (cm)	Dimension(mm)			Area (cm²)	Radius of gyration (cm)
No.	A×B	t			No.	A×B	t		
1	25×25	3	1.427	0.483	25	100×100	10	19.00	1.95
2	30×30	3	1.727	0.585	26	100×100	13	24.31	1.94
3	40×40	3	2.336	0.79	27	120×120	8	18.76	2.38
4	40×40	5	3.755	0.77	28	130×130	9	22.74	2.57
5	45×45	4	3.492	0.88	29	130×130	12	29.76	2.54
6	45×45	5	4.302	0.874	30	130×130	15	36.75	2.53
7	50×50	4	3.892	0.98	31	150×150	12	34.77	2.96
8	50×50	5	4.802	0.976	32	150×150	15	42.74	2.92
9	50×50	6	5.644	0.963	33	150×150	19	53.38	2.91
10	60×60	4	4.692	1.19	34	175×175	12	40.52	3.44
11	60×60	5	5.802	1.18	35	175×175	15	50.21	3.42
12	65×65	5	6.367	1.28	36	200×200	15	57.75	3.93
13	65×65	6	7.527	1.27	37	200×200	20	76.00	3.90
14	65×65	8	9.761	1.25	38	200×200	25	93.75	3.88
15	70×70	6	8.127	1.37	39	250×250	25	119.4	4.90
16	75×75	6	8.727	1.48	40	250×250	35	162.6	4.83
17	75×75	9	12.69	1.45					
18	75×75	12	16.56	1.44					
19	80×80	6	9.327	1.58					
20	90×90	6	10.55	1.78					
21	90×90	7	12.22	1.77					
22	90×90	10	17.00	1.74					
23	90×90	13	21.71	1.73					
24	100×100	7	13.62	1.98					



properties, allowable displacements, and nodal load components are shown in Table 15~17.

Since stress constraints are classified into four parts according to what steel type is selected from nine steels, optimal designs are performed with four steels, respectively, which are selected from four parts. The results for all the four cases are tabulated in Table 18.

Table 15 Data for 25-bar space truss

Modulus of elasticity	2.047×106kgf/cm²
Specific weight	0.00785kgf/cm³
No. of design variables	8
No. of load cases	2

Table 16 Allowable displacements for 25-bar space truss

Node	Displacement limits (cm)		
	x	y	z
1	±1.0	±1.0	±1.0
2	±1.0	±1.0	±1.0

Table 17 Nodal load components(kgf) for 25-bar space truss

Load case	Node	x	y	z
1	1	454.0	4,540.0	-2,270.0
	2	0.0	4,540.0	-2,270.0
	3	227.0	0.0	0.0
	6	227.0	0.0	0.0
2	1	0.0	9,080.0	-2,270.0
	2	0.0	-9,080.0	-2,270.0

Table 18 Optimum results for 25-bar space truss

Design variable	Member No.	Cross-sectional area(cm²)			
		SS 400	SWS 490	SWS 520	SWS 570
1	1	1.427	2.336	1.427	1.427
2	2-5	18.760	19.000	19.000	19.000
3	6-9	18.760	19.000	19.000	19.000
4	10,11	1.427	1.427	1.427	1.427
5	12,13	2.336	2.336	3.492	3.492
6	14-17	12.220	12.220	16.560	16.560
7	18-21	22.740	22.740	29.760	29.760
8	22-25	18.760	22.740	19.000	19.000
Total weight(kgf)		1,073.21	1,121.48	1,247.89	1,247.89

5.2 72-bar space truss

Discrete optimal design is performed with the truss structure equal to the truss in section 4.2. The material properties, allowable displacements, and nodal load components are shown in Table 19 ~21.

Also, optimal designs are performed with four steels, respectively, and the results for this four cases are presented in Table 22.

Table 19 Data for 72-bar space truss

Modulus of elasticity	2.047×10^6kgf/cm^2
Specific weight	0.00785kgf/cm^3
No. of design variables	16
No. of load cases	2

Table 20 Allowable displacements for 72-bar space truss

Node	Displacement limits(cm)		
	x	y	z
1	±0.635	±0.635	-
2	±0.635	±0.635	-
3	±0.635	±0.635	-
4	±0.635	±0.635	-

Table 21 Nodal load components(kgf) for 72-bar space truss

Load case	Node	x	y	z
1	1	2270.0	2270.0	-2270.0
2	1	0	0	-2270.0
	2	0	0	-2270.0
	3	0	0	-2270.0
	4	0	0	-2270.0

Table 22 Optimum results for 72-bar space truss

Design variable	Member No.	Cross-sectional area(cm^2)			
		SS 400	SWS 490	SWS 520	SWS 570
1	1-4	5.802	5.802	5.644	4.802
2	5-12	7.527	7.527	7.527	7.527
3	13-16	4.692	5.802	5.644	5.802
4	17-18	8.127	8.127	9.761	9.761
5	19-22	5.802	5.802	9.761	5.802
6	23-30	5.802	5.802	5.802	6.367
7	31-34	1.427	1.427	1.427	1.427
8	35-36	1.727	1.427	1.427	1.427
9	37-40	5.802	5.802	5.802	5.644
10	41-48	5.802	5.802	5.802	7.527
11	49-52	1.427	1.427	1.427	1.427
12	53-54	1.427	1.427	1.427	1.427
13	55-58	9.761	5.802	7.527	7.527
14	59-66	5.802	5.802	5.802	7.527
15	67-70	1.427	1.427	1.427	1.427
16	71-72	1.427	1.427	1.427	1.427
Total weight(kgf)		835.469	825.117	861.107	924.812

6. Conclusions

This study describes the application of GA in the practical discrete optimal design of truss structures. As a result of performing the optimal design of 25-bar and 72-bar truss structures with continuous and discrete design variables to verify the validity and applicability of GA, it shows that GA is able to obtain the contented optimal solutions. GA could solve the constraints which are changed at any time by steel type, shape type and slenderness of members using the exterior penalty function. Also, this study showed the practical design of trusses by performing the optimal design of trusses based on Standard Specifications for Highway Bridges, and by selecting freely the the structural steel types by users.

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