Optimum Design of Lattice Dome by Genetic Algorithm

AUTHORS

FUMIHIKO ASANO[1] * — Graduate Student, graduate school of Natural Science and Technology, Kobe University, Kobe, Japan.

KAZUTOSHI TSUTSUMI[2] — Engineer Design Administration Department, Fujita Co., Dr.Eng., Tokyo, Japan.

TERUMASA MIURA[3] — Engineer Design Administration Department, Fujita Co., Tokyo, Japan.

AKINORI TANI[4] — Associate Professor, Dr.Eng., Department of Architecture and Civil Engineering, Faculty of Engineering, Kobe University, Kobe, Japan.

HIROSHI KAWAMURA[5] — Professor, Dr.Eng., Department of Architecture and Civil Engineering, Faculty of Engineering, Kobe University, Kobe, Japan.

ADDRESSES

[1], [4], [5] : KAWAMURA-Laboratory, 1-1 Rokkodai, Nada, Kobe, 657-8501, Japan.
[2], [3] : Fujita Co. Engineer Design Division, 4-6-15 Sendagaya, Shibuya, Tokyo, 151-0051, Japan.

Phone: +81 78 803 1015 Fax: +81 78 803 1010 E-mail: 977t001n@ipc.kobe-u.ac.jp

1. INTRODUCTION

Lattice dome[1] is very light and rigid structure. So it is suitable for space structure. However, it takes very long time to analyze mechanical behaviors of lattice dome accurately. Due to a great number of parameters, the combinations become very immense and it is difficult to search an optimal dome one by one in all combinations.

GA (genetic algorithm)[2] is well known because of the comparatively good ability to get optimal solutions of various combination problems in a short time.

This paper proposes a practical optimization method of the structural planning of single layer lattice domes by GA.

In this paper, an objective network pattern of domes is assumed to be GRID DOME. (cf. Fig.1)

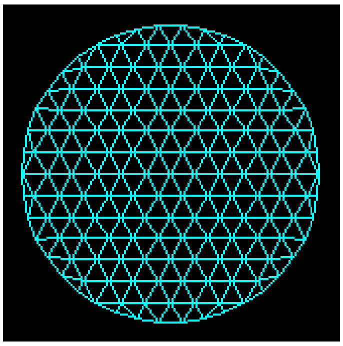


Fig.1 Grid Dome

2. ANALYSIS OF DOME

In this paper, the following 6 parameters are employed to determine the configuration of grid dome and its structural members.

P_1 : Diameter of dome: **L**.
P_2 : Rise ratio.
Rise ratio is defined the ratio of the height of dome **H** to the diameter of dome **L**.
P_3 : Approximate length of structural members: **l**.
The division number of dome **Ndvi** is calculated by the following Eq. (2-1) with .**l**, the radius of curvature **RR** and **theta** shown in Fig.2.

$$\mathrm{Ndvi} = \mathrm{Round}\left(\frac{\mathrm{RR} \times \mathrm{theta}}{\mathrm{l}}\right) \qquad (2-1)$$

The division number **Ndvi** is integer.

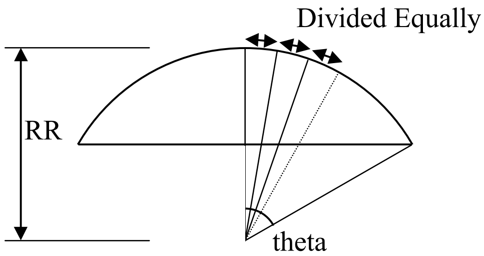


Fig.2 The Division Number Of Dome

P_4 : Ratio of diameter to length of structural member.
It is defined by **r**/**l**.
Here, **r** denotes the diameter of a structural member.
P_5 : Ratio of thickness to diameter of structural member.
It defined by **t**/**r**.
Here, **t** denotes the thickness of a structural member, respectively as shown in Fig.3. **t** is defined as for top member of dome. In this paper, steel tubular members are employed as structural ones and these members are made of ready-made steel plates of which values of thickness are assumed to be 4, 6, 9, 12, 16, 19, 22, 25, 28, 30, 32, 35mm.

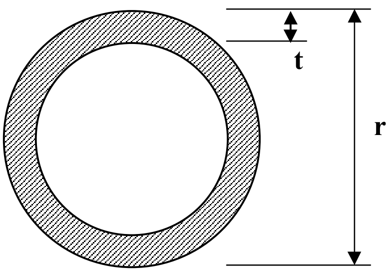


Fig.3 Section of Structural Member

P_6 : Difference step of thickness between the structural members at the top and the bottom of dome.
In this paper, the thickness of structural members is changed at the location of them. For example, if **P_6** = 2 and the thickness of structural member at the top of dome is 12mm, thickness of structural member at the bottom of dome is 19mm which is given by the 2 step up number in the series of numbers mentioned above. The values of thickness of the other members are interpolated as the location of them.

By using these 6 parameters, exact values of structural members are calculated and the dome configuration is determined. To discuss the stability, deformation, equivalent weight, and so on, it is necessary to perform structural analysis of objective dome. However, it takes a long time to perform structural analysis generally. In this paper, multi-layered neural network is employed to perform the structural analysis in practical time. Fig.4 shows the configuration of a multi-layered neural network. This network has 3 layers, i.e., input, hidden and output layers. Input layer has 6 units and these correspond to 6 parameters mentioned before. Output layer has 1 unit because network is trained for the deformation at the top of dome, global buckling load, axial load of the structural member and reactions one by one in this paper.

To make training data, structural analyses are carried out. In these structural analyses, 3 cases of values in each parameter as shown in Table1 are used. However, all the combinations of these parameters become 729. To reduce the number of combination, 'The Design of Experiments' is introduced. Here, by using Latin Squares L81 of this method, 162 combinations are selected. Structural analyses corresponded to these cases are carried out by GTSTRUDL* which is developed in Georgia Institute of Technology, U.S.A.. by using the obtained results of analyses, proposed neural networks are trained by the error back propagation method.

*: GTSTRUDL is a registered service mark of Georgia Tech Research Corporation, Atlanta, Georgia

Table1 Parameters

Case	P_1	P_2	P_3	P_4	P_5	P_6
1	60	0.1	5	0.03	20	0
2	120	0.25	7.5	0.06	45	1
3	180	0.4	10	0.09	70	2

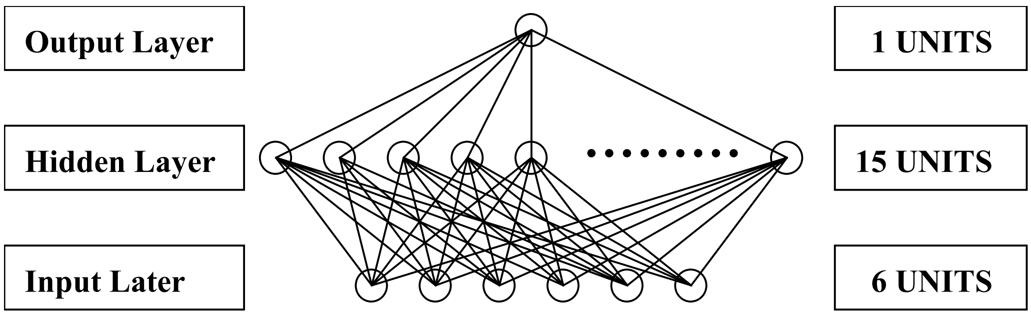


Fig.4 Structure of Neural Network

3. OPTIMUM DESIGN

3-1 System of Optimum Design

In this paper, the diameter of dome is fixed and assumed to be 100 meters. To optimize the configuration of dome and its structural members, genetic algorithm(GA) is employed.

At first, a genotype[2] is assumed as shown in Fig.5. Each set of 3 bits of it corresponds to 5 parameters except for the diameter of dome $\mathbf{P_1}$ mentioned in chapter 2, respectively. Each bit has a binary value, so each parameter can have 8 different values. In these 8 values, the maximal and minimal ones are assumed to be the same as the ones in Table1. The other 6 values are interpolated equally between the maximal and minimal ones.

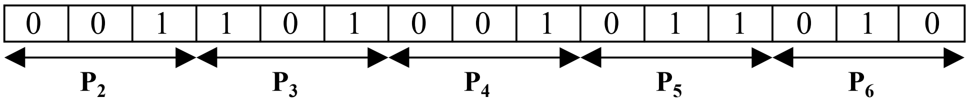


Fig.5 Genotype

The outline of GA operations is as follows.

1) Population size is assumed to be 20. Initially, 20 genotypes are made randomly.
2) Each genotype is evaluated by evaluation functions that will be mentioned later and the fitness value is calculated.
3) 5 genotypes which have higher fitness values than others are selected as parents and genotypes in the next generation are generated by the operation of crossover. The crossover is performed in all the combinations of 5 parents.
4) The operation of mutation is performed in accordance with a given mutation probability.
5) GA operations are repeated until the number of generations equal to 100. The genotype which has the highest fitness values is selected as an optimal one.

Fig.6 shows a flowchart of the proposed optimum design system.

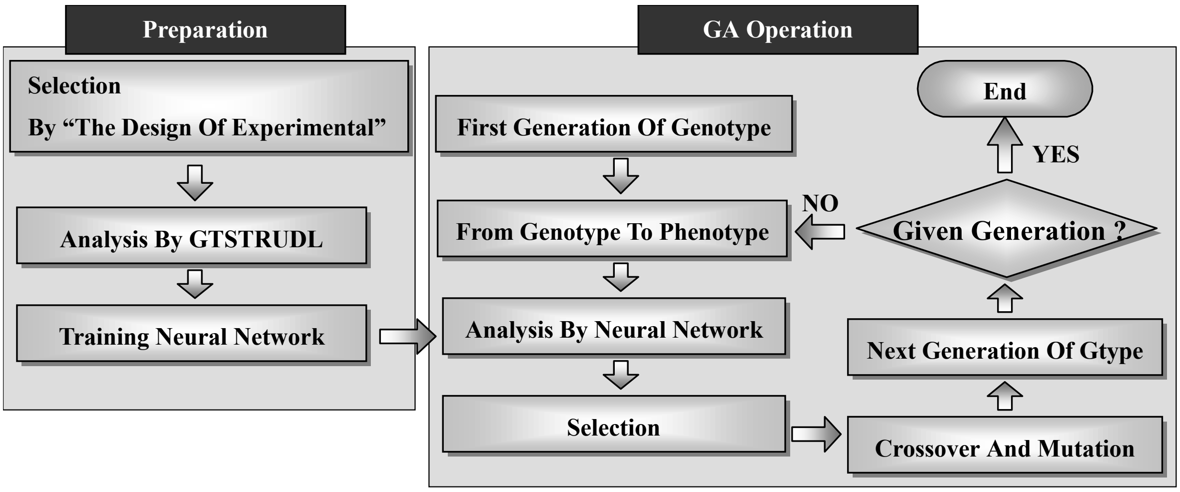


Fig.6 Flowchart of Optimum Design System

3-2 Evaluation Functions

In this paper, optimal domes are determined under the conditions of have designated structural stability and the lowest equivalent weight. Dome is evaluated by 4 evaluation functions i.e., equivalent weight of dome, deformation, buckling load of whole dome and that of structural members. Details of evaluation functions are as follows;

1) Equivalent Weight of Dome: M_1

For the Evaluation of equivalent weight, weight of dome and joint weight in framework are take into account. Joint weight is changed to equivalent weight. This equivalent weight is added to weight of dome so that total equivalent weight of dome can be obtained. As an evaluation function of equivalent weight, the value which are reduced from 5000 by the total weight is an evaluation degree of equivalent weight as shown in Eq.(3-1) and Fig.7(a) because the maximum value is thought to be less than 5000 as followed: Fig.7 (a)

$$M_1 = 5000 - (\text{Weight of Dome} + \text{Equivalent Weight of Joint}) \qquad (3\text{-}1)$$

2) Deformation: M_2

As for the deformation, the evaluation value is calculated by the ratio of deformation of top of dome to diameter as shown in Eqs.(3-2), (3-3) and Fig.7(b).

If 1/200 < Deformation / Diameter

$M_2 = 0,$ (3-2)

If Deformation / Diameter < 1/200

$M_2 = 1.$ (3-3)

3) Buckling Load of Whole Dome: M_3

As for the buckling load of whole dome, the evaluation value is calculated by the buckling factor, i.e., the ratio of buckling load to given load as shown in Eqs.(3-4), (3-5) and Fig.7(c).

If 10 < Buckling Factor

$M_3 = 1,$ (3-4)

If Buckling Factor < 10

$M_3 = 0.$ (3-5)

4) Buckling Load of Structural Members: M_4

As for the buckling load of structural members, the evaluation value is calculated by the buckling factor, i.e., the ratio of buckling load to given load as shown in Eqs.(3-6), (3-7) and Fig.7(d).

If 10 < Buckling Factor

$M_4 = 1,$ (3-6)

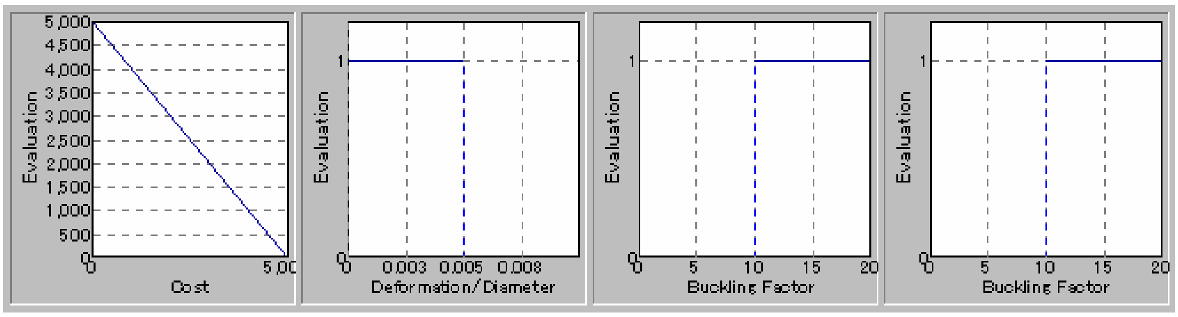
If Buckling Factor < 10

$M_4 = 0.$ (3-7)

Total Evaluation: M

The total evaluation value of dome is given by the following Eq.(3-8).

$M = M_1 * M_2 * M_3 * M_4$ (3-8)



(a) (b) (c) (d)

Fig.7 Evaluation Functions

3.3 Result and Inspection

Generally, obtained results are varied when the initial value of a random number generator used is changed. To discuss the effect of the initial values of random number generator, 10 times trials are performed. Table2 shows the results of these trials. Fig.8 shows a example of transitional curves on evaluation values such as maximal, average and minimal ones.

Furthermore, the perfect optimum design by all the combinations of 5 parameters is performed to discuss the proposed method. In this case, the number of combinations are 32768(=8^5). Table3 shows the results of this calculation which have the first 10 ranks.

Table2 Optimal Results (in case of GA)

Case	1	2	3	4	5	6	7	8	9	10
Generation	55	12	28	80	41	16	59	20	4	9
P_2	.143	.143	.143	.143	.143	.143	.143	.143	.143	.186
P_3	5	5	5	5	7.14	7.14	5	5	5	5
P_4	.064	.064	.064	.064	.073	.073	.064	.064	.064	.064
P_5	55.7	55.7	62.9	55.7	70.0	70.0	48.6	62.9	55.7	48.6
P_6	0	0	0	0	0	0	0	0	0	0
Evaluation M	4656.5	4656.5	4656.5	4656.5	4635.9	4635.9	4656.5	4656.5	4656.5	4648.5

Table3 Optimal Results (in case of all the combinations of given parameters)

Optimal Order	1	2	3	4	5	6	7	8	9	10
P_2	.143	.143	.186	.186	.186	.142	.186	.186	.186	.142
P_3	5	5	5	5	5	7.14	5.71	5.71	5.71	5.71
P_4	.064	.064	.064	.064	.064	.073	.064	.064	.064	.073
P_5	55.7	62.9	48.6	55.7	62.9	70.0	55.7	62.9	70.0	55.7
P_6	0	0	0	0	0	0	0	0	0	0
Evaluation M	4656.5	4656.5	4648.5	4648.5	4648.5	4635.9	4632.7	4632.7	4632.7	4631.6

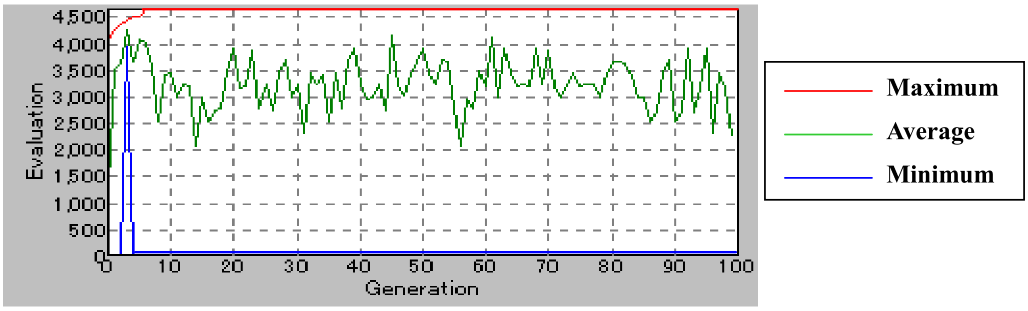


Fig.8 Transitional Curve

4 DISCUSSION AND CONCLUSION

The optimal results in case of GA appeared in the 32.4th generation on average. It means that about 650 models of dome were evaluated and these are about 2% of all the combinations. Though only 7 cases in the GA results agreed with the most optimal result in case of all the combinations, another cases obtained such a high evaluation less than the first 6 ranks. As shown in Fig.8, i.e., one of examples of the transitional evaluation curves, maximal evaluation values were obtained in pretty early generation.

In this paper, the optimal design system of grid dome is proposed by using genetic algorithm. The results of simulations show that genetic algorithm(GA) is an very effective tool on multi-objective optimization problems. It is also proved that the proposed method is very effective and can determine the optimal configuration of grid dome and its structural members in a short time. The proposed method can be applied another network patterns of dome easily[6][7][8].

REFERENSE

[1] Heki, K., Hangai, M., Kato, S. and Yamada, H., Stability Analysis of Lattice Dome, Subcommitee on Space Frame, Managing Committee on Shell and Space Frame, Architecture Institute of Japan, 1989, (in Japanese).
[2] Holland, J. H. 'Adaptation in natural and artificial systems', MIT Press, Second Printing, 1993.
[3] Tanaka Y., Narumi T. (Eds.), 'Handbook of Structural Analysis by Personal Computer, 3 Design of Experiments', Kyoritsu Shuppan, 323(9), 1986, (in Japanese).
[4] Rumelhart, D. E., Hinton, G. E., Wikkams, R. J., 'Leaning Representation by Back-Propagating Errors', Nature, 1986.
[5] Yagi, K. and Suzuki, Y., Neuro information processing technology, Kaibundo, 1992. (in Japanese)
[6] Asano, F., TsuTsumi, K., Miura, T., Tani, A. and Kawamura H., Optimum Design of Lattice Dome by Genetic Algorithm, Proc. of Annual Meeting of Architectural Institute of Japan, Kinki Branch, Structural Division, pp.365-368, July, 1997. (in Japanese)
[7] Asano, F., TsuTsumi, K., Miura, T., Tani, A. and Kawamura H., Optimum Design of Lattice Dome by Genetic Algorithm, Proc. of Annual Meeting of Architectural Institute of Japan, Vol.A-2, pp.439-440, Sep. 1997. (in Japanese)
[8] Asano, F., TsuTsumi, K., Miura, T., Tani, A. and Kawamura H., Optimum Design of Lattice Dome by Genetic Algorithm, Proc. of 20th Symposium on Computer Technology of Information, Systems and Application, pp.403-408, Dec. 1997. (in Japanese)