

Study of Morphogenesis of a Large-span Roof That Satisfies Its Form Design Requirements

Two-purpose Evaluation of Image and Mechanical Rationality

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Abstract— We developed an idea support morphogenesis system that satisfies the designer's image and proposes the form with high mechanical rationality using a Genetic Algorithm. The image of an old system was input in two directions (X and Y). In the new system, the complex forms are created by the image input for three directions (X1, Y1, and Y2) or four directions (X1, X2, Y1, and Y2). The form is defined by control points of a spline curve. The form created by the image input is changed slightly by moving the control points. This system creates various forms by changing the moving quantities of control points and proposes Pareto solutions of "image" and "mechanical rationality." Based on the results, we analyze how the form is changed by differences in the moving quantities of control points.

Keywords—component; Morphogenesis, Large-span roof, Evolutionary Computation, Designer's image

I. RESEARCH BACKGROUND

The performance of computers has been improving over time, and various system optimizations have been developed by evolutionary computing. [1].

In morphogenesis, there have been many studies of mechanical optimization for structural forms, but there have been few studies of morphogenesis taking into consideration the designer's esthetic sensibility and image. We developed an idea support morphogenesis system that satisfies the form design requirements and proposed the design with a high mechanical rationality using a genetic algorithm (GA). [2] [3].

However, the form design proposed by existing research is limited because of its symmetric form, and the proposed design does not provide a guarantee of satisfying the designer's form requirements.

To resolve these problems and to develop a more effective system, the following improvements were made in this study:

- 1) Enable the input of an asymmetric form design.
- 2) Propose Pareto solutions to a two-purpose optimization problem of "image satisfaction" and "equivalent stress," and develop a system by which the designer can specify the final form.
- 3) Obtain design knowledge related to morphological changes necessary to improve mechanical rationality.

II. OUTLINE OF THE EXISTING SYSTEM

The existing system is composed of an image input system and a rational valuation system.

In the image input system, the designer inputs his image by setting certain control points, and the system displays his image in 3D form.

In the rational valuation system, the control points input by the designer using the image input system are moved slightly, and mechanically excellent roof forms are generated using the GA. The GA can solve this optimization problem easily because genetic loci can easily express the amounts of change in the control points.

In particular, the control points of a spline curve expressing the form are moved slightly along the vertical direction using the 15 patterns listed in Table 1, thus, generating a new form. FEM analysis is performed for this new form, and the fitness of the GA is calculated as the mean value of the analyzed equivalent stresses for each element.

The GA is repeated until the specified generations by the designer and the form with minimum equivalent stress is proposed. The results of these analyses for a similar model of Ogunityoumin-taikukan are shown in Fig. 1.

TABLE 1 Gene locus for changing pattern for the control points

0	0	0	0	$-0.7 \times \alpha(m)$	1	0	0	0	$0.7 \times \alpha(m)$
0	0	0	1	$-0.6 \times \alpha(m)$	1	0	0	1	$0.6 \times \alpha(m)$
0	0	1	0	$-0.5 \times \alpha(m)$	1	0	1	0	$0.5 \times \alpha(m)$
0	0	1	1	$-0.4 \times \alpha(m)$	1	0	1	1	$0.4 \times \alpha(m)$
0	1	0	0	$-0.3 \times \alpha(m)$	1	1	0	0	$0.3 \times \alpha(m)$
0	1	0	1	$-0.2 \times \alpha(m)$	1	1	0	1	$0.2 \times \alpha(m)$
0	1	1	0	$-0.1 \times \alpha(m)$	1	1	1	0	$0.1 \times \alpha(m)$
0	1	1	1	0m	1	1	1	1	0m

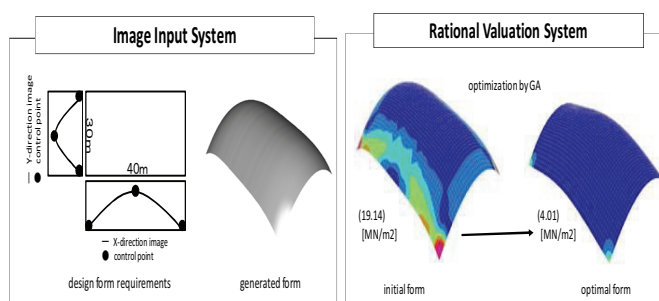


Fig. 1 Analysis results of existing system

III. OUTLINE OF THE NEW SYSTEM

In the existing system, the confronted two facades among the four outer facades are assumed to be the same facade. The designer inputs his image from two directions (X and Y). So, the existing system can create only symmetrical forms.

However, because the designer's proposed form may be asymmetric, the new system was improved to allow creation of asymmetric and complex forms by image input from three facades. The control point variation coefficient α is a variable that shows the amount of movement from the initial image.

In the existing system, the rational valuation system was implemented for the designated control point variation coefficient α by the designer. However, in this method, the obtained optimum solution is limited within that range. It is difficult to specify the control point variation coefficient α , and better optimum solutions may exist outside the designated α . Therefore, we developed a new system in which the rational valuation system was implemented using many control point variation coefficients without using the specified control point variation coefficient by the designer, and supposed the mechanically optimum form for each control point variation coefficient as the Pareto optimal solution of [Change of image] and [Equivalent stress].

The form that satisfies the requirements of both "image satisfaction" and "equivalent stress" is selected by the designer from all elite forms as the final form. The flow chart of the new system is shown in Fig. 2.

IV. APPLICATION EXAMPLE

To obtain design knowledge regarding the morphological changes in each control point variation coefficient, we created model-1, which has curvatures in one direction, and model-2, which has curvatures in two directions, using the image input system. The control points of these models were applied to the rational valuation system by 14 patterns of each control point variation coefficient α from 0.5 to 5.0, with an interval of 0.25. However, the control points of edges were not applied and were not moved. The planar shapes of both model-1 and model-2 are 40 m in the X direction and 30 m in the Y direction.

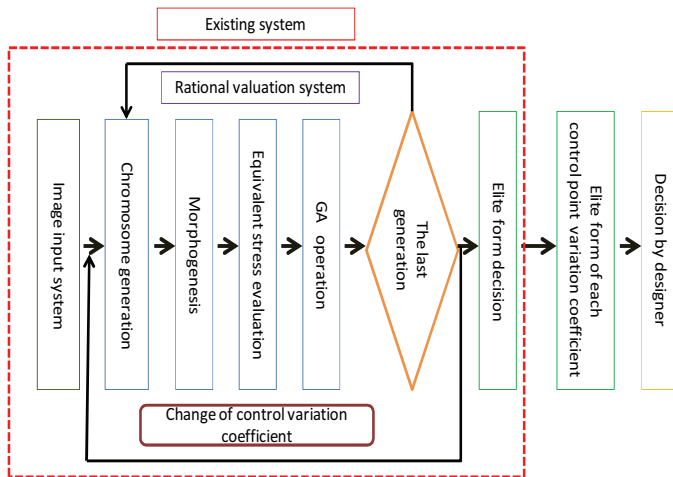


Fig. 2 Flow chart of new system

A. Outline of model-1

The characteristics of model-1 are as follows:

- Roof thickness of 0.15 m, load of 0.0036 MN/m² (only self-weight), modulus of elasticity of 20600 N/mm², and Poisson's ratio of 0.16.
- The parameters of the GA are as follows: The number of individuals is 40, the last generation is 50, the intersection method is a multi-point intersection method, the intersection rate is 100%, and the mutation rate is 5%.
- This model has three control points in the Y1 direction, three control points in the X direction, and five control points in the Y2 direction (Fig. 3).
- The edges are not moved because they are support points. The control points other than the edges are moved.
- This model has a single curvature in the X and Y1 directions, and multiple curvatures in the Y2 direction.
- The fitness of the GA is equal to the equivalent stress, which is calculated on the basis of the Mises yield criterion.

B. Execution results of model-1

Figure 4 shows the relationship between the control point variation coefficient α and the equivalent stress obtained from the analytical results. Figure 5 shows the elite forms of each control point variation coefficient. Figure 6 shows the relationship between the vertical coordinate values of the control points and the control point variation coefficient α .

The following points should be considered:

- 1) The equivalent stress converges when α exceeds 3.5 (Fig. 4), and the vertical coordinates of the control points (No. 8, 9, and 10 in the Y2 direction) with multiple curvatures become almost equal. This shows that mechanical rationality tends to increase when a curved surface with multiple curvatures is transformed to a curved surface with a single curvature.
- 2) Control point No. 2 in the Y1 direction and control point No. 5 in the X direction, each of which has a single curvature, tended to move in the direction in which the rise ratio increased.

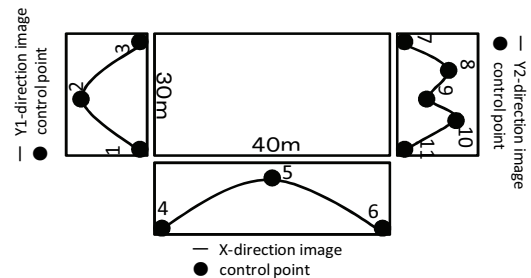


Fig. 3 Control points of model-1

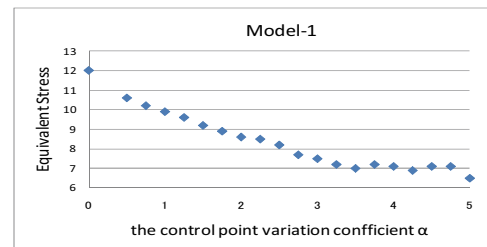


Fig. 4 Relation of equivalent stress and the control point variation coefficient α

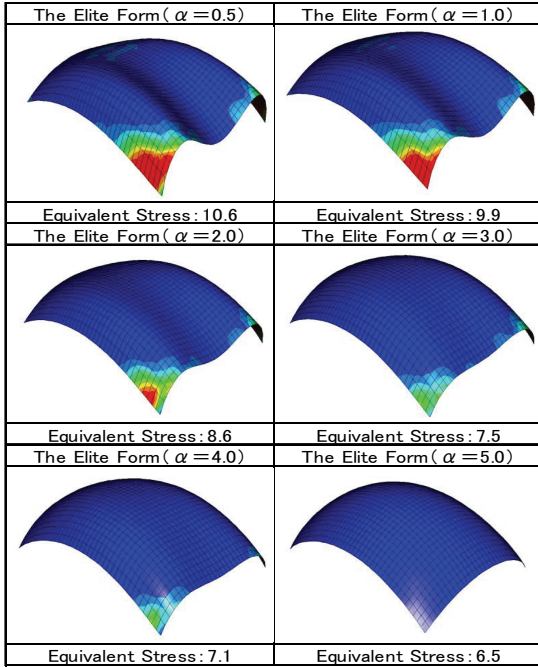


Fig. 5 Elite forms per the control point variation coefficient α

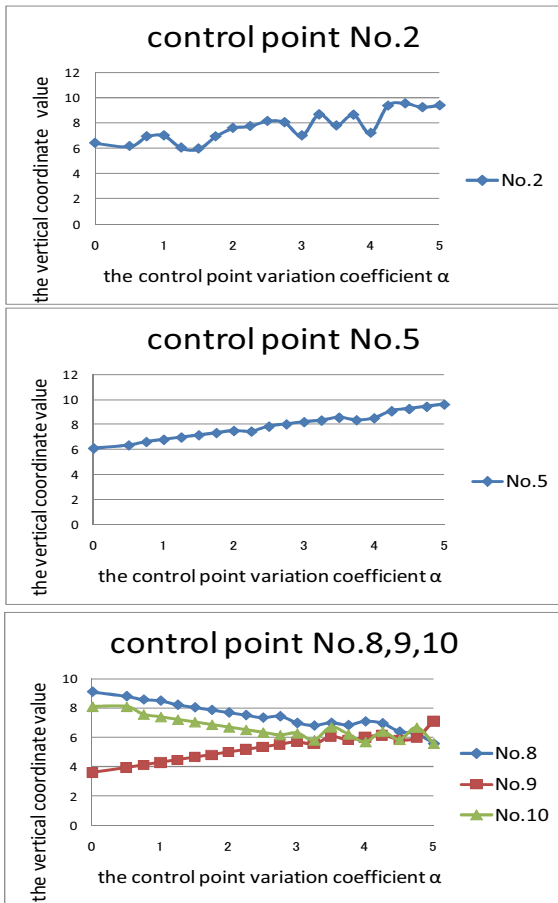


Fig. 6 Relation of the vertical coordinates of control points and the control point variation coefficient α

C. Outline of model-2

The characteristics of model-2 are as follows:

- Roof thickness of 0.15 m, load of 0.0036 MN/m² (only self-weight), modulus of elasticity of 20600 N/mm², and Poisson's ratio of 0.16.
- The parameters of the GA are as follows: The number of individuals is 40, the last generation is 50, the intersection method is a multi-point intersection method, the intersection rate is 100%, and the mutation rate is 5% (Fig. 7).
- This model has three control points in the Y1 direction, five control points in the X direction, and five control points in the Y2 direction.
- The edges are not moved because they are support points. The control points other than the edges are moved.
- This model has a single curvature in the X direction and multiple curvatures in the Y1 and Y2 directions.
- The fitness of the GA is equal to the equivalent stress, which is calculated on the basis of the Mises yield criterion.

D. Execution results of model-2

Figure 8 shows the relationship between the control point variation coefficient α and the equivalent stress obtained from the analytical results. Figure 9 shows the elite forms of each control point variation coefficient. Figure 10 shows the relationship between the vertical coordinate values of the control points and the control point variation coefficient α .

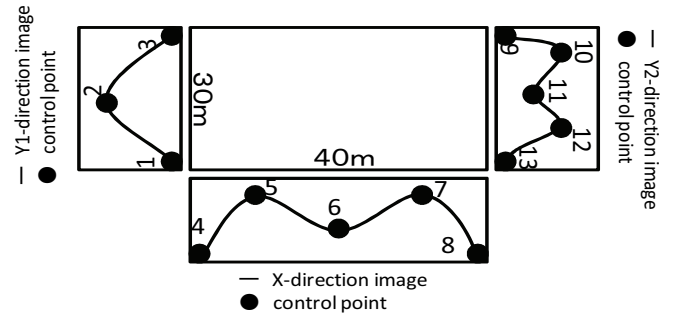


Fig. 7 Control points of model-2

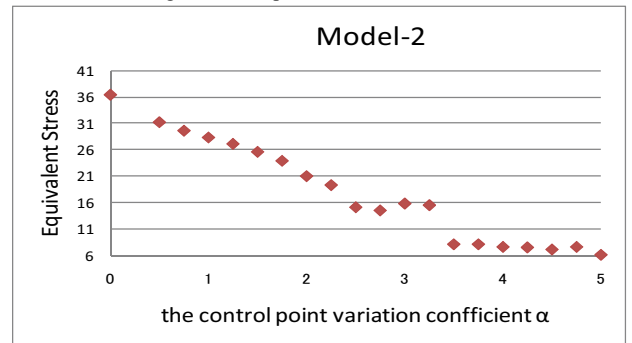


Fig. 8 Relation of equivalent stress and the control point variation coefficient α

- 1) In the case of model 2, the equivalent stress converges into two stages. The first convergence occurs when the control point variation coefficient α exceeds 2.5, and the vertical coordinates of the control points (No. 5, 6, and 7 in the X direction) with multiple curvatures become almost equal. That is, convergence occurs when a surface with multiple curvatures transforms to a surface with a single curvature.
- 2) The second convergence occurs when the control point variation coefficient α exceeds 3.5, and the vertical coordinates of the control points (No. 10, 11, and 12 in the Y2 direction) with multiple curvatures become almost equal. That is, convergence occurs when a surface with multiple curvatures transforms to a surface with a single curvature. Control point No. 2 in the Y1 direction, which has a single curvature, tends to move in the direction in which the rise ratio increases.

V. CONCLUSIONS

The following conclusions can be drawn from this study:

- 1) The equivalent stress decreases with an increase in the control point variation coefficient; however, the difference in the form image from the initial form increases. Thus, there is a trade-off between “image satisfaction” and “equivalent stress.”
- 2) It becomes possible for the designer to select the form with both high image and mechanical rationality by proposing several elite forms for each control point variation coefficient.
- 3) From the execution results of model-1 and model-2, it is clear that mechanical rationality increases when a surface with multiple curvatures transforms to a surface with a single curvature.

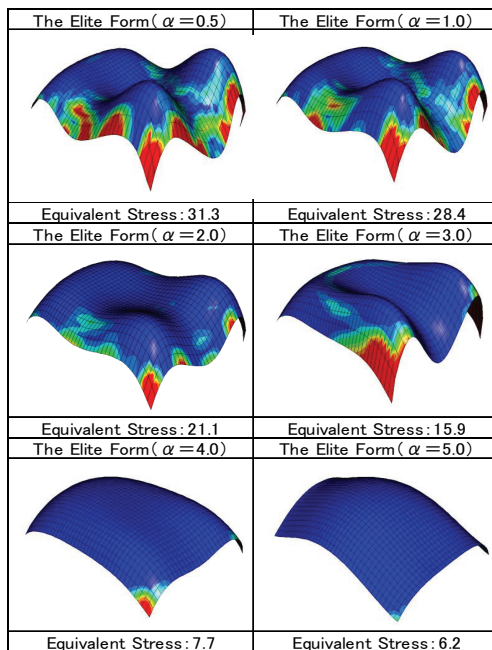


Fig. 9 Elite forms per the control point variation coefficient α

VI. FUTURE TASKS

We intend to improve the proposed design in the following manner:

- 1) Input the image from four directions
- 2) Diversify the planar shape
- 3) Diversify the fitness function

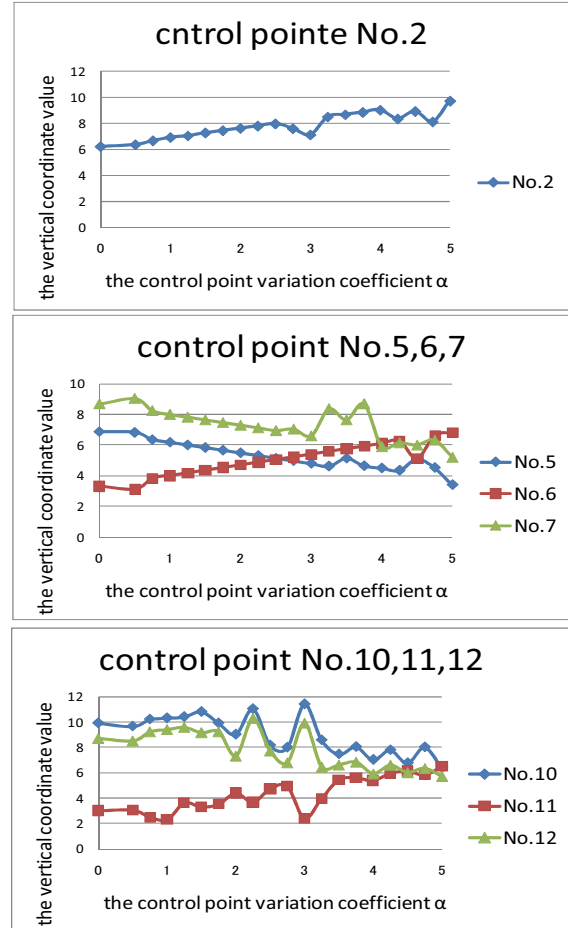


Fig. 10 Relation of the vertical coordinates of control points and the control point variation coefficient α

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