Education Tool in Structural Design by Means of New Concept Engine

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SUMMARY:
This research aims at development of a computer-assisted education system with respect to a compound slab that consists of steel deck plate and concrete slab. Structural design is rather difficult for the new students or the new comers in practical design field. They have to study for getting higher skills of the design. The compound slabs are settled in a steel building as the floors and are rather popular in construction in Japan. In spite of the fact that the compound slabs are belong to steel structures, they are designed with the rules of concrete structures. Therefore, the beginners in structural design might be confused with respect to design process.
This paper concludes that the system presented here is powerful tool for education in structural design.

Keyword : Design tool, Structural design, Education

1. INTRODUCTION

In recent years, architectural design industry, especially structural design industry face an advancing aging crisis reduction of the young. Accordingly, structural designer is required an important part. Structural designer should design a structure considering safety, workability and economy, and should have clear design concept. For this reason, structural designer is required a more advanced design decisions, cultivating an excellent structural designer in haste. However, the skill of structural design to a structural designer does not improve immediately. It improves based on many the designer itself experiences, and it is required considerable patience and training so that it reaches the expert level.

For such present conditions, in late years, a new generation design system using the knowledge processing is proposed. In this article, the author discusses it about the development of a new education support system using the knowledge processing. It deepens the flow of the design and understanding of the structure for beginners.

2. NEW CONCEPT IN STRUCTURAL DESIGN

In this study, it is aimed for the construction of the structure design system that has the structure that beginners get structure design ability, and improves. To do this, the system with the function that can be explained to the others, and can be secured an understanding of information, and grasp for the user of a system is required. The author performs comparison with the design using the new structural design concept, which made "multiple solution acquisition" and "transparency" the keyword, and the design using the conventional system.

2.1. Designable Space and Multiple Solution

In the structural design, the solutions that are adapted, and are not adapted for a design exist. Universal sets of the solution that can be adapted for a design as shown in Fig.2.1 are defined as "design space."

However, the number of the solutions that exist in design space is huge, and it is difficult to grasp the all to human being. In addition, calculating all solution that can design is non-efficiency to decide a design solution due to need much time. Therefore, the partial space that is extracted multiple design solutions from the design space, is defined as "designable space". Furthermore, the solutions in the designable space, which are obtained by beans of the structure design system, are defined as "plural solutions". The structural design system proposed in this research has a structure that a designer can chooses one design solution among multiple solutions.

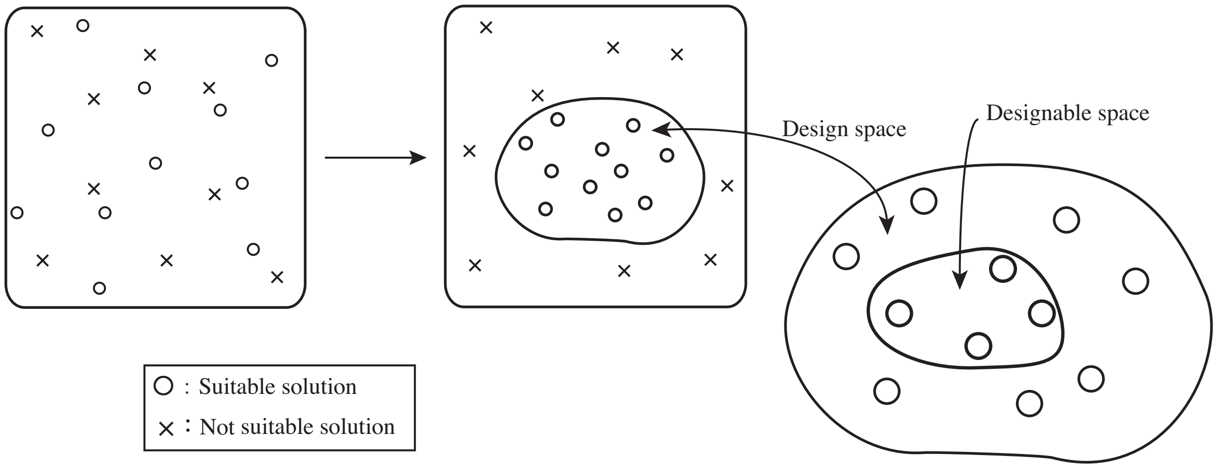


Figure 2.1. Design space and designable space

3. DECK COMPOUND SLAB

Deck compound slab is a structure which shares load with both steel reinforced concrete slab that placed a main reinforcement in the ditch of the deck plate and a deck plate. The structural analysis of the deck compound slab at the time of completion is conducted as "single direction slab" or "double direction slab" depending on the thickness of monotonous part-shaped concrete on the deck plate.

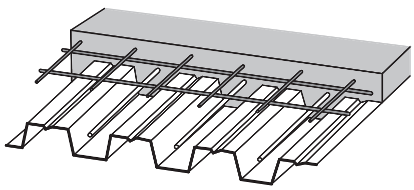


Figure 3.1. Deck compound slab

3.1. Single Direction Slab

The section of single direction slab is shown in Fig. 3.2. One rebar passes in the direction of a ditch of a corrugated steel plate that is call as a deck plate. As a general rule, the single direction slab has a concrete plate whose the thickness at flat part is more than 50 mm and less than 120 mm, and a steel deck plate whose the thickness is more than 0.8mm, and a rebar whose the clearance from the skin of the deck is more 30 mm.

3.2. Double Direction Slab

The section of double direction slab is shown in Fig. 3. 3. Four steel rebars pass along two directions at the top-and-bottom the slab. As a general rule, the double direction slab consists of a concrete whose the thickness of flat part is more than 120 mm, a steel deck plate whose the thickness is more than 0.8mm, and a rebar whose the clearance from the skin of the deck is more than 30 mm.

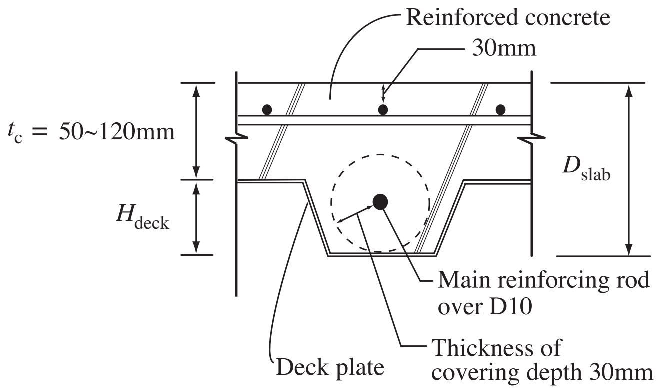


Figure 3.2. Section of single direction slab

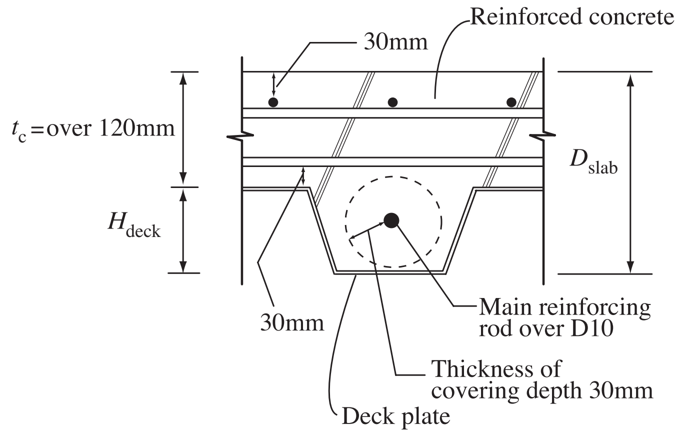


Figure 3.3. Section of double direction slab

4. DESIGN CALCULATION LANGUAGE

In this research, the system was built by DSP that was developed by Nagasawa et al. DSP is a kind of data-flow languages and is a special language that has a function of generate-and-test method. This is possible to extract simultaneously two or more solutions, which can be designed out of a design catalog that stored the information of the steel material.

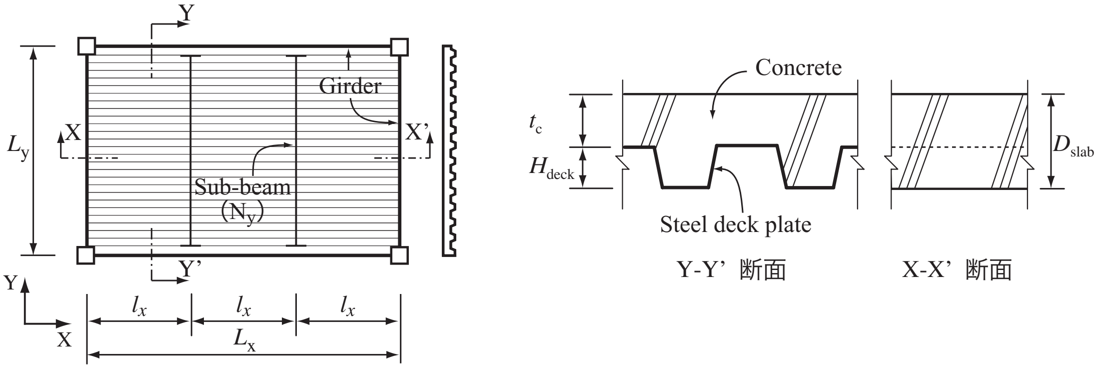
A program module can be described with the way of writing as a design specification. Description with a procedure-driven language such as Fortran language forces a programmer laborious work, since the order of process has to be kept strictly. The data-flow language is represented by DSP that can describe the program code along the order of the description in the design specification. It is easy for the user to be able to grasp the inside of a module easily and to change description to own use by this.

5. EVALUATION OF STRUCTURAL DESIGN WITH EXAMPLE

The evaluation of the deck compound slab is performed in the designable space. Here, change of the design solution of the deck compound slab was compared in case that L_x was 3.6 m (Slab A) and L_x was 7.2 m (Slab B) as shown in Fig. 5.1. As a design example, an office floor was chosen. Steel sub-beams were situated under the slab along short-side direction (Y direction). The deck compound slabs were designed and evaluated by means of the structural design system.

5.1. Design Condition

A layout of the deck compound slab and its section is shown in Fig 5.1, and information of for design of the slab in Table 5.1. The information, such as lengths of the floor, which the frame needs for the design of deck compound slab (L_x, L_y), live load (L_{L1}, L_{L2}), mechanical properties of concrete and deck plate and so on is required for achievement of the design. For retrieving a designable space with respect to the problem, the ratio of existing bending stress to allowable bending stress was given covering over the range of 0.6~1.0. By using this input information, one or more design solutions that fulfill the requirement of the design specification from a design catalog including the cross-sectional information on a deck plate are outputted.



(a) Floor plan of a steel deck slab designed (b) Section of a steel deck slab designed

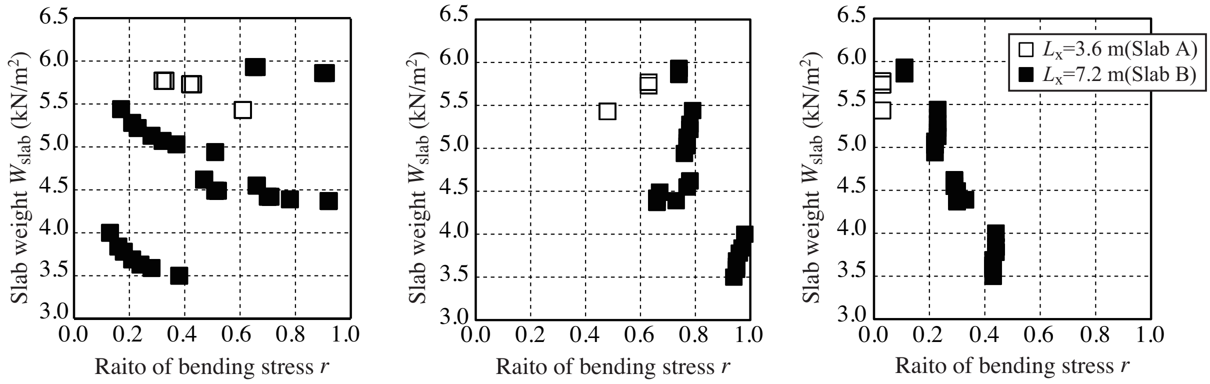
Figure 5.1. Layout and section of slab

Table 5.1. Information for design of slab

Size of steel deck slab		Length of X-direction	L_x (m)	3.6 , 7.2
		Length of Y-direction	L_y (m)	3.6
The number of steel sub-beams			N_y (本)	1
Load		Live-load at completed	L_{L1} (N/m^2)	2900
		Live-load at construction	L_{L2} (N/m^2)	1470
		Weight of finish	L_F (N/m^2)	700
Material	Deck plate	Young' s modulus	E_s (N/mm^2)	205000
		Allowable stress	f_t (N/mm^2)	235
	Concrete	Specified design stress	F_c (N/mm^2)	18
		Thickness	t_c (mm)	60 , 120 , 180
	Rebar	Specified design stress	F_r (N/mm^2)	295

5.2. Example of Design Solution

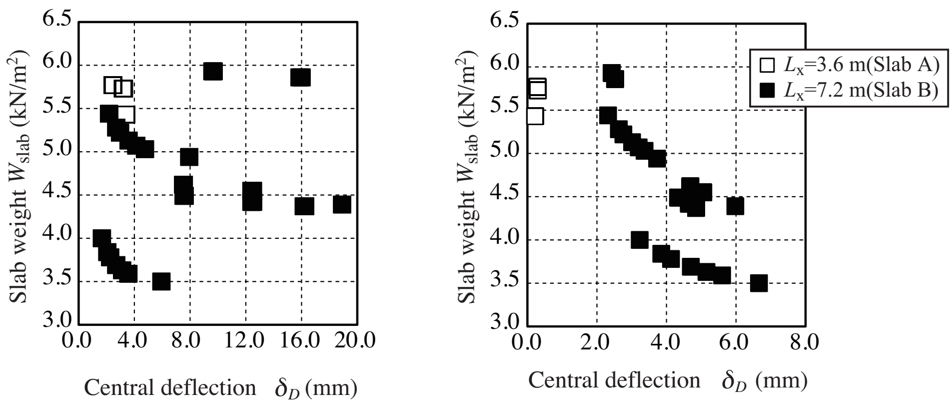
The relationships between the ratio of existing bending stress to allowable bending stress and the slab weight are shown in Fig. 5.2. The stress ratio is checked under both construction and post-construction. In case of Slab A, there is a margin between the stress ratio under construction and that of post-construction. Conversely, The values of both stress ratio under construction and that of post-construction are almost the same and are nearly 1.0, in case of Slab B. Fig. 5.2 shows the relation between the bending stress ratios under construction and post-construction versus the slab weight with respect to the design of deck compound slab.



(a) Under construction (b) Positive bending-unit-stress (c) Negative bending-unit-stress

Figure 5.2. Relationship between bending stress ratio versus slab weight

The relationships between the deflection at the center of the slab and the slab weight are shown in Fig. 5.3. In each case, they are drawn in each graph with respect to both under construction and post-construction. Since the deflections during the time of completion distribute the value of 8 mm or less, Slab A and Slab B are able to obtain the generous design solution. On the other hand, almost solutions distribute 16 mm or less.



(a) Under construction (b) Post-construction

Figure 5.3. Central deflection and slab weight

The relationships between the slab depth and the slab weight are shown in Fig. 5.4. It turns out that they almost keep the proportional relationship. Referencing Fig. 3.2 and Fig. 3.3, the total slab depth of floor is the sum of the concrete thickness and the deck plate depth. Therefore, the slab depth of floor that is one of design solutions with large value of the concrete thickness becomes large, and the slab weight becomes large. When the concrete thickness becomes large, the stress ratio of bending under construction is influenced strongly.

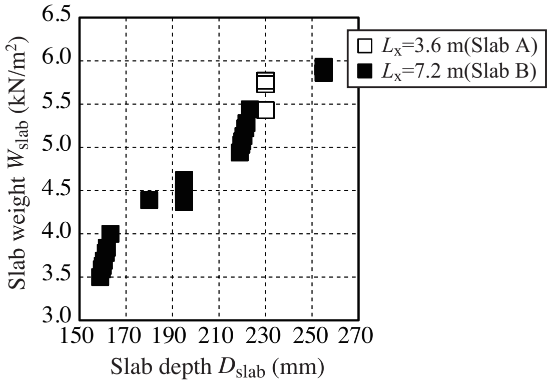


Figure 5.4. Relationship between slab depth and slab weight

When each graph is compared, it turns out that the designable space of Slab B is large. Meanwhile, designable space of Slab A is quite small. It is hard work for a beginner to select a proper solution out of designable space of a large area. However, it is possible to find out the design solution, which suited the purpose of designer by using various graphs of evaluation criteria.
Therefore, it turned out that it is greatly helpful to examine the design solution of deck compound slab using the graph according to evaluation criteria visually, as one of the educational materials which supports a beginner's design feeling.

6. PERFORMANCE RESEARCH OF COMPOUND SLAB

For the preceding chapter, the limited design solution, which was prepared constraints, was extracted about the design solution of deck compound slab. This chapter performs evaluation of deck compound slab in design space.

6.1. Purpose of Research

By grasping the design space of deck composite slab, the beginner can understand the feature of deck compound slab that what kind of scale can the deck compound slab performs a design, what kind of proportion does deck compound slab fit. That makes it possible to select the design solution suitable for the purpose in a short time and correctly. Therefore, it is useful for the acquisition and improvement of structural design skill in a beginner to evaluate deck compound slab.

6.2. Research Summary

Using the framing plan showing in Fig. 5.1, as shown in Table 6.1, the thickness of concrete (t_c) and the length of the span (l_x) are changed and it is investigated what kind of change design space has for slab extremely big from an extremely small slab. Moreover, the existence of the examination in execution investigates what kind of change a spread of design space has.

Research result is shown in Table 6.2. The numerical value in the column of "A" shows the number of design solutions with respect to performing examination both under construction and post-construction, and the numerical value in the column of "B" shows the number of design solutions with respect to performing examination only under construction. Therefore, when the numerical value of the row of A and B is the same, the existence of the examination in execution is not influential in a spread of design space. On the other hand, when the difference of the numerical value of the sequence of A and B becomes big, the examination in execution will have influenced change of design space greatly.

Table 6.1. Information of design slab in examination

<table>
<tr><td colspan="2" rowspan="2">Size of steel deck slab</td><td>Length of X-direction</td><td>L_x (m)</td><td>2.7, 3.6 ,5.4 ,7.2</td></tr>
<tr><td>Length of Y-direction</td><td>L_y (m)</td><td>3.6</td></tr>
<tr><td colspan="3">The number of steel sub-beams</td><td>N_y (本)</td><td>1</td></tr>
<tr><td colspan="2" rowspan="3">Load</td><td>Live-load at completed</td><td>L_{L1} (N/m^2)</td><td>2900</td></tr>
<tr><td>Live-load at construction</td><td>L_{L2} (N/m^2)</td><td>1470</td></tr>
<tr><td>Weight of finish</td><td>L_F (N/m^2)</td><td>700</td></tr>
<tr><td rowspan="5">Material</td><td rowspan="2">Deck plate</td><td>Young' s modulus</td><td>E_s (N/mm^2)</td><td>205000</td></tr>
<tr><td>Allowable stress</td><td>f_t (N/mm^2)</td><td>235</td></tr>
<tr><td rowspan="2">Concrete</td><td>Specified design stress</td><td>F_c (N/mm^2)</td><td>18</td></tr>
<tr><td>Thickness</td><td>t_c (mm)</td><td>60 ,120 , 150 ,180</td></tr>
<tr><td>Rebar</td><td>Specified design stress</td><td>F_r (N/mm^2)</td><td>295</td></tr>
</table>

In the cases that the thickness of concrete is 60 mm and 120 mm, the tests of "single direction slab" were conducted. Moreover, in the cases that the thickness of concrete is 150 mm and 180 mm, the tests of "double direction slab" were conducted. As for "single direction slab", it is found that the number of the design solutions according to the diameter of the rebar (D10, D13 and D16) settled in slots of the steel deck. Since the three kinds of rebar were used and they were placed at top and bottom in the section of concrete plate in bi-direction, the number of the solutions with respect to "double direction slab" largely increased compared with the solution of "single direction slab".

6.3. Results

According to that the span length becomes long, of course, the number of solutions of "single direction slab" decreases. When especially l_x changes from 1.8m to 2.7m, in the case that the diameter of a rebar is D10, the number of the solutions becomes 0. Furthermore, as for "single direction slab", it turns out that the test result does not affect the change of the number of solutions. Therefore, The length of about 3m is appropriate to the length of span that designs slab (l_x) in "single direction slab".

The number of solutions of "single direction slab" in the case that l_x is 2.7m does not have a difference from that of "double direction slab". When l_x changes from 3.6m to 4.5m, however, the number of solutions has a big change between the results of the case of “A” and the case “B”. The difference of the design solution in case that especially l_x is 4.5m is about 6 times. Therefore, as for "double direction slab", the number of solutions strongly affects the change of the number of solutions. The thick concrete like "double direction slab" gives heavy burden to steel deck plate. The reason why the number of solutions changed between the case “A” and the case “B”, is that the concrete plate merely is load under construction. This showed that the design of "double direction slab" whose long length of the span as that l_x is 4.5m was possible.

Table 6.2. Summary of results

(a) l_x = 1.8 m

		Slab type							
		Single direction slab				Double direction slab			
t_c(mm)		60		120		150		180	
Judging method		A	B	A	B	A	B	A	B
Reber	D10	25	25	25	25				
	D13	33	33	33	33	1476	1476	1476	1476
	D16	33	33	33	33				

(b) l_x = 2.7 m

		Slab type							
		Single direction slab				Double direction slab			
t_c(mm)		60		120		150		180	
Judging method		A	B	A	B	A	B	A	B
Reber	D10	0	0	0	0				
	D13	15	15	25	25	1380	1380	1180	1380
	D16	23	23	33	33				

(c) l_x = 3.6 m

		Slab type							
		Single direction slab				Double direction slab			
t_c(mm)		60		120		150		180	
Judging method		A	B	A	B	A	B	A	B
Reber	D10	0	0	0	0				
	D13	0	0	0	0	378	786	456	1086
	D16	0	0	15	17				

(d) l_x = 4.5 m

		Slab type							
		Single direction slab				Double direction slab			
t_c(mm)		60		120		150		180	
Judging method		A	B	A	B	A	B	A	B
Reber	D10	0	0	0	0				
	D13	0	0	0	0	54	345	81	471
	D16	0	0	0	0				

7. CONCLUSIONS

The evaluation of the deck compound slab was performed using the structural design system with new concept. The knowledge acquired here is described below.

In design of the deck compound slab, the slab with thick concrete thickness like "double direction slab" has especially big influence at examination in execution.

The single direction slab is adequate for the design of the deck compound slab in condition that span length of the slab is almost 3m. On the other hand, the double direction slab can bridge over the span between supports at most 4.5m because the reinforced concrete plate bears the loads in bi-direction. Here, the span length of the slab is the value of distance between the sub-beams.

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