Computer–assisted Steel Structural Design Tools for Beginners



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Abstract

This paper is concerned with a development of computer–assisted education tools for the beginners in steel structural design in Japan. The tools are to be easy to use and effective in education of structural engineering for them. Dealing with preliminary design of multi-storied steel building in Japan, a prototype system is presented in this paper. The presented tools in this research have some new concepts, which are multiple solution acquisition and traceability of the answers provided by the tools. The Acquisition of multiple solution aids the beginners in structural design to find a pertinent solution in short time. This concept was introduced by Yamanari. On the other hand, the traceability of the solution is realized by using DSP which is programming language based on data-flow technology and is developed by Nagasawa et al.. Some examinations were conducted with the tools on column layout of floor plan and sub-beam layout of a slab with deck plates. Evaluation of total weight of steel members was discussed with change of column layout as well as sub-beam.

Keywords: Design system, floor plan, eccentricity, knowledge system, sub-beam design

1. Introduction

Nowadays, structural engineers usually educate beginners with computer software of structural design in Japan. It is also recognized that education for beginners need new computer software which can be helpful for education from enquate research by the authors. This means that a commercial software like an automated design program is not adequate an education for beginners because it is a black box and the result of calculation is just one.

This paper shows the new computer systems which can be helpful to improve a sense of structural design of beginners. The systems give them eccentricity-ratio of a floor in a building and design solutions of steel sub-beam on a floor in one trial. This means that systems present multiple results simultaneously. This systems give architects information of structural design for planning, and the result by this software is good for beginners as well as experts.

2. Eccentricity-ratio of Floor Plan

This system outputs the eccentricity-ratio of floor plan. Eccentricity-ratio is defined as shown in Eq. (1).

$$R_{ex} = \frac{e_y}{\gamma_{ex}} \qquad R_{ey} = \frac{e_x}{\gamma_{ey}} \tag{1}$$

Where e_x, e_y are the distance between center of gravity and center of rigidity.

γ_{ex}, γ_{ey} are the value calculated with torsional rigidity and story drift stiffness.

This system is designed by the dataflow programming language DSP. DSP is the special computer language, which is developed by I. Nagasawa et.al. and is useful to describe for structural design codes. This system can get designable solutions simultaneously.

2.1. Module

As for DSP, a module stands for a program as a conventional expression. The module outputs information for eccentricity-ratio like a center of gravity. This system unifies information from the module, and outputs the ratio. It is assumed that an inflection point on deformed column is the center of the member and story drift stiffness (K_x) which is shown in Eq. (2).

$$K_x = \frac{12EI_x}{H^3} \qquad (2)$$

Where E is Young's modulus. I_x is the secondary moment of X direction. H is story height.

2.2. Dataflow Programming Language

The modules are scripted according to the building code for seismic design in Japan. It is laborious for the programmer to describe the programming code because they have to consider the order of the series of the operations in accordance with the specification. Conversely, they do not need to consider that with dataflow programming language, so they can grasp contents of modules and change it easily.

The authors suggest a need of transparency through the process of solution. DSP has the function and gives the beginners the processes of solution.

2.3. System Installation

The authors equipped a personal computer with this new design system, which was activated by Windows operating system. Users enter the information for eccentricity-ratio; the number of spans, coordinates, axial tension, the secondary moment of the column section, story height and Young's modulus, into the module on the computer. They can change a floor plan easily by replacing with other values of them. The dataflow diagram of this system is shown in Fig.1.

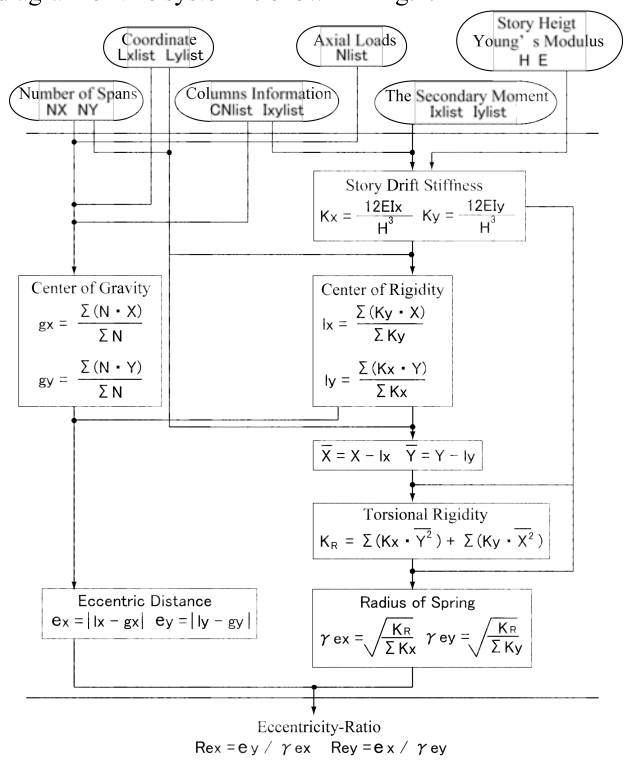

Figure 1. Data flow of eccentricity-ratio

2.4. Verification

A moment frame was applied for verification of this system. The frame is shown in Fig.2. The eccentricity-ratio in X direction of the frame exceeds 0.15 specified in the building code of Japan. The authors demonstrate some improvements of the floor plan with three cases. On this occasion, the change of this floor plan is evaluated with total weight of columns in CASE1 and CASE2, and by eccentricity-ratio in CASE3.

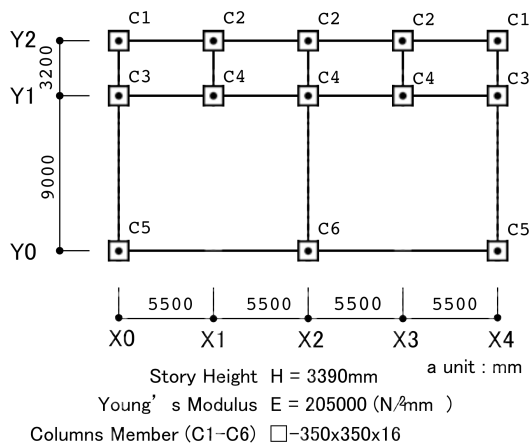

Figure 2. A floor plan of verification

CASE1. Change with the Number of Columns

This case shows the pattern to add two columns to the position of 4500mm from Y0. The eccentricity-ratio of X direction does not satisfy the limited value with R_{ex}=0.162 by the addition. It becomes R_{ex}=0.146 by the third addition and satisfies the limited value. By increasing of more two columns, it becomes R_{ex}=0.115, although the total weight of columns increases 40% in comparison with the initial frame as shown in Fig.3 (a).

CASE2. Change with the Member of Columns

Decrease of the ratio by replacing columns on Y0 axis with large sections is presented in this case. In the case that □-400*400*16 is chosen, the ratio becomes 0.133 and is satisfied the limited value. Furthermore, it can be reduced about 80% in the case □-400*400*25 is used, and the weight increase that becomes 20% as shown in Fig.3 (b).

CASE3. Change with the Position of Columns

The authors moved columns on Y1 axis toward Y0 axis and examined the change of eccentricity of the floor as shown in Fig.3. There is no change of the total weight because the size of columns is not changed. Then, the relationship between the ratio and the change of the distance was examined.

About 10% eccentricity-ratio decreases when columns on Y1 axis are brought toward Y0 axis by 500mm. When the columns moved 2000mm, the ratio become Rex=0.138 and satisfy the limited value. The ratio decreases more than 90% when the distance between Y0 axis and Y1 axis becomes 3200mm. Furthermore, the ratio increases about 30% in comparison with the default plan when the change of the distance between Y0 axis and Y1 axis is 7000mm. The change of the ratio with this work is shown in Fig.3 (c).

2.5. Evaluation

Users can decrease eccentricity-ratio effectively in three approaches. These three improvements are done under the same work. The use of this module enables them to improve the ratio in a short time. The system has a great capability in education to improve design minds of beginners. Furthermore, the process of the solution acquisition is verifiable, therefore design system with this module can be powerful to educate the beginners on structural design.

3. Knowledge System for Sub-beam Design

Generally, the structural engineers use commercial software or programs made by them for sub-member design. At the early stage of structural design, they design sub-member such as floor slabs and sub-beams. At that time, they have to examine the direction of sub-beam array or the number of them. However, it is difficult for beginners to determine them. The authors developed a computer-assisted system for steel sub-beam design. This system gives them multiple prospective results and shows them useful information for sub-beam design.

3.1. Development of the System

This system was developed with DSP-language. The input information consists of dimension of deck slab and limited span for it. The system calculates the span of sub-beam and the stress of it with respect to the direction, and the number of sub-beams. Eventually, the system gives the users allowable stress ratio, size of the members, total weight of beams and maximum deflection. The dataflow of this system is shown in Fig.4.

3.2. Restriction of Sub-beam Design

The number of sub-beams are designed under a restriction. The deck plate used for verification is summarized in Fig.5.

Allowable bending stress (f_b) was 156N/mm^2 because the floor slab is made of steel and concrete slab and sub-beam does not occur lateral buckling. The range of the variation of the allowable stress ratio (σ_b / f_b) was assumed to be 0.55-0.99 as a restriction. The permitted value on the deflection was assumed; the slope deflection shall be less than 1/300 and the maximum deflection shall be less than 200mm.

The value and the condition for verification are noted in Table 1.

Table 1. Information for composite deck slab

Dimention of Floor Plan	Span of X direction	Lx (m)	8.0
	Span of Y direction	Ly (m)	5.8
Floor Load		w (kN/m^2)	4.8
Limited Span for Deck plate		Ld (m)	3.0
Allowable Bending Stress of Sub-beams		f_b (N/mm^2)	156
Material	Sub-beams	SS400	
Structural Form	Sub-beams	Simple beam	
	Deck Plate	Composite Deck Slab System	

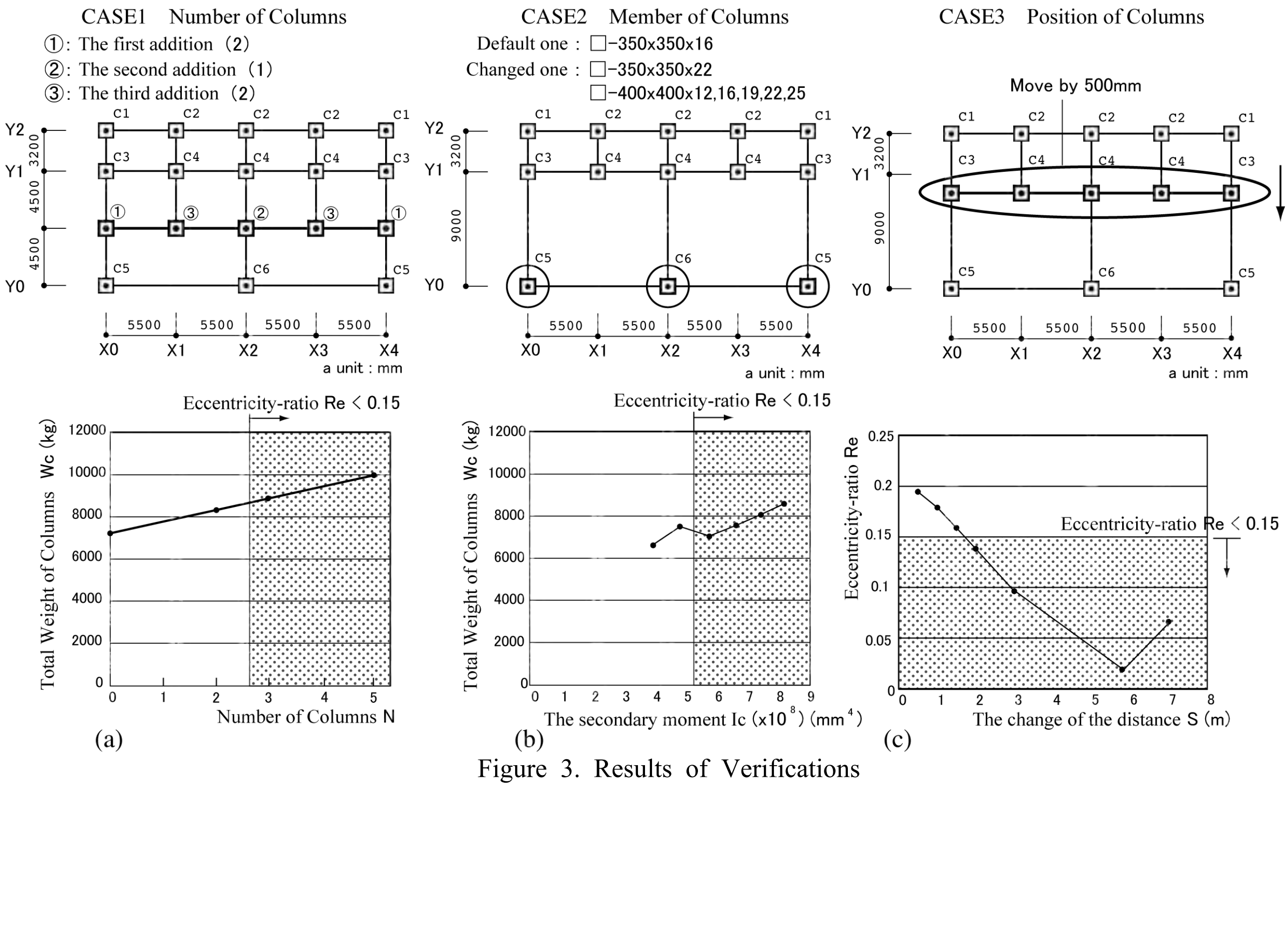

Figure 3. Results of Verifications

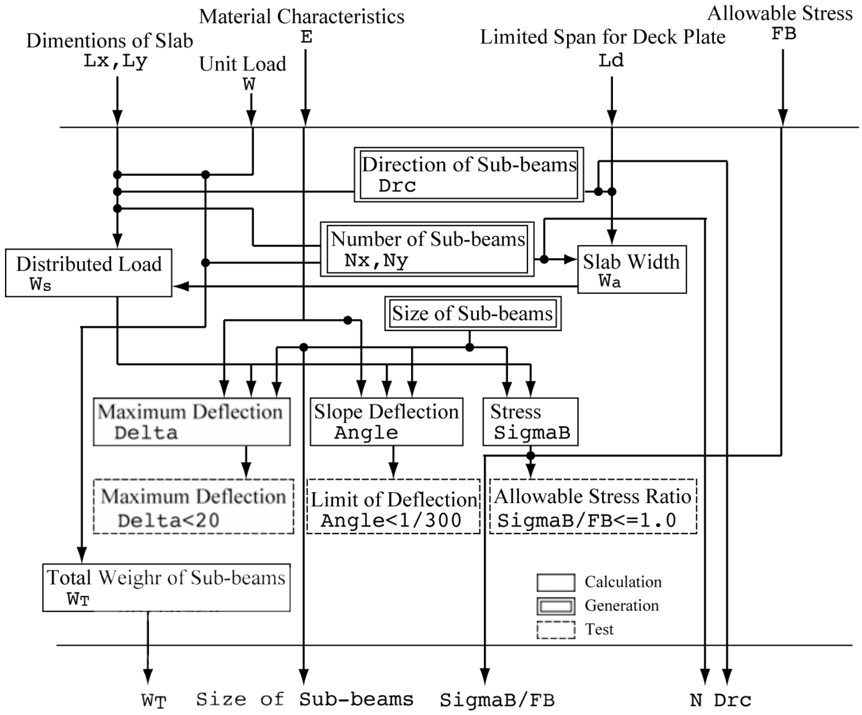

Figure 4. Dataflow of sub-beam

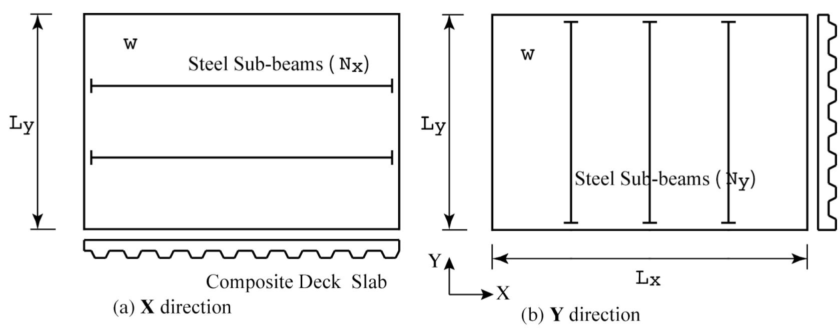

Figure 5. Composite deck slab

3.3. Extraction of Design Solutions

In this verification, this system reported that one sub-beam was needed when it was laid along X direction, and two sub-beams were needed when it was laid along Y direction. The case that one member was added to them n was considered. At last, 13 kinds of solutions with respect to X and Y directions were obtained. Because the range of the allowable stress ratio was taken wide, the extract contained not only narrow sections but also wide sections. The beam depth varied from 200mm through 446mm. The total weight of sub-beams scattered from 370kg through 790kg. The number of these extract seem to be enough for examination for the design.

3.4. Evaluation of Design Solutions

The relation between total weight of sub-beams and three elements; allowable bending stress ratio (a), maximum deflection (b) and beam depth (c) are shown in Fig.6. The ordinates take the total weight of sub-beams, and abscissa takes the allowable bending stress ratio, the maximum deflection or the beam depth. Among these extract, rational solutions which had narrow flange sections were divided. One group is for X directions and another is Y directions. The former was drown with open circles and the latter was drown with solid circles in Fig.6.

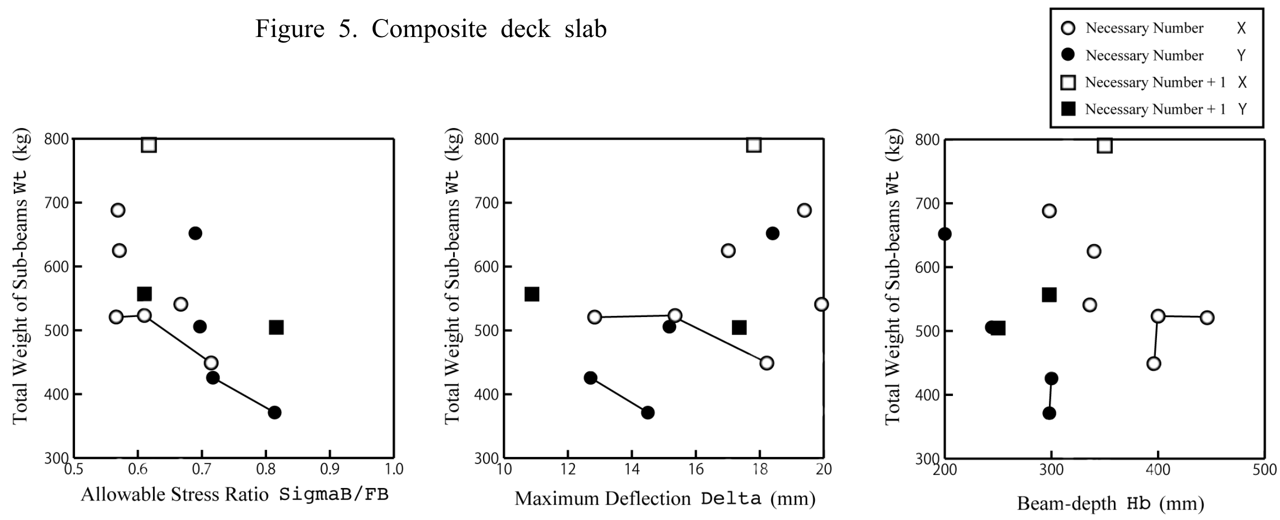

Figure 6. Evaluation

3.5. Relationship Allowable Bending Stress Ratio and Total Weight

It was expected that total weight decrease while the ratio increase. As a result, the solutions agreed with the expectation. It is clarified that the lightest beam is laid along Y direction and has narrow flange sections as shown in Fig.6 (a).

3.6. Relationship Maximum Deflection and Total Weight

The total weight of sub-beams along X direction is closer to limited value than those along Y direction. Therefore, the sub-beams along Y direction deform small, and design of sub-beams become much easier as shown in Fig.6 (b).

3.7. Relationship Beam Depth and Total Weight

Obtained beam depths scatter around 300mm for Y direction, on the other hand, those for X direction scatter around 400mm. These values should be standard value for the design of sub-beams as shown in Fig.6 (c).

3.8. Evaluation

The users of this system can get the pertinent solution out of the extracts obtained by this system. Therefore, this system should be helpful for users to design of steel sub-beams because the multiple solutions can be obtained with this system

4. Conclusion

In this paper, the authors suggested two structural design systems; layout of column member with respect to eccentricity of floor plan and knowledge system for sub-beam design of steel deck slab. Verification of these systems shows that the development of them is helpful.

There is no black box in them because they have usability and transparency, so results from them are good for beginners as well as experts, and it is exactly that these knowledge systems become tools for education.

5. References

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