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A STUDY OF THE OPTIMAL DESIGN AND MECHANICS SENSIBILITY IN THREE HINGE TRUSS

"For two asymmetrical truss with different or equal component section sizes"

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・ ABSTRACT

In carrying out a structural design, mechanics sensibility is important. However not all registered architects have sufficient mechanics sensibility. The purpose of this research is to offer the design know-how by analysis of the optimal solution in order to cultivate mechanics sensibility. This research formulates the form height and the section depth size, with the minimum weight for the load and span length, for a three hinge H-beam truss, using the admissible stress formula of compression. Analysis and verification of the form are performed by parameter analysis after formulation, and then the differences between both patterns are considered.

This research compared 2 patterns for an asymmetric three hinge truss. The conclusions gained are as follows:

1) In terms of form height, a truss with a same section size will be higher than that with a different section size.

2) In terms of section size, for a section size of short span, a pattern with same component section size is larger than that with different component section sizes. On the other hand, for section size of long span, a pattern with different component section size is larger than that with same component section sizes.

The above-mentioned conclusions contribute to design know-how for three hinge trusses, with such know-how being effective to cultivate mechanics sensibility.

・ KEYWORDS

Mechanics sensibility, Mechanics rationality, Design know-how, Optimal design

1. INTRODUCTION

In carrying out a structural design, mechanics sensibility is important. However not all registered architects have sufficient mechanics sensibility. In order to cultivate sensibility generally, it is important to experience a "genuine article ". What is the "genuine article" for mechanics sensibility? In this research, the minimum weight solution is treated as the "genuine article". It is thought that by analyzing the mechanics rational forms which become minimum weight, under the structure form to which the domain for a design, the loading condition, and the boundary condition were set, it is possible to gain design knowhow. The objects of this paper are as follows:

・ The asymmetrical truss with different component section sizes and with compression force
・ The asymmetrical truss with equal component section sizes and with compression force

The purpose of this research is to determine the form height and the section depth size with the minimum weight for the load and span length and height position, and it is to provide design know-how by comparing both patterns in order to cultivate mechanics sensibility.

2. The asymmetrical truss with different component section sizes and with compression force

This model is shown in Figure 1. Although section shape does not need to be considered for a tension member, the section shape does need to be considered for a compression member with buckling phenomenon. The section shape parameters of a component are shown in Figure 2.

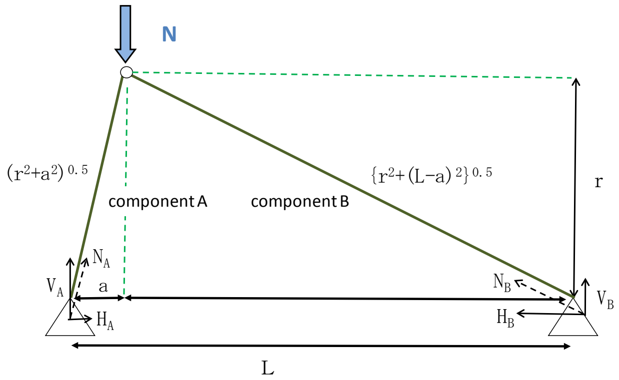


Figure 1. Model

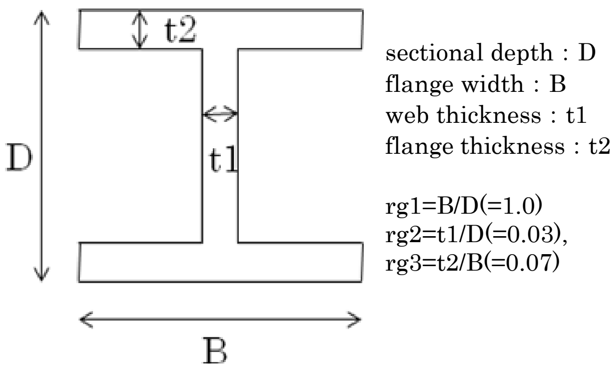


Figure 2. The form ratio of a section

2-1. Analysis method

This research formulates the form height with the minimum weight for the load and span, using the admissible stress formula of tension and compression. The optimal form with mechanics rationality is searched using the created formula. Analysis and verification of the form are performed by parameter analysis.

2-2. Formulization

For the formulization, refer to the last paper. (Toru Katori, 2012)

2-3.Analysis result

When the values of N were from 100 to 200 [kN] at 20 [kN] intervals, the values of L were from 300 to 600 [cm] at 50 [cm] intervals, the values of section depth size of the component A of assumption 2 and 3 and the section depth size of the component B of assumption 3 were from 1 to 20 [cm] at 0.01 [cm] intervals, and the values of a1 were from 0.1 to 0.5 at 0.1 intervals, the form height and the sectional depth size with the minimum weight were computed. The sectional depth size ratio and the height ratio are shown from Figure 3 to Figure 5. Here, the value of compressive force, span length, and material strength are normalized as a formula (1) in order to give general versatility.

$$N1=\frac{N}{F\cdot L^2}, r1=\frac{r}{L}, a1=\frac{a}{L}, D_A1=\frac{D_A}{L}, \frac{a}{L}, D_B1=\frac{D_B}{L}, \frac{a}{L} \quad (1)$$

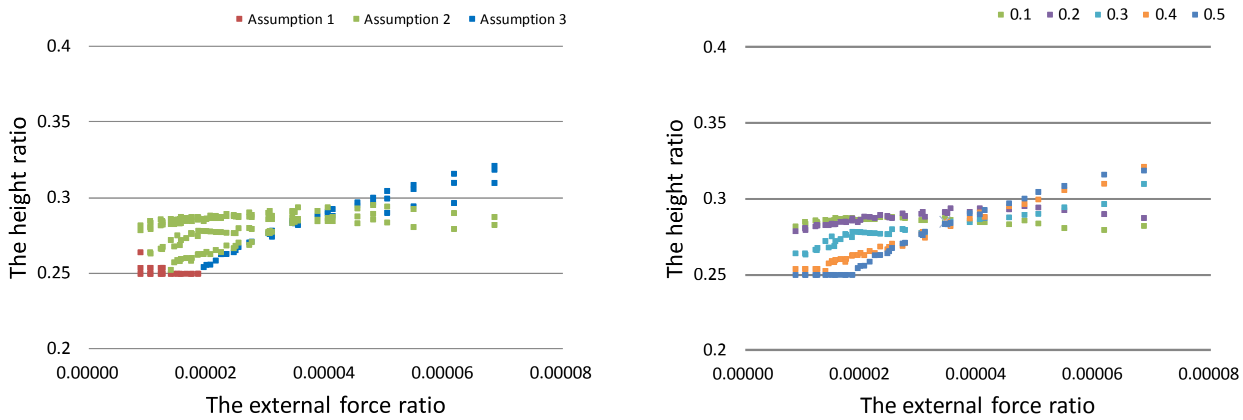


Figure 3. The height ratio for different component section size

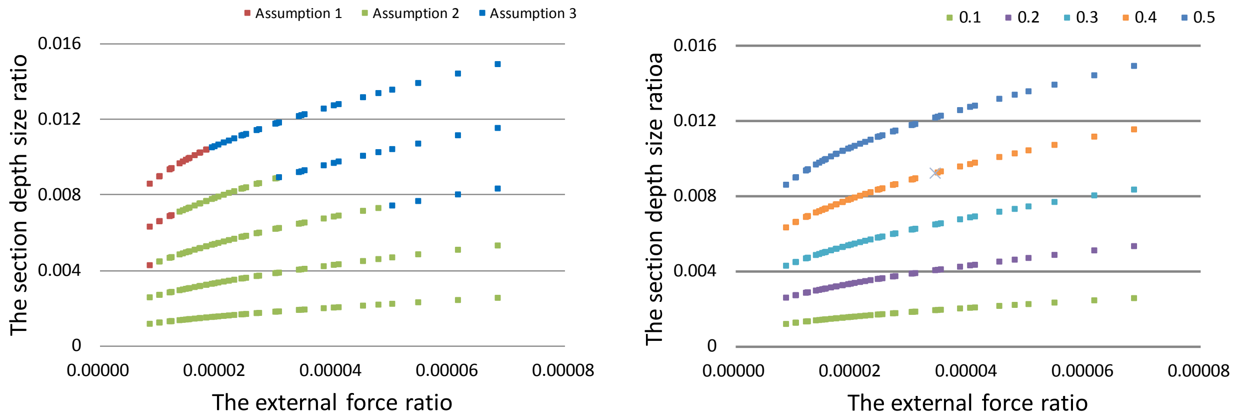


Figure 4. The section depth size ratio of the component A for different component section size

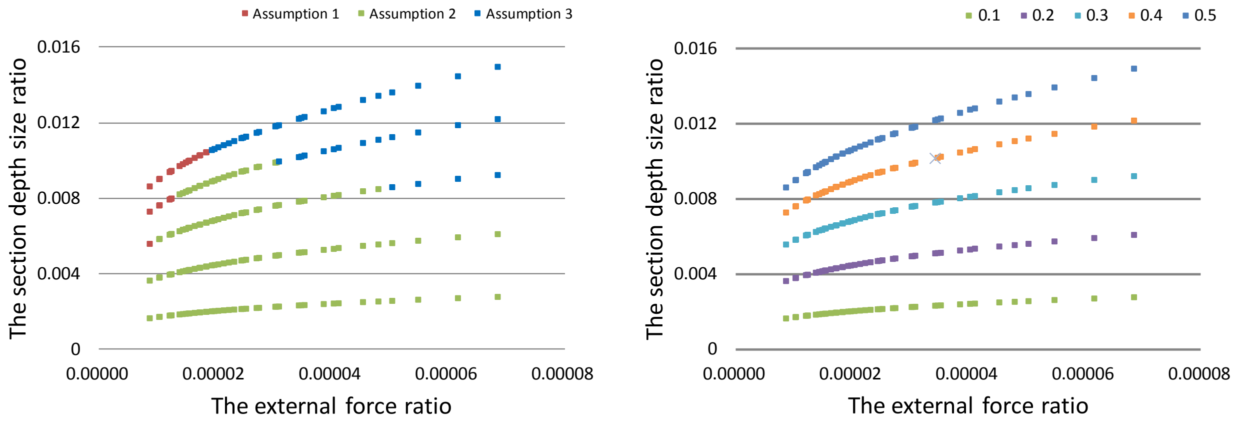


Figure 5. The section depth size ratio of the component B for different component section size

2-4. Verification and the approximate expressions of exponential functions

Figure 3 to 5 show that the height ratio of assumption 1 can be approximated as a straight line. The height ratio of assumption 2 and 3 and the section depth size ratio can be approximated as the exponential functions. The approximate expressions of assumption 1 and 3 of the height ratio were determined by using the values of a1=0.3, 0.5. The approximate expressions of assumption 2 of the height ratio were determined by using the values of a1=0.1, 0.4. The approximate expressions of the section depth size ratio were determined by using the values of a1=0.1, 0.3, 0.5. The approximate expressions are expressed from a formula (2) to (6).

・The height ratio for the external force ratio and height position ratio

Assumption 1: $r1' = -0.0706a1 + 0.2853$ (2)

Assumption 2: $r1' = (1.4115a1+0.1168)N1^{(0.315a1-0.037)}$ (3)

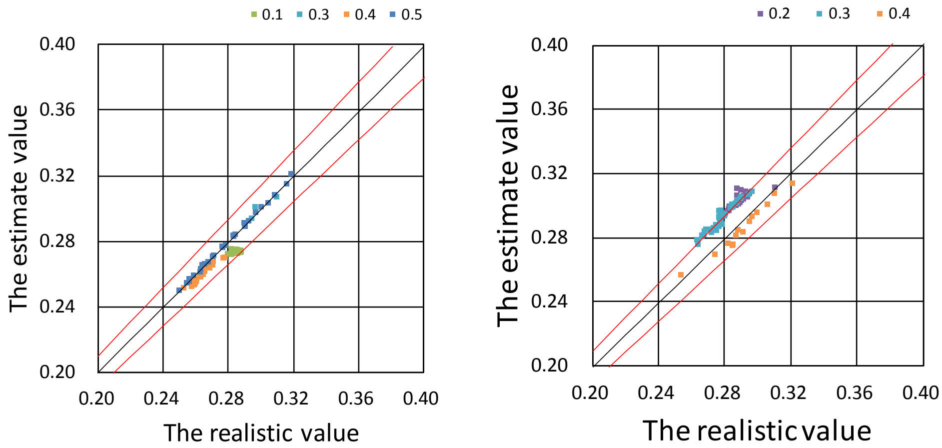
Assumption 3: $r1' = (-0.749a1 + 2.243)N1^{(-0.0635a1 + 0.2154)}$ (4)

・The section depth size ratio for the external force ratio and height position ratio

The component A: $D1A' = (-1.2162a1^2+0.9635a1-0.0023)\ N1^{(-0.2603a1+0.3921)}$ (5)

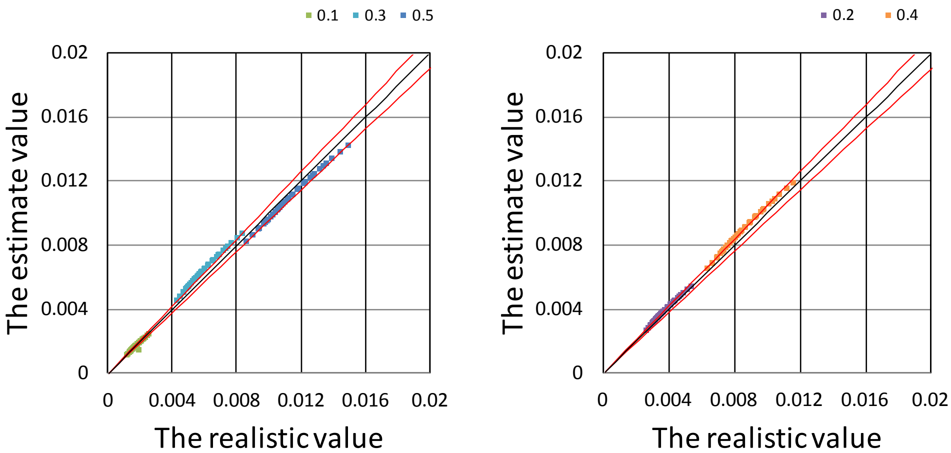
The component B: $D1B' = (0.3615a1-0.0083)\ N1^{(0.0198a1+ 0.2445)}$ (6)

We carried out numerical experiments in order to check the validity from formula (2) to (6). The validity of the height ratio of assumption 1 and 3 was verified for a1=0.4, the validity of the height ratio of assumption 2 was verified for a1=0.2, 0.3, and the validity of the section depth size ratio was verified for a1=0.2, 0.4. The form height and the sectional depth size with the minimum weight were computed. The relation between the assumed height ratio and an actual height ratio is shown in Figure 6. The relation between the assumed section depth size ratio and the actual section depth size ratio is shown in Figure 7 and Figure 8.



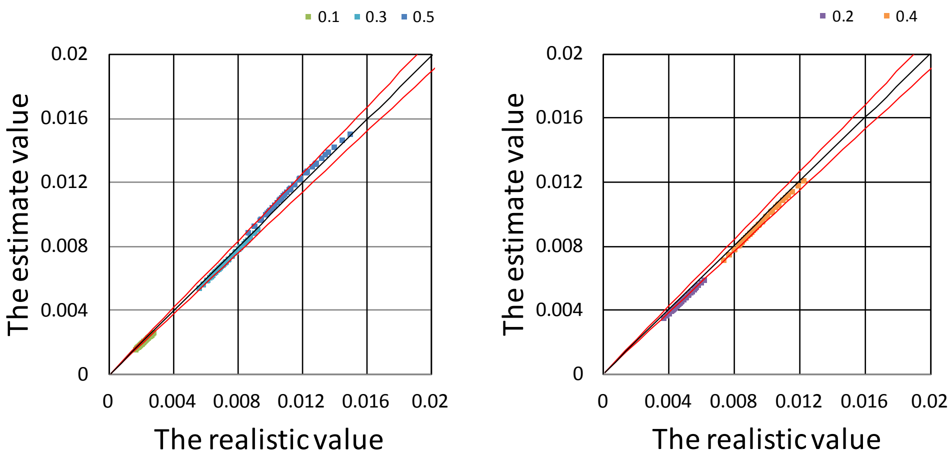
(a) Learning data (b) Verification data

Figure 6. The height ratio for different component section size



(a) Learning data (b) Verification data

Figure 7. The section depth size ratio of the component A for different section component size



(a) Learning data (b) Verification data

Figure 8. The section depth size ratio of the component B for different section component size

2-5.Consideration

The following results were found:

1. Assumption 1 is dependent on the height position and the span length regardless of external force or material strength. However, assumption 2 and assumption 3 are dependent on external force, material strength, the span length, and the height position.
2. In terms of height ratio, from Figure 3 to 5 show that in the range from a1=0.1 to 0.2 only assumption 2 is present. In the range from a1=0.3 to 0.4, all from assumption 1 to 3 are present. And at a1=0.5, assumption 1 and 3 are present.
3. As the value of a1 increases, the actual section depth size ratio becomes larger. Furthermore, the increment of the actual section depth size ratio for the vertex position ratio is the same degree.
4. The approximation formula of height ratio in assumption 1 can be expressed by a straight line. The approximation formula of height ratio in assumption 2, 3, and the approximation formula of actual section depth size ratio can be expressed by an exponential function of the force ratio. Figure 6 to 8 show that the accuracy of the approximate expression is good.
5. In terms of the height ratio, Figure 3 to 5 show that an inversion phenomenon occurred for the vertex position ratio. On the other hand, this did not occur for the actual section depth size ratio. In regards to this too, further investigations will be carried out.

3. The asymmetrical truss with same component section sizes and with compression force

This model and the section shape parameters of a component are shown in Figure 1 and Figure 2.

3-1. Analysis method

When the span length and height form, height position ratio, and the form height were set, the sectional depth sizes with the minimum weight were computed. When determining the member section, the stress ratio of the two components was compared, and the section size of member component whose stress ratio is close to the 1 is adopted.

3-2. Analysis result

When the values of N were from 100 to 200 [kN] at 20 [kN] intervals, the values of L were from 300 to 600 [cm] at 50 [cm] intervals, the values of the form height were from 50 to 200 [cm] at 0.05 [cm] intervals, the values of section depth size were from 1 to 20 [cm] at 0.01 [cm] intervals, and the values of a1 were from 0.1 to 0.5 at 0.1 intervals, the form height and the sectional depth size with the minimum weight were computed. The sectional depth size ratio and the height ratio is shown in Figure 9 and Figure 10. Here, the value of compressive force, span length, and material strength are normalized as a formula (1) in order to give general versatility.

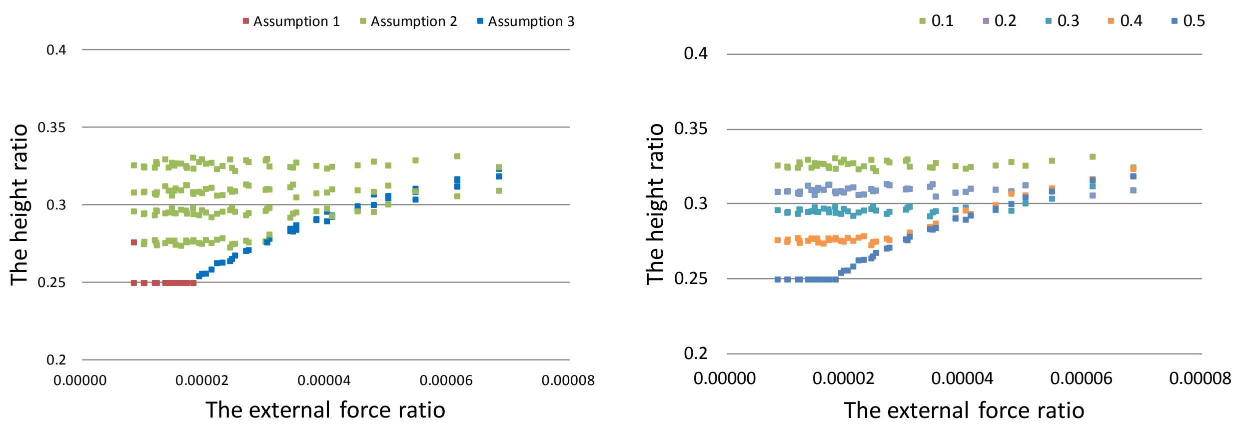


Figure 9. The height ratio for same component section size :

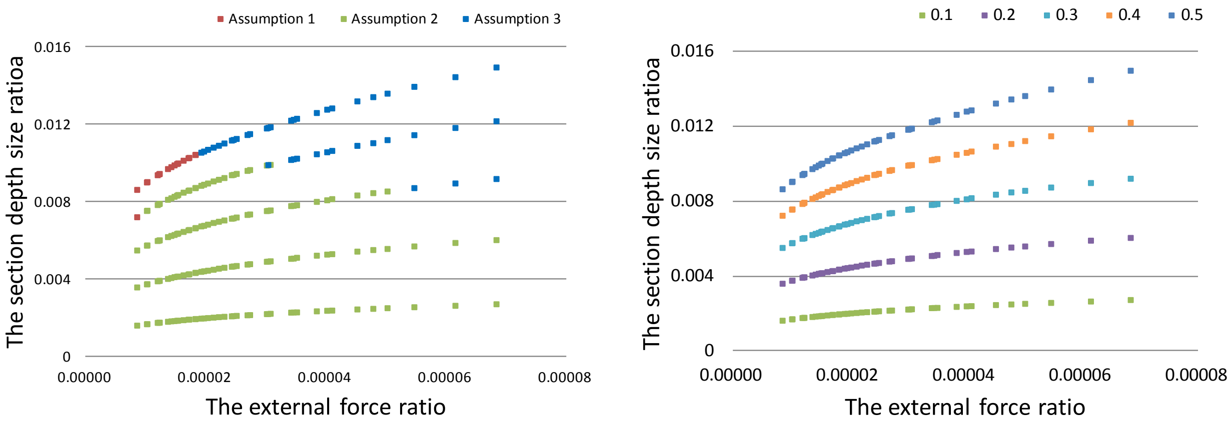


Figure 10. The section depth size ratio for same component section size

3-3. The approximate expressions of exponential functions, and Verification

Figure 9, 10 shows that the height ratio of assumption 1 and 2 can be expressed by straight lines. The height ratio of assumption 3 and the section depth size ratio can be expressed by exponential functions. The approximate expressions of assumption 1 and 2 of the height ratio were determined by using the values of a1=0.1, 0.3, 0.5. The approximate expressions of assumption 3 of the height ratio were determined by using the values of a1=0.3, 0.5. The approximate expressions of the section depth size ratio were determined by using the values of a1=0.1, 0.3, 0.5. The approximate expressions are expressed from formulas (7) to (9).

・The height ratio relation with the external force ratio and height position ratio

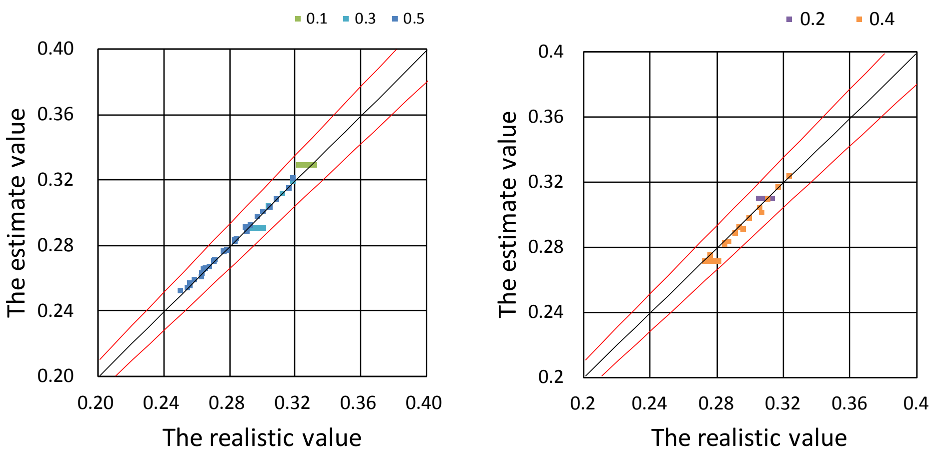
Assumption 1, 2: $r1' = -0.1916a1 + 0.3483$ (7)

Assumption 3: $r1' = (-3.345a1 + 3.541)N1^{(-0.163a1 + 0.2651)}$ (8)

・The section depth size ratio relation with the external force ratio and height position ratio

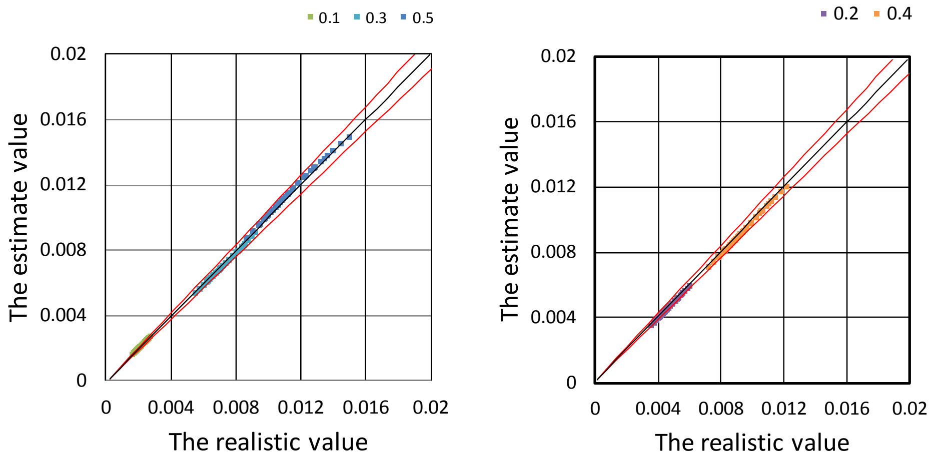
$D1' = (0.364a1 - 0.0074)N1^{(0.022a1 + 0.2457)}$ (9)

We carried out numerical experiments in order to check the validity from formulas (7) to (9). The validity of the height ratio of assumption 1 and 2 was verified for a1=0.2, 0.4, the validity of the height ratio of assumption 3 was verified for a1=0.4, and the validity of the section depth size ratio was verified for a1=0.2, 0.4. The form height and the sectional depth size with the minimum weight were computed. The relation between the assumed height ratio and an actual height ratio is shown in Figure 11. The relation between the assumed section depth size ratio and the actual section depth size ratio is shown in Figure 12.



(a) Learning data (b) Verification data

Figure 11. The height ratio for same component section size



(a) Learning data (b) Verification data

Figure 12. The section depth size ratio for same component section size :

3-4. Consideration

The results gained are as follows:

1. Assumption 1 and assumption 2 are dependent on the height position and the span length regardless of external force or material strength. However, assumption 3 is dependent on external force, material strength, the span length, and the height position.
2. With regard to the height ratio, in the range from a1=0.1 to 0.3, only assumption 2 is present. At a1=0.4, all assumptions 1 to 3 are present. At a1=0.5, only assumptions 1 and 3 are present.
3. As the value of a1 increases, the actual section depth size ratio becomes larger. Furthermore, the increment of the actual section depth size ratio for the vertex position ratio is the same degree.
4. Assumption 1, 2 for the height ratio can be expressed by straight lines. Assumption 3 for the height ratio, and the actual section depth size ratio can be expressed by exponential functions of the force ratio. Figure 9 to 10 show that the accuracy of the approximate expression is good.
5. In terms of the height ratio, an inversion phenomenon occurred for the range of a1=0.3 to 0.5 when the external force ratio increases. On the other hand, in terms of the section depth size ratio, inversion phenomenon did not occur for the vertex position ratio. In regards to this too, further investigations will be carried out.

4. Conclusions

This research compared 2 patterns for an asymmetric three hinge truss, that is, their two component member sizes are same or different. The conclusions gained are as follows:

1. From Figure 3 and Figure 9, the approximate expressions of assumption 2 are expressed by curve in case of the different component section sizes, but are constant in case of the same component section sizes.
2. From Figures 6 to 8 and Figure 11, 12, the approximate expressions of the actual section depth size ratio and the height ratio are effective.
3. In terms of the height ratio, an inversion phenomenon occurred for the vertex position ratio, for 2 patterns together. On the other hand, for the actual section depth size ratio, an inversion phenomenon did not occur.
4. A form height of truss with same component section size is higher than that with a different component section size.
5. For component member of short span, member section size of same component member pattern is larger than that of different component member pattern. On the other hand, for component member of long span, member section size of different component pattern is larger than that of same component member pattern.

The above-mentioned conclusions contribute to an element of design know-how for three hinge trusses, and it is thought that such know-how will be effective for the cultivation of mechanics sensibility. Hereafter, it is necessary that the design know-how is learned by analyzing the mechanics rational forms which become minimum weight, under various structure forms.

References

Toru Katori, Kazutoshi Tsutsumi (2012)、A study on mechanics sensibility and the optimal design ～In case of three hinge truss～,The Seventh China-Japan-KoreaJoint Symposium on Optimization of Structural and Mechanics Systems Huangshan.