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Experimental Study of In-situ Production of Precast Concrete Members

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Abstract: The precast concrete (PC) structure has been preferred for reasons of shortening the construction time and securing the quality and, in particular, it has a cost saving effect in case of long span and heavy loaded structure with high floor height. Most engineers take it for granted to install the plant produced PC members. Researchers in several papers have argued that slander PC members such as columns and girders can be cost-effective if in-situ production is possible, while ensuring quality equal to or better than in-plant production. However, this argument is not officially accepted because objective verification has not been done. Therefore, the purpose of this study is to experimentally conduct in-situ production of PC members to verify the above claim. For this study, a storage building with long span and heavy loaded structure with high floor height was selected as a case study site. For the site, most of the PC members were supplied from the plant, and some of the columns were produced in the site for this study. As a result, it has been confirmed that it has a cost saving effect of 20% while having superior quality to plant-produced PC columns.

Key words: experimental study, precast concrete, in-situ production, cost reduction, quality

1. INTRODUCTION

The precast concrete (PC) structure has been preferred for reasons of shortening the construction time (Badir et al., 2002; Chan and Hu 2002; Eastman and Sacks, 2008) and securing the quality and, in particular, it has a cost saving effect in case of long span and heavy loaded structure with high floor height. Most engineers take it for granted to install the plant produced PC members. Researchers in several papers have argued that slander PC members such as columns and girders can be cost-effective if in-situ production is possible (Lee et al., 2011b; Lee, 2012; Hong et al., 2014; Lim, 2016), while ensuring quality equal to or better than in-plant production (Lim et al., 2011; Lee et al., 2011a; Lee et al., 2011b). However, this argument is not officially accepted because objective verification has not been done. Therefore, the purpose of this study is to experimentally conduct in-situ production of PC members to verify the above claim. Here, The definition of in-situ production is to produce PC members within the working radius of cranes such as tower or mobile cranes, which distinguishes it from the on-site production in and around the site. For this study, a storage building with long span and heavy loaded structure with high floor height is selected as a case study site. For the site, most of the PC members were supplied from the plant, and some of the columns is produced in the site for this study.

This experimental study is carried out in three stages as follows.

1) Selecting a case site and establishing an in-situ production plan. In this process, The columns for in-situ production are selected, and the production modules and layouts are decided. And a module operation plan that satisfies the erection schedule is established.

2) Performing in-situ production according to the established plan.

3) Analyzing the cost reduction effect compared with in-plant production cost after calculating the cost of in-situ production.

2. PRELIMINARY STUDY AND PLANNING OF IN-SITU PRODUCTION

In order to analyze the quality assurance and cost reduction effect in the in-situ production of the PC members, the case site was selected and the in-situ production plan was established. The brief description of the case project, which is a large warehouse building, is shown in Table 1. The case project consists of RC core and steel roof with main PC structure on the 4th floor above. What is remarkable is that the case building is a 10m floor height, a 12m long span, a maximum of 24m long, and a heavy loaded building of 2.4ton /m^2.

Table 1. Construction overview

Description	Contents
Location	Cheonan-si, Chungcheongnam-do
Site area	53,055.60 m^2
Building area	42,406.07 m^2 (246m long x 178m width)
Total floor area	167,614.82 m^2
No. of floors	4 stories(floor height 10m)
Structure	Columns, Girders, Slabs : Precast concrete structure,
	Cores : Reinforced concrete structure,
	Roof : Steel structure
Remarks	Column span : Normal 12m long, Longest 24m long
	Load condition : 2.4ton/ m^2

2.1. Preliminary study

For this study, 5 apprentices of site engineers were arranged to train the PC production process in advance and visited the PC plant directly to confirm the production process as shown in Fig.1. First, as shown in Fig. 1 (a), reinforcing bars are assembled accurately on the basis of shop drawings in the rebar fabrication and installation steps. Then, as shown in Fig.1 (b), the form oil is applied to the inside of the mold to facilitate demoulding, and the assembled steel is placed in the steel mold using a crane. After concreting as shown in Fig. 1 (c), PC members are cured as shown in Fig.1 (d). Finally, the quality of the cured PC members is inspected according to the check list. Partial defects of the PC members are patched and touched up before yard stacking.

(a) Fabricating rebar **(b) Setting rebar** **(c) Casting concrete** **(d) Curing**

Figure 1. PC production process

Five apprentices carried out seven cycles of the production process including reinforcement fabrication and installation, concrete casting and curing for 3 weeks. In this process, they have fully learned the influence factors on the quality and productivity of the PC production process. Using the acquired experience and knowledge, the required manpower and time for each detail activity required for production are analyzed as shown in Fig. 2.

According to the data analyzed in Fig.2, most activities are covered by two common and skilled labors. And it takes a total of 1,052 minutes, or 17.53 hours, for 1 cycle production. For reference, 5 apprentices of site engineers were included in the experimental study of in-situ production of PC members, not skilled and common labors. The reason is that they will take on a role as a future in-situ production leader by the knowledge and experience gained through participation in the production of PC members.

Process	Detailed work	Required labor	Work time (min)
Rebar Fabrication	Installing rebar fabrication frame	One common labor	4
	Distributing main rebar & stirrups	Two common labors	15
	Tying middle bars for binding main bars	Two common labors	50
	Installing splice sleeves	One common labor	15
	Installing both end forms	One common labor	15
	Placing rebar spacers	One common labor	10
Concrete casting	Applying form oil on side forms	One common labor	3
	Concreting and vibrating	Two common labors	20
	Troweling concrete surface	One common labor	5
	Installing embedded items	One common labor	2
Curing	Placing curing cover	Two common labors	10
	Steam curing	One common labor	720
Other works	Demolding and yard stacking	One common labor	23
	Quality inspection	Each one of skilled & common labor	60
	Patching and touching up partial defects	One skilled labor, One common labor	100

Fig. 2. Process, manpower and working time analysis of PC production

2.2. Selection of PC columns

Decisions for experimental study of in-situ PC production have been delayed since PC erection began. Therefore, it is necessary to adjust the amount of PC members already ordered to the plant, and it is necessary to review the already established PC installation schedule. Since most of the columns in the first floor were installed at the time of establishing the in-situ production plan, total 240 columns were selected, 123 in the second floor and 117 in the third floor repectively, as shown in Fig. 3 (a) and (b). The selected columns are identical in size and similar in reinforcement detail to achieve effective cost savings while performing a stable experimental study.

2.3. Decision of production molds and layouts

The mold used in this experimental study is made of steel as used in the plant. The initial cost of steel mold is high, but the cost can be reduced as the number of reuse increases. Therefore, considering the construction cost, the production of the PC columns should be planned with the maximum number of reuses and the minimum number of steel molds. A total of 8 molds were estimated in consideration of PC installation schedule and lead time. Generally, for the in-situ production of PC members, the mold layout is determined considering the production quantity satisfying the installation schedule, the production time for each module, and the stacking area (Lim et al., 2016). In this study, after analyzing the production time, it is assumed that two PC columns are produced at one time and one column is produced at one time as shown in Fig. 4 (a) and (b) repectively.

As shown in Fig. 4 (a) and (b), both production modules include boiler, curing cover, and stacking area after production. In order to ensure safety and smooth passage of workers, a space of 0.5m was secured around each production module. For reference, the capacity of the boiler was determined by the number of PC columns produced at one time, and the produced columns were stacked in two layers. When these conditions are taken into account, the required area is calculated as 117 m2 and 91 m2 as shown in Fig. 4 (a) and (b). Fig. 4 (a) and (b) are named module A and module B, respectively, for mold layout planning.

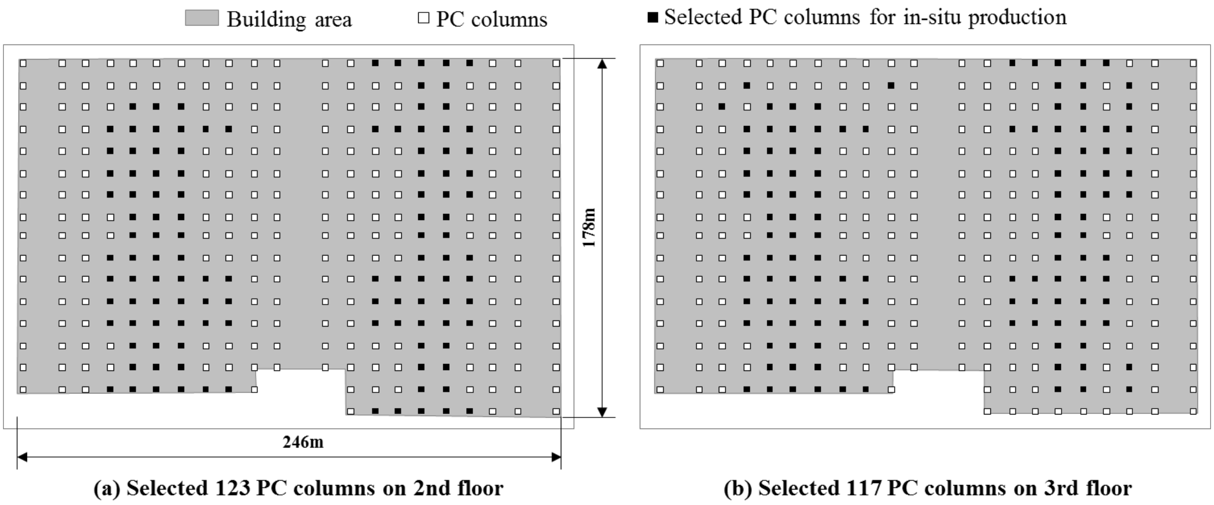

Fig. 3. Selected 240 PC columns for in-situ production

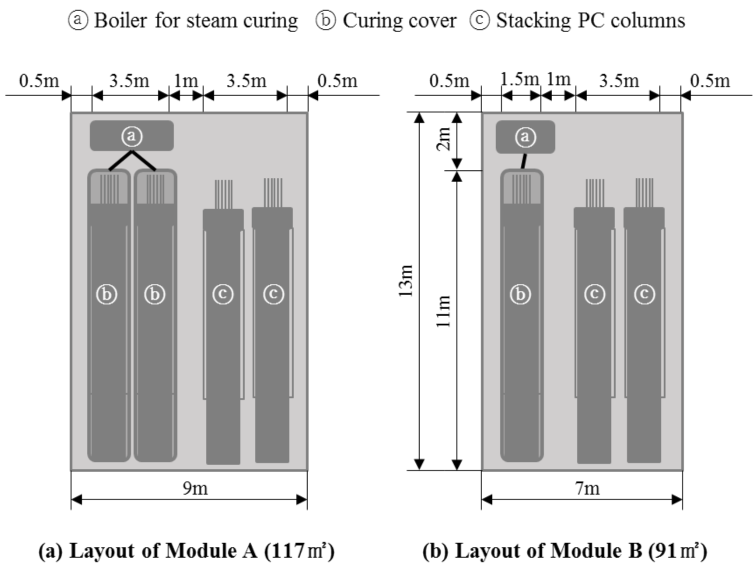

Fig. 4. In-situ production layout of PC columns

2.4. Planning of in-situ production

If the building size is not large, the in-situ production of the PC members can be performed at a predetermined place within the working radius of the crane. However, PC members of large-scale buildings such as the case study site should be produced in a location where erection is easy, ie, where installation crane can directly lift. In addition, for a heavy loaded precast concrete structure with a large floor area, the production plan should be established in accordance with the safe working line considering the productivity of the cranes. In the case of this study, PC erection is carried out with three mobile cranes including two 550ton cranes and 450ton crane. As shown in Fig. 5, since the mobile crane is erecting while moving, the work required for horizontal movement does not occur when members are produced within the working radius considering movement. There is no additional cost incurred.

As a result of reviewing the drawings with floor and site plans and erection schedule considering this point, it is confirmed that the PC members can be produced within the working radius of the crane as shown in Fig. 5 and four production areas with short moving distance are selected.

When the module A of Fig. 4 was applied, it was confirmed that 52 columns in location A-1 and 54 columns in area A-2 were produced as shown in Fig. 5. When the planning was implemented by applying module B in Fig. 4, it was confirmed that 76 columns in location B-1 and 58 columns in location B-2 were produced. As shown in Fig. 5, crane A and C erect the columns produced in locations B-1 and B-2, respectively. Crane B erects the PC columns produced in locations A-1 and A-2. All columns are produced in the working radius of crane while satisfying the erection schedule.

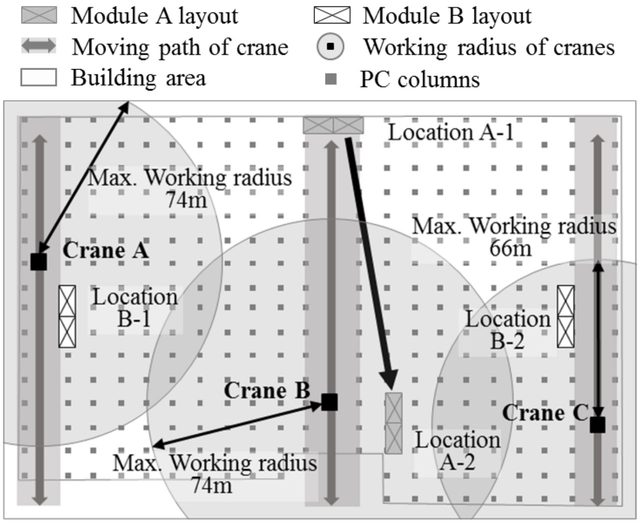

Fig. 5. Planning of in-situ production (240 columns)

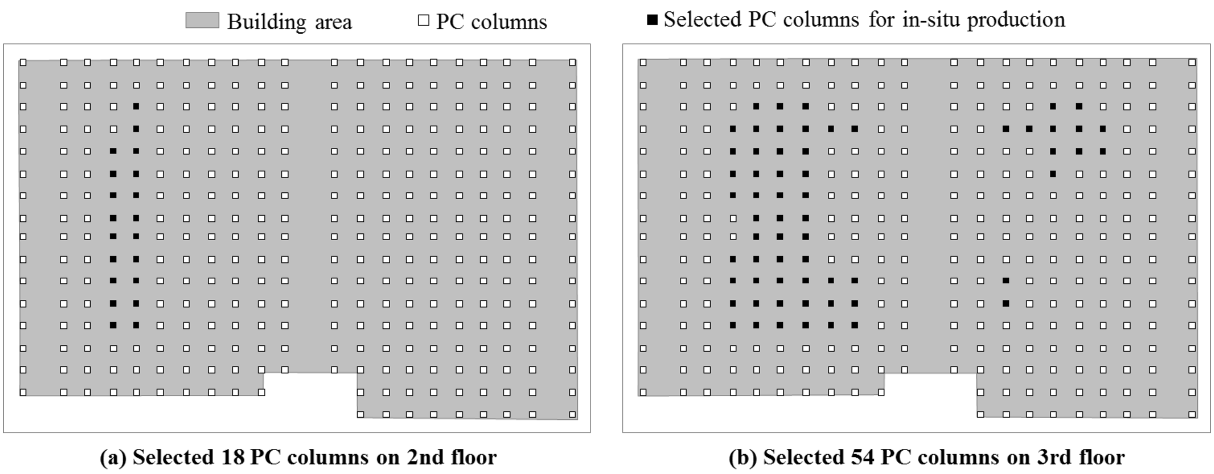

Fig. 6. Selected 72 PC columns for in-situ production

3. IMPLEMENT OF IN-SITU PRODUCTION

Based on the conditions of the case site, the production plan of PC columns was established. However, due to delays of the decision making of project participants, it was necessary to review the plans and production status. As a result of reviewing the site conditions, part of the second floor columns were already being produced at the PC plant. Sufficient lead time must be ensured to erect PC columns on schedule. Therefore, many of PC columns planned for in-situ production were produced to in-plant production, and the production plan of 240 columns was changed to 72 columns. As shown in Fig. 6 (a) and (b), with lead time for in-situ production, 18 in the second floor and 54 in the third floor, repectively, were selected.

Since the number of PC columns for in-situ production decreases compared with that of the initial plan, the production layout plan of Fig. 5 should be modified as shown in Fig.7. In-situ production site was selected considering installation of PC columns within the working radius of cranes. As shown in Fig. 5, the original PC column was intended to be produced inside the building where crane work is possible, but actual production took place outside the building as shown in Fig. 7. The reason is that the number of PC columns to be produced in site has decreased, so the production was possible even in a small area.

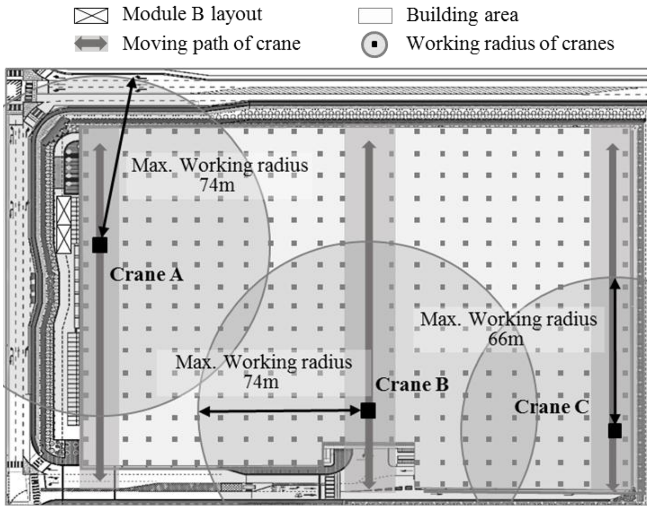

Fig. 7. In-situ production of 72 PC columns

As shown in Table 2, when the 72 PC columns were produced in site, the total cost was estimated to be 160,544 USD, which is 40,104 USD less than the plant-ordered price of 200,648 USD. It has been confirmed that this is about 20% less than the plant-ordered price. The cost per column is calculated to be 2,787USD in case of plant production and 2,320USD in case of in-situ production, respectively, with a savings of 647 USD per unit.

Table 2. Cost comparison of in-plant and in-situ production

Description	In-plant production	In-situ production	Balance
Total cost	200,648 USD	160,544 USD	40,104 USD
Unit cost	2,787 USD	2,230 USD	647 USD
Cost ratio	100%	80%	20%

On the other hand, 240 columns were planned to be produced in-site, but it was changed to 72 in actual production. Using the data used for the 72 columns production, the cost of 240 columns production was estimated. As a result, it is estimated that the in-situ production can be reduced by 39.4% relative to the in-plant production since the number of mold reuse increases.

Hong et al. (2014) claimed that in-situ production in equal production conditions could provide equal or better quality of PC members than in-plant production. However, this study did not actually produce in-site PC members and did not verify. In this study, in order to ensure the quality of the PC members, inspection checklists were created and checked according to KCI (Korea Concrete Institute) PC production and erection guidelines. Through checking in case of crack, breakage, size and strength, it was confirmed that the problem corresponding to the quality regulation did not occur. However, in the case of PC columns of the plant production, it was reproduced because of the problem of crack, breakage, size and different reinforcement. Therefore, it was confirmed that the in-situ produced PC columns can be secured 100% quality compared with the in-plant ones.

4. CONCLUSION

In this study, a detail plan of in-situ production of PC columns was established and applied to the case site. In addition, in terms of cost and quality, it was compared with in-plant production and actual verification was made on the possibility of in-situ production. The conclusions drawn from this experimental study are as follows.

First, 72 PC columns were compared with the costs incurred in in-situ production and in-plant production. As a result, it was confirmed that the cost of in-situ production is 20% less than that of in-plant production. However, it is predicted that if 240 columns were produced in-site as planned in this experiment, it would have a cost saving effect of about 39.4% compared to plant production. Using this data, it is expected to reduce the cost even more when the number of column members is increased.

Second, the number of columns changed from 240 to 72 in the in-situ production planning process. The reason for this was due to delayed decision at the in-situ production planning. It was confirmed that delays in decision making caused by inadequate cooperation and communication among project stakeholders had an adverse effect on the cost as well as on the construction time.

Third, it was confirmed that the quality of the PC columns produced in site was better than the plant production according to KIC regulations. Through this study, it is solved the distrust of quality which is one of the reasons why field managers avoid the in-situ production of PC members.

The result of this study will be able to reduce cost through the generalization of in-situ production of PC members at the construction site. In addition, verification of cost reduction will be more accurately confirmed as the number of applications of in-situ production increases.

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