THE INTEGRATED CONSTRUCTION SYSTEM

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ABSTRACT

On the premise that a construction methods and soft-ware is the key technology for increasing a economy of construction work, the integrated construction system has been developed. This system has a expert system as a useful tool for calculation, graphics and drafting to design the optimum conditions for construction planning. This results in economy. The logistics of minimizing manpower, temporary materials and other resources for prefabrication and erection on site were studied for a composite slab construction method of the integrated construction system.

1. INTRODUCTION

A composite construction method using large-sized half-precast concrete panel has been developed based on the new concept that "by outside execution of critical path work and just-in-time introduction of large-sized semi-finished product to the production process, a high level of productivity can be achieved at the construction site." Large-sized half-precast concrete panels are made at the construction site by layer-casting method, and when formulating the production plan for this, labor concerned with production of the PC panel was definished as much practicable to improve familiarization with operations of the workers engaged, and at the same time a logic for optimization of work to human errors was established. Construction projects were planned and implemented based on this logic, production data were collected therefrom, and the appropriateness of the logic was evaluated.

2. LARGE-SIZED HALF-PRECAST CONCRETE COMPOSITE SLAB METHOD

An outline of the large-sized half-precast concrete composite slab structuring method is shown in Table 1 and Fig.1. This is a structuring method in which the lower half of the slab of a building frame is made as a single precast concrete slab without being broken up into sections and this is fabricated on site. Using this large-sized half-precast concrete panel as a form, concrete is placed in situ to constitute a

Table 1 Features of Large-sized Half-Precast Concrete Panel Composite Slab Construction Method

1	Use large-sized half-precast concrete panels one panel per grid.
2	Fabricate concrete panels in layer-casting on site.
3	The result is a composite slab of two-way structure.

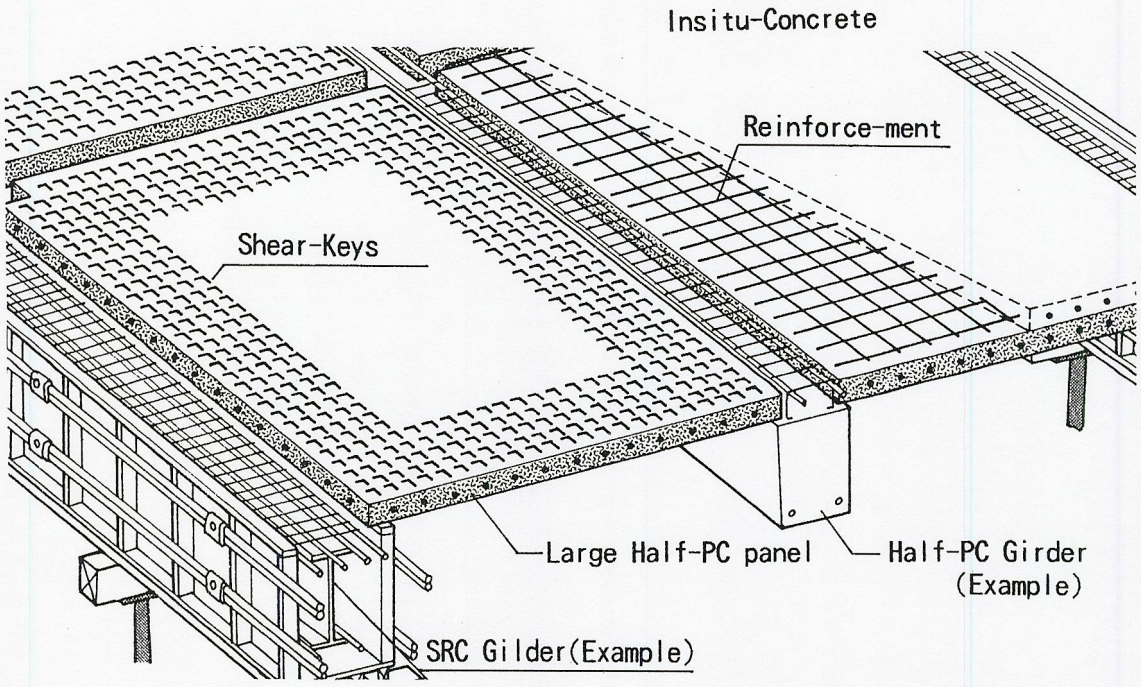

Fig.1 outline of the new composite slab system

composite slab. By this method, it becomes possible for "critical path work to be done on off-lines, with large-sized semi-finished product deliveried to the production process just in time."

3. STRUCTURING OF OPTIMIZATION LOGIC

The results of studies on optimization of work for fabrication of large-sized half-precast concrete panels are described below.

3-1. Objective of Study and Sorting of Conditions

The logic of plans for optimization of the work to fabricate large-sized half-precast concrete slabs at the construction site with the objectives of improving productivity at the site and reducing human errors in the work was studied, the aims in implementing the study and the constraining conditions were arranged, and are given in Table 2.

Table 2 Objective and Constructing Conditions

Objective	Minimization of resources inputted by regularization of work.
Constructing Conditions	1 Regularization of fabrication work of precast concrete slab [Constant number of crews, constant number of crew members, constant work quantity, production facilities of constant quantities and scales, constant height of fabrication of precast concrete panels, etc.]
	2 Regularization of production quantity of precast concrete panels. [One panel/day·bed, constant number of panels/floor, etc.]
	3 Regularization of building frame work. [Constant construction speed/story, constant number of work area sections/story, etc.]

3-2. Basic Model

The basic model of the precast concrete panel fabrication process is shown in Fig.2. The number of days required for PC panel fabrication consists of the number of days for making the PC panel "X", number of days of curing the PC panel "Y" (the minimum number of days of curing required for the top-layer PC panel of the PC panels made by layer casting method), number of days of allowance "v", and number of days "d" for hoisting the PC panel into the place of installation. The construction speed "T" is the number of days of interval for supplying the PC panel to the site of the building frame, and is the number of days "tl" required for a one-story portion of the building frame work to rise up, or when a single story is constructed divided into a multiple

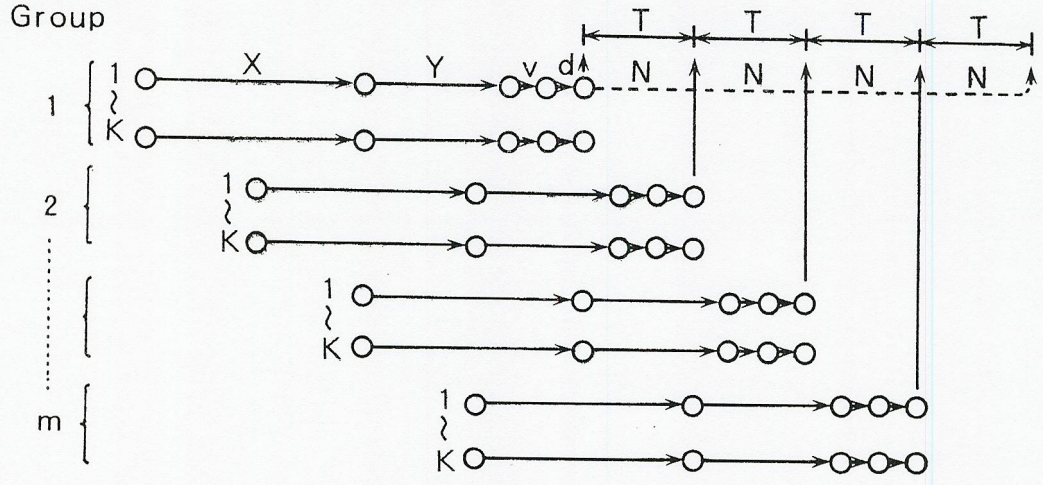

Fig.2 The basic model of the PC panel casting process

number of sections, the dividend "t2" of "t1" divided by the number of section in the single story "A" (t2 = t1/A). As for the number "N" of PC panels to be supplied, it is the number "n1" of PC panels to be laid on the single story, or when constructing the single story divided into a multiple number of sections, the dividend "n2" of "n1" divided by the number of sections (n2 = n1/A).

From the construction speed "T" (t1 or t2), the number of PC panels to be supplied "N" (n1 or n2), and the maximum number of layers "x" of PC panels that can be made, there are cases when a plural number of beds will be necessary. The plural number of beds for fabricating, curing, and supplying these PC panels at the same time is defined as a "group." There are "k" number of beds in a single group. Here, from the minimum number of days required for fabricating, curing, and supplying these PC panels, in case the number of days in the interval for supplying a PC panel is small ($T < X + Y + D$), a plural number of bed groups "m" will be required.

At this time, when the number of precast panels is the same for each story from the constraining conditions of Table 2, and when the number of base in each group is made the same from the point of view of equalization of labor, the total number of beds at a single construction site will be "mk".

3-3. Placing of Concrete for Precast Panel

When placing concrete in a form for fabricating precast panels on a bed at the construction site, there will be no concrete conveying work involved if direct pouring by chute is done from the concrete transporting vehicle and less quantity of labor for placement will be required.

Assuming thickness of one precast panel including temporary bondless between precast panels to be "h", and the maximum layer-casting height at which placement by chute is possible to be "H", the number "x" of PC panels possible to place by chute is the maximum integer value satisfying $x \leqq H/h$, where the condition according to Table 2 is to manufacture one PC panel per day so that $x = X$ (number of layers of PC panels and number of days of fabrication being identical). In this case, beds of the minimum integer number satisfying $k \geqq N/X$ are necessary in a single group.

3-4. Personal Allocation Plan

In order to study improvement in efficiency of the team of workers (crew) engaged in fabrication of PC panels on site, a "crew" was considered as the unit. Besides reducing amounts of labor, time, and temporary facility materials spent through increased familiarization with work, planning is done so that operations of the crew will be repetitive ones with no interruptions in operations aiming for reductions in human errors. The movements of the crew are shown in Fig.3. The crew, after being engaged in fabricating PC panels of group "i" for "X" days, is then engaged in fabrication of PC panels of group "k". This is the same with a plural number of crews. It is necessary to have a condition in which PC panels are being made every day at whichever one of the groups by the same number as the number of crews existing.

When all of crews have been completely equalized, the following two equations would be satisfied;

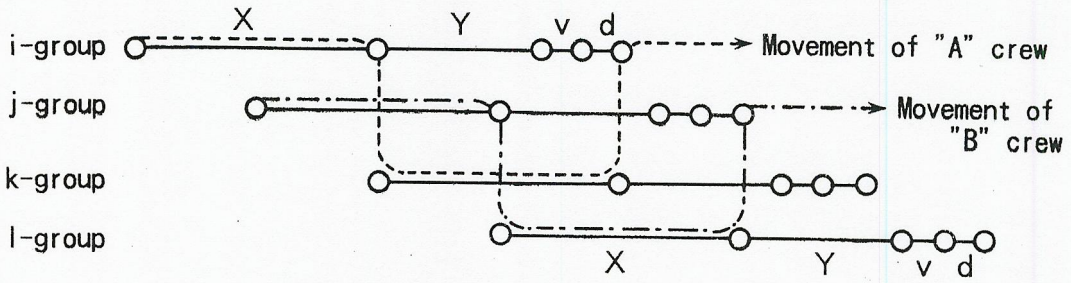

Fig.3 The movement of the crews

$$X + Y + v + d = C_1 T \quad \cdots\cdots\cdots\cdots\cdots \quad (1)$$
$$X = C_2 T \quad \cdots\cdots\cdots\cdots\cdots \quad (2)$$

where, C_1 and C_2 are positive integers, provided that C_1 is set up to be the minimum integer value.

Eq. (1) can be satisfied by giving consideration to the number of days allowance "v" in work. Regarding Eq. (2), designing is done satisfy it through the number of PC panels "N" for a single story (one work area), the number of work sections "A", construction speed "T", and number of precast concrete panels it is possible to be layered on a single bed "x".

3-5. Number of Days Curing of Concrete

For standardization of the construction program, it will be easier for planning and controlling to be done by specifying concrete strength F_C of the PC panel to be a given value. Here, F_C = 120 kgf/cm^2 was taken with the number of days of curing to be the number of days required for the compressive strength of concrete in the top-layer precast panel to exceed 120 kgf/cm^2. Consequently, the number of days of curing will vary depending on the type and specified strength of the concrete, and the construction period.

With the number of days of curing using normal concrete as "Y_n" and that when using high-early-strength concrete as "Y_f", and with X + Y + v + d = B used for calculations, the following will be the minimum value for number of days of curing.

When $B \geqq Y + Y_n + d$,
$Y = Y_n$, $v = B - (X + Y_n + d)$ $\cdots\cdots\cdots\cdots\cdots$ (3)
When $B < X + Y_f + d$,

not enough curing time can be secured and this is not acceptable.

When $X + Y_f + d \leqq B < X + Y_n + d$,
$Y = Y_f$, $v = B - (X + Y_f + d)$ $\cdots\cdots\cdots\cdots\cdots$ (4)
or $Y = Y_n$ $\cdots\cdots\cdots\cdots\cdots$ (5)

provided that in this case, PC panels are to be made using high-early-strength concrete from the top layer down to the number of layers corresponding to $Y_n - Y_f$.

3-6. Fabricating Sequence of PC panels

Precast concrete panels are manufactured on top of a bed by layer-casting method. Therefore, hoisting is started from the PC panel of the

top layer. Consequently, the sequence of PC panel fabrication will be the reverse of the sequence of laying of PC panels. The laying and fabricating sequences of PC panels are shown in Fig.4.

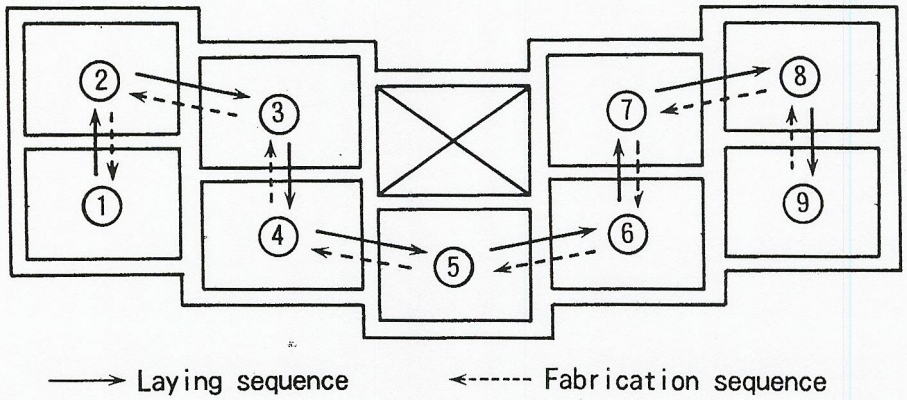

Fig.4 Laying and fabrication sequence of PC panel

In case the number of days "k" in a group is k ≧ 2, the order of hoisting of precast concrete panels will differ depending on the method of hoisting. In this case, when the individual beds are far apart and time is required for movement of cranes and workers assigned to beds, it is more reasonable to move to hoisting of panel on the next bed after hoisting of all panels on one bed has been completed, while when the individual beds neighbor each other, hoisting of the PC panels is done going back and forth between a number of beds. An example in case of k = 2 is shown in Fig.5. which is to be emphasized would be decided at the time of setting up the construction planning.

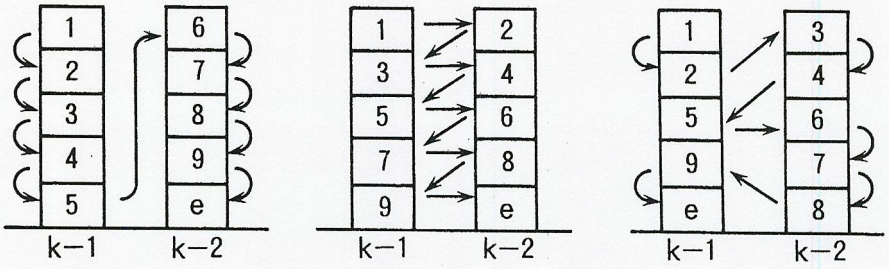

Fig.5 Example orders of hoisting PC panel (k=2)

3-7. Minimization of Bed Area

In order to minimize bed area, the respective dimensions of precast concrete panels fabricated on a plural number of beds are considered and rearrangement of the panels is done so that large-sized and small-sized panels will be fabricated divided between large and small beds. Fig.6 shows an example of two beds in a single group.

Regarding the dimensions of precast concrete panels, the long sides of the individual panels are focused on, and when the panels are regarded in order from the maximum long side panel in reverse order from

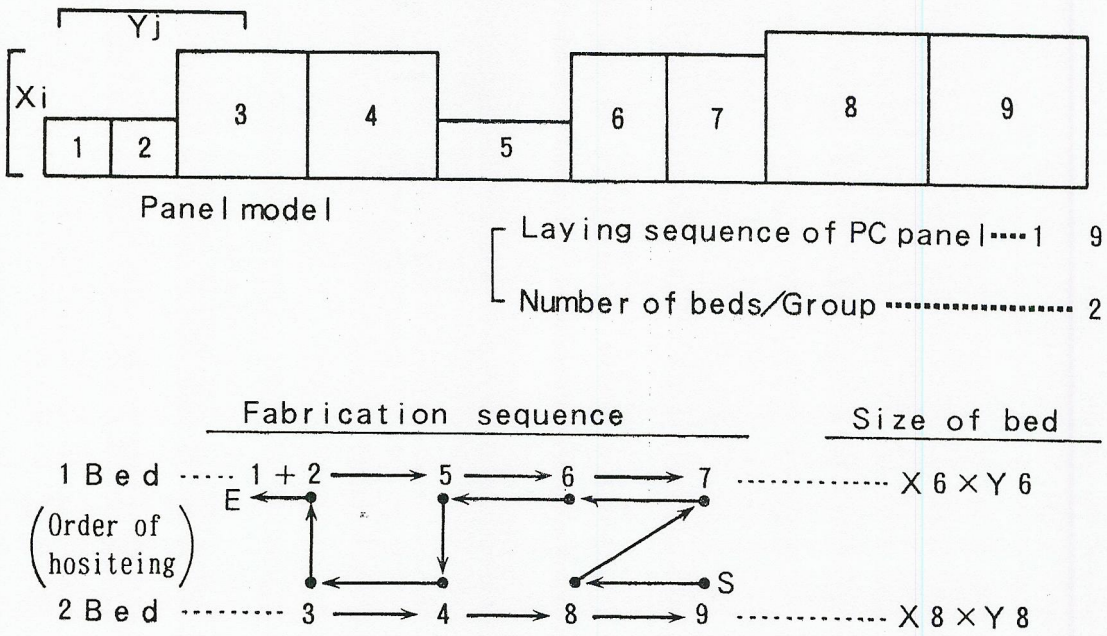

Fig.6 Rearrangement of PC panels

the order of PC panel laying, (order of PC panel fabrication), the result will be 9 → 8 → 7 = 6 = 4 = 3 → 5 → 2 = 7, where, in case the long sides "X_i" are equal, and the arrangement is changed to be in order from the longest short sides, it will become 9 → 8 → 4 = 3 → 7 = 6 → 5 → 2 = 1. Next, when the case of a plural number of small PC panels put together being smaller than a single large-sized panel is examined, the result will be 1 + 2 < 6, and it will be possible for precast panels 1 and 2 to be fabricated laid side by side on a bed for fabricating precast concrete panel 6.

In effect, at bed A (small bed), fabrication is done in the order of 9 → 6 → 5 → (2 + 1), and the size of the bed is made to match PC panel 7. At bed B (large bed), fabrication is done in the order of 9 → 8 → 4 → 3, and the size of the bed is made to match PC panel 9.

At this time, the order of hoisting of panels and beds are 9 (B) → 8 (A) → 6 (A) → 5 (A) → 4 (B) → 3 (B) → 2 (A) → 1 (A), and the crane will make three trips between the beds A and B.

3-8. Minimization of Number of Beds

The smaller that the area required for making precast concrete panels at the construction site of a building is, the more area will there be that can be used for other temporary facilities.

In case the area for beds is small, although there will be more work required for placing concrete at high places, it will become possible to set up a construction planning for the total bed number to be reduced by changing the maximum height of layer-casting of the half-precast concrete panels.

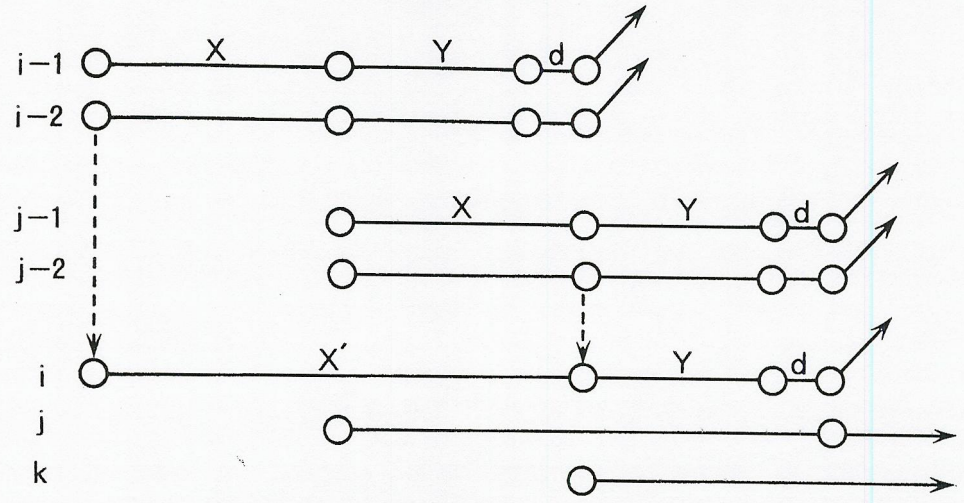

Fig.7 Changing the amximum height of layser-casting of the PC panel

In such case, as shown in Fig.7, from

$$X' = Ha/h,$$
$$k = N/X = N_h/H_a, \text{ and}$$
$$m = (X' + Y + d)/T,$$

where, "H_a" is the allowance height of concrete placement basing on the change in the temporary facilities planning: the minimum number "Z" of beds required will be according to Eq. (6).

$$Z = mk = N_h\,(X + Y + d)/H_a \cdot T \qquad \cdots\cdots\cdots\cdots\cdots \quad (6)$$

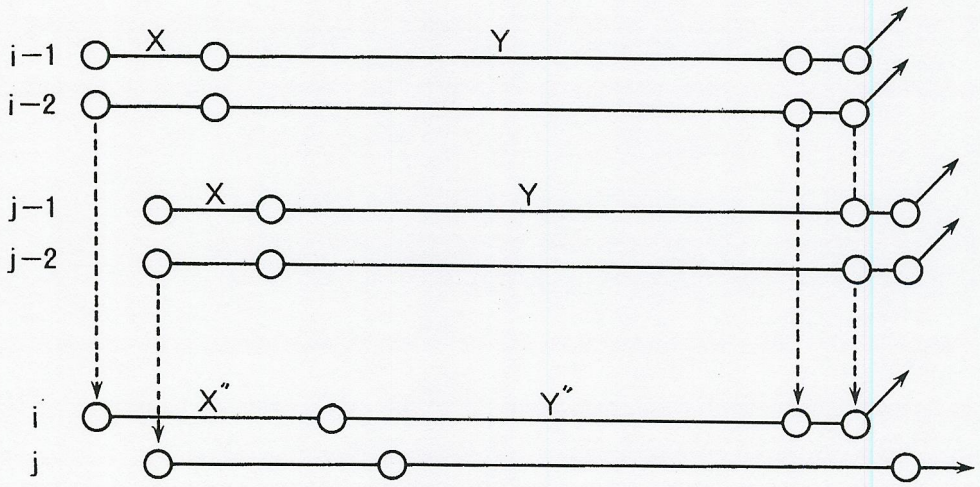

Fig.8 Cosolidatting of groups

And, as shown in Fig.8, it is possible for the number of beds to be reduced through consolidate of groups. That is, if there is adequate allowance in number of days of work so that

$$Y'' = Y - X \geqq Y_n \text{ or } Y_f \quad \cdots\cdots\cdots\cdots\cdots (7)$$
$$2X'' \leqq H_a/h \quad \cdots\cdots\cdots\cdots\cdots (8)$$

will be viable, and moreover, if there exists the allowable height for concrete placement, it will be possible for a single new group to be made compositing two groups.

In this case, the X", d", and T" of the new fabricating schedule for half-precast concrete panels can be determined by Eqs. (9), (10), and (11) below.

$$X'' = 2\ X \quad \cdots\cdots\cdots\cdots\cdots (9)$$
$$d'' = 2\ d \quad \cdots\cdots\cdots\cdots\cdots (10)$$
$$Y'' = Y - X \quad \cdots\cdots\cdots\cdots\cdots (11)$$

4. OUTPUT OF SYSTEM

In order to obtain the solution regarding the large-sized, half-precast concrete panel fabrication schedule, the various items of the previous section are calculated in sequence. These are computerized, and "Support System for Construction Planning of Large-sized Half-Precast Concrete Panel Composite Slab Method" was prepared to make it possible for the optimum construction planning to be formulated in a short period of time at individual construction sites. Example of outputs of Support System are shown in Figs. 9, and 10. In Fig.9, the groups and number of beds, numbers of days for fabrication, curing, allowance, and hoisting of PC panels, equalized movements of crews, etc. are shown together with the schedule of actual days of work. Regarding actual days of work, when building frame work is not going on due to a reason such as rain, link-up is made by not performing fabricating work either. Fig.10 shows which precast concrete panels are made by which crew at which bed.

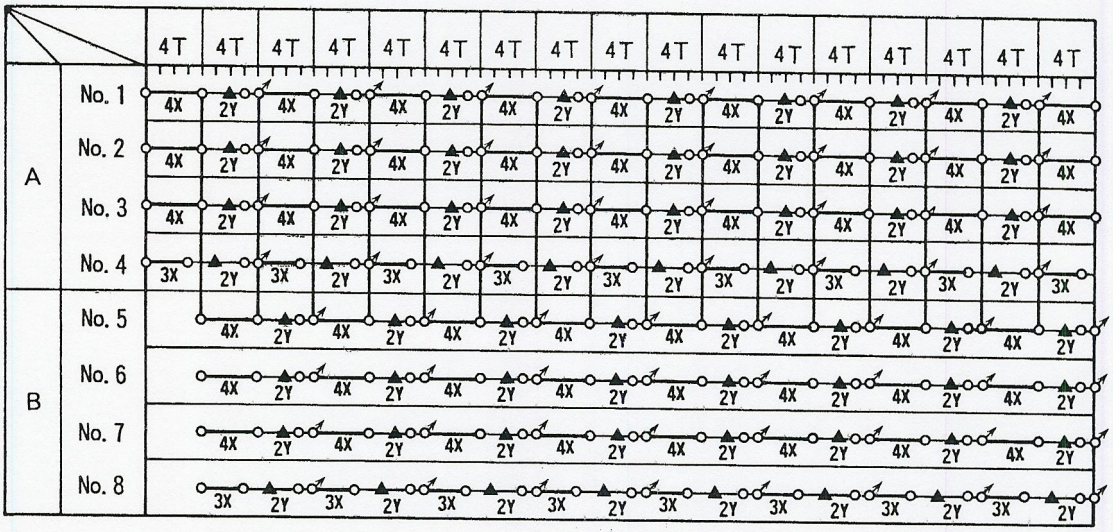

Fig.9 Example out-put of Support System (No.1)

Bed		March' 89																					May													
		4	5	6	7	8	9	11	12	13	14	15	16	18	19	20	21	22	23	25	26	27	28	6	7	9	10	11	12	13	14	16	17	18	19	20	21	23
A	No. 1	24	20	18	12					29	30	27	28					24	20	16	12					29	30	27	28					24	20	16	12	
	No. 2	11	10	9	8					26	22	25	23					11	10	9	8					26	22	25	23					11	10	9	8	
	No. 3	7	6	5	4					18	21	17	19					7	6	5	4					18	21	17	19					7	6	5	4	
	No. 4	3	2	1						14	13	15						3	2	1						14	13	15						3	2	1		
B	No. 5					29	30	27	28					24	20	16	12					29	30	27	28					24	20	16	12					29
	No. 6					26	22	25	23					11	10	9	8					26	22	25	23					11	10	9	8					26
	No. 7					18	21	17	19					7	6	5	4					18	21	17	19					7	6	5	4					18
	No. 8					14	13	15						3	2	1						14	13	15						3	2	1						14

Fig.10 Example out-put of Support System (No.2)

5. CONCLUSIONS

With regard to half-precast concrete panel fabricating works, the ratio of the calculated value of total amount of labor inputted according to the logic that equalization of labor is completely possible to those of actual work on site was between 1.168 and 0.499, while for total number of days worked, it was between 0.875 and 1.085.

The principal reasons for this difference between logic and actual work, although many varied causes can be considered according to the individual construction sites, may be summed up essentially to the 6 points below.

1) When disposing of a given amount of work, in Supporting System the working efficiency of workers is kept constant and the number of workers allocated is calculated to determine the given number of component members of the crew. In actual work, differences were seen in the working efficiency of the crew depending on the number constituting the crew, and this influenced the amount of labor on site.

2) The fabricating work for half-precast concrete panels was carried out making up crews of unskilled workers, and making the workers into multiple-function workers. Therefore, it was not reasonable to expect the same working efficiency as specialist technicians from the beginning. However, as a result of "improving productivity by composing each crew with the same members of the same number and repeating the same operations to become familiarized with the work," which is the fundamental concept of Supporting System, it became possible to reduce the amount of labor on site.

3) There were substitutions of workers making up the crew during fabrications of half-precast concrete panels with the effect of familiarization reduced by that amount to cause the amount of labor on site to be increased.

4) Interruptions of operations occurred during the half-precast concrete panel fabrication with the effect of familiarization by the workers reduced by the amounts of the interruptions, with corresponding increase in the amount of labor on site.

5) The half-precast concrete panel fabrication work was executed using unskilled workers as multiple-function workers. Accordingly, the amount of labor on site was increased at first due to mistakes in work, but this was gradually reduced.

6) When designing the work of this structuring method, it was decided to leave detailed techniques to the supervisor of the work instead of fixing it beforehand. Accordingly, a number of new methods were tried with the aim of improving the productivities of the half-precast concrete panel fabrication work at the individual construction sites, and as a result, the ratio of familiarization with work was raised each time the trial operations were repeated.

At present, Supporting System of even higher precision is being structured putting to use the abovementioned information.

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