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Risk Analysis of Yard Stock Layout Management for In-Situ Production of Steel-Connected Precast Concrete Members

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***Abstract* -** A previous study confirmed that the in-situ production of steel-connected precast concrete (PC) members could reduce the cost by approximately 14.5–39.4% compared to factory production. Moreover, if PC members are produced in the field under equal conditions, the same or higher quality is secured compared to factory production. According to these studies, PC members should be produced on-site, because it is advantageous in terms of cost and quality. However, it is difficult to produce the necessary quantities on-site because of various constraints, including the allotted time. In particular, the storage area is significantly larger than the production area, and the availability of in-situ production is determined by the storage area. However, in the existing studies related to the in-situ production of PC members, no specific studies on storage yard layout management risk were conducted. The objective of this study was a basic risk analysis of yard stock arrangement management for in-situ PC production. In the future, depending on the frequently changing conditions at a construction site, the method developed in this study could be used to review the storage location.

***Keywords*:** risk analysis, yard stock layout, in-situ production, steel-connected precast concrete

1. Introduction

The surge in online sales by large retailers has driven the global demand for large logistics buildings [1]. The features of these buildings include long spans, large floor heights, and the ability to withstand heavy loads. In most cases, precast concrete (PC) components are adopted for businesses that require a quick startup [2-3]. Large-scale warehouse facilities require the installation of 5–10 m long columns and beams. Therefore, the capital-intensive PC method is advantageous at a time when equipment and material costs are falling and labor costs are rising [4-7]. Most heavy-duty PC frames in long-span logistics buildings are completed with structures designed with pin joints [8]. Structural stability and construction safety problems may occur when PC members are installed [9], which increases the construction period and cost because a connection problem must be solved after the joint concrete is poured [10]. In other words, time is very important because much equipment and manpower are required to safely connect girders and columns. To solve this problem, a smart frame was developed as a future-oriented construction method. It can easily be assembled using a steel-connected PC (SCPC) with a tapered steel joint similar to that used in a steel structure installed at both ends of a PC component [11].

Like a steel structure, a smart frame with moment frame action not only secures the structural stability and construction safety during the assembly process, which is a problem with pin-joint PC frames, but also makes the installation of tapered joint details easier and faster than with general frames [12-13]. In particular, several studies have shown that the smart frame is superior to the existing PC frame in terms of structural stability, construction safety, and economic feasibility [13-15], like the general PC frame, the smart frame is moved to the site after the members are manufactured in a factory [16]. Thus, transporting a PC component with a large unit member and long span is disadvantageous. However, if the PC member is produced on-site, there is no need to transport it from the factory to the site.

The in-situ production of PC members involves the same process steps as used in a factory, including the installation of rebars, pouring of concrete, curing, and storage. If the number of PC members produced on-site is increased, the cost can be reduced by up to 39.4% compared to factory production [17-19]. If a PC member is produced on-site under equal conditions, it is possible to secure a quality that is equal to or higher than that of factory production [20-24]. A study conducted on the in-situ production of PC members [25-28] showed that its competitiveness in terms of convenience, quality, cost, and time. Despite these advantages, in-situ production is avoided because of the risks that may arise in the process of project management. However, if the risk factors of PC members are analyzed before in-situ production is carried out and responses are taken, the opportunities for in-situ production can be increased [29].

The storage area accounts for more than five times the production area, which is a fairly high ratio [30-31]. The research on the in-situ production of PC members [32-34] has mainly focused on the production area, with no study on the storage yard layout risk management. A review of the research on yards at construction sites showed that there has been no study on yards for the in-situ production of PC members [35-39], using manufacturing theory for the proper inventory management at construction sites. Therefore, the purpose of this study was to conduct a basic risk analysis of storage yard layout management for in-situ PC production.

2. Previous Studies

2.1. Smart Frame

The smart frame connects SCPC components, including columns and girders, similar to steel structures using bolts, as shown in Figs. 1(a) and (b) (Hong et al., 2017). As shown in Fig. 2(b), steel is placed within a range of approximately 8 m from the joints of the columns and girders of a building. In other words, in this structure, all the joints are connected by bolts, and the structural performance of the smart frame is similar to that of a steel structure. It has the advantages of both RC and steel structures [40]. After construction, concrete is poured into the joint to form a moment frame [41]. As shown in Fig. 2(c), the smart frame, in which the column and girder are connected with a tapered shape, can be constructed quickly and accurately, and its structural stability can be secured immediately after joining [42-43].

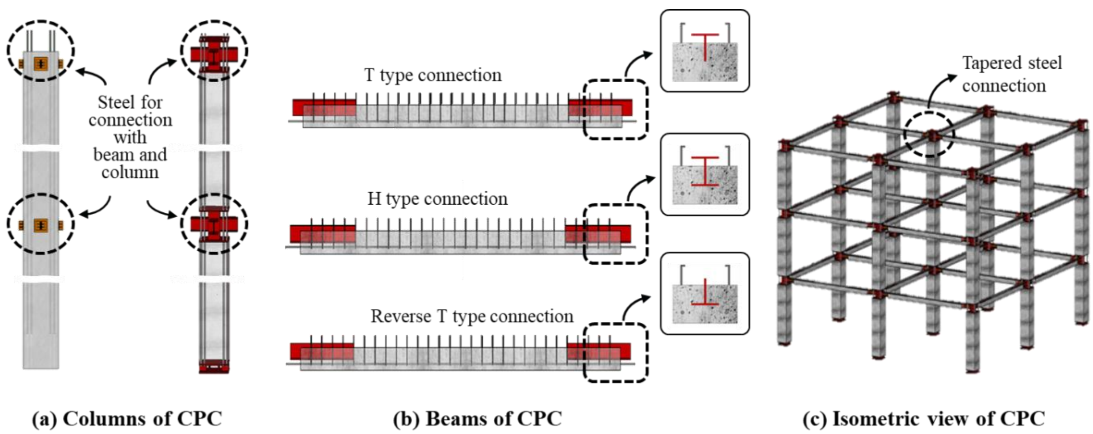

Fig. 1: Details of SCPC frame.

2.2. Inventory Management

The environmental, social, and economic aspects of inventory management have seen significant increases in awareness and interest over the past few decades [44]. The focus on supply chain (SC) management (SCM) has shifted from a specific economic perspective to the widespread adoption and development of other sustainability, environmental, and social aspects [45]. Sustainability can be defined as development that meets the needs of the present generation [46]. Ávila (2018) defined an improvement in the quality of life as a sustainability goal based on meeting human needs and achieving aspiration[47]. Therefore, more equitable redistribution of resources, higher productivity levels, and substantial technological changes are needed. The integration of the concept of sustainability into SCM has been extensively studied by researchers [48]. Thus, sustainable SCM was defined as the creation of a coordinated SC by integrating economic, environmental, and social issues with major industrial systems [49]. Generally, the purpose of inventory management is to maximize profits while simultaneously satisfying customer service maximization and low-cost factory operation goals. Inventory management is a tactical activity that maximizes revenue by balancing inventory and services and maximizes profits by minimizing costs. Stocking management requires sustainable inventory management (SIM), which means stocking up on-site PC members and making decisions about the equipment used for stocking.

3. Storage Yard Layout Risk Analysis of SCPC members

3.1. In-situ Production Risk Analysis

Because risk is unavoidable in any construction project, it is important to plan for, identify, evaluate, prioritize, respond to, and monitor risk factors (Project Management Institute 2017). In general, when utilizing PC members, it is necessary to establish an installation plan at the site, a member production plan based on the order in which they are installed, and then a storage plan. After removing errors through a mutual review of the installation, production, and stocking plans, it is necessary to minimize the risk by applying it to the actual site.

1) Installation risk of SCPC member

A weekly or daily installation plan should be established for PC members based on the zoning plan of the case project in consideration of the in-situ production time that satisfies the time requirements of the client. The installation plan reflects the estimated installation time per member using a crane. In the actual field, it is more accurate to establish a daily installation plan to reflect the frequently changing field conditions and minimize risk. The general PC method is a pin-jointed PC frame, and there are concerns about structural stability and construction safety during construction. In addition, errors may occur when pouring jointed concrete after placing the girder on the upper part of the column. Because concrete pouring is a critical path, it takes a considerable amount of time when it is included in the erection [6].

2) Production risk with SCPC member

The time derived from the installation plan should be used to establish an in-situ production plan. At this time, the installed quantity and in-situ production quantity are the same, and the number of molds reflecting the quantity and in-situ production time is simultaneously calculated. As shown in Fig. 1(c), when the steel frame is embedded in the entire span, it becomes larger than the existing PC structure, but the structural performance is maintained. Based on the number of parts, the conditions in Table 1 are applied to calculate the manufacturing time. Because the construction must be completed within the scheduled time, it is necessary to accurately measure the required time. It is assumed that the production (min) of each member is calculated using the detailed processes (A–G), and that each member is produced a PC member by 2-Day. As shown in the table below, 793 min (approximately 14 h) is sufficient to reach the design strength, but it is calculated as a 2-day production cycle to provide sufficient curing time. At this time, because curing takes the most time, the production time of one member should be given the greatest consideration. After the number of members that can be produced in the mold within a limited time is determined, the number of molds should be calculated considering the time.

Table 1: Calculation of in-situ production time.

Detailed process		Division	Working group	Time (min)
A. Pallet cleaning and peeling agent application	Common	2 people 1 group		Column 5, Beam 4
B. Formwork installation	B-1 Column inner formwork	Pillar	2 people 1 group	1
	B-2 Column outer formwork	Pillar	2 people 1 group	1
	B-1 Beam side formwork	Report	2 people 1 group	1
C. Rebar support installation		Report	2 people 1 group	1
D. Reinforcement and steel frame placement		common	4 people 1 group	50
E. Pouring concrete		common	4 people 1 group	10
F. Steam curing		common	2 people 1 group	720
Total sum				793

3) Storage risk of SCPC member

After the installation plan and production plan for the in-situ production volume are established, the in-situ production schedule is completed. Fig. 2 is an example of an in-situ production schedule for a total of 10 weeks with a lead-time of 5 weeks. First, PC members are produced, and if the number of installed members is excluded, the number of stored members is expressed. For example, in W+2, the members produced in W+1 and W+2 have accumulated, and the number of stockpiled members is 60. In W+6, the number of stockpiled members is 140, excluding the number of installed members (40) from the cumulative number of members produced (180) over 6 weeks. W+1 to W+5 only involves the lead-time for production, and W+14 to W+16 only involves installation, which is the time-lag. The in-situ production calculation time can be calculated as the sum of the time excluding the last installation time-lag from the PC member installation period and the in-situ production lead time (Na Young-ju, 2017).

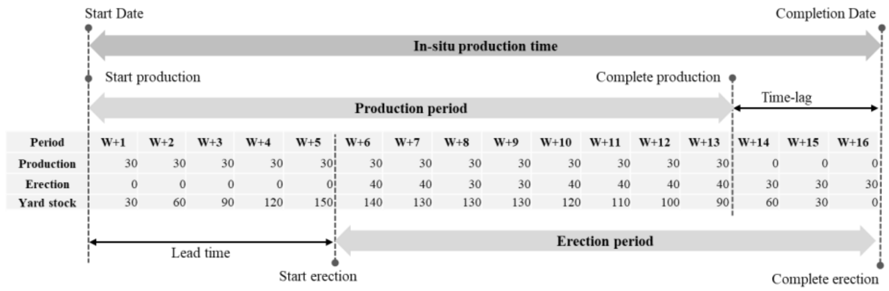

Fig. 2: Example of in-situ production schedule.

The total storage area for the members shown in Fig. 2 is an important risk factor. The cross-sectional size of an SCPC component is relatively small compared to that of a PC component under the same design conditions. This requires a small amount of in-situ production space and storage area, which increases the space available for construction [20]. In other words, it means that the risk to the storage area is reduced. Because production and loading are carried out within the crane's turning radius, the produced members must be stacked near the mold.

3.2. Storage Yard Layout Risk Analysis

As shown in Fig. 4, the stacking of SCPC members was based on stacking 10 SCPC columns in 3 tiers, using the columns and beams of Fig. 3. For SCPC columns, an area of 251 m^2 was required. The H-type steel was placed in one layer, and the members were stacked on it. In addition, in the case of storage on the 4th floor, storage was carried out in one layer. Thus, when storing 30 pieces, an area of 753 m^2 was required. During storage, 30 cm of clearance between the members was secured, and the PC member storage unit was 4200 × 11000 mm for the girder and 3000 × 11000 mm for the pillar.

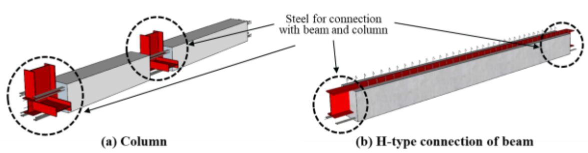

Fig. 3: Yard stock of SCPC members.

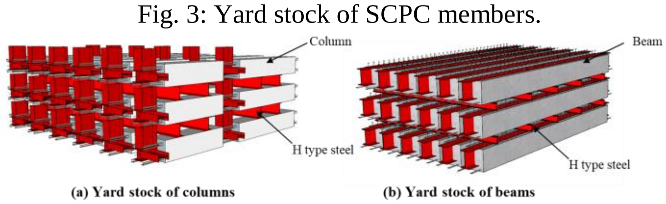

Fig. 4: Yard stock of SCPC members.

If a PC member needs to be installed in the yard where the members are loaded on the floor, the yard must be moved to another space for installation. If the calculation of the number of yard movements is expressed as a formula, the following equation is obtained:

$$N_{stock-mov.} = Min \sum f(x_i) \quad , \qquad (1)$$

where $N_{stock-mov.}$ is the total number of yard moves that have occurred.

In addition, by using the queue and stack methods, inventory rules are created to establish a detailed inventory plan. Accordingly, a yard simulation is carried out, and if there are errors in the yard usage sequence and yard sequence, the simulation is corrected (feedback routine). If there are no errors, the field simulation is complete. Because the installation sequence for three-tiered storage is different from the in-situ production sequence, various storage rules for storage simulation are required. At this time, it is based on the fact that the PC members of all the yards are sequentially stocked from the 1st yard → the nth yard.

The storage rules utilize the first in first out (FIFO) principle from left to right using the queue method, and the first in last out (FILO) principle from top to bottom using the stack method [29]. The total number of members in one yard can be calculated as the product of the number of stacking levels and the number of columns. In the case of a yard consisting of a $n \times m$ matrix, in which rows are stacked and columns are queued, the positions of the stocking order and production order can be expressed in a determinant form. If the storage area is narrow, storage and installation must be carried out at the same time in one storage area. For example, Fig. 5 shows a cross-section of the 11th member in the installation order and the 35th member in the stocking order moved to the yard.

4. Storage Yard Layout Risk Factor Analysis

In the case of PC material production, because it proceeds at the same time as the stockpiling, various influencing factors, including the stockpiling, interfere with each other when calculating the quantity of in-situ production [39]. For all the processes, it is necessary to establish a production plan for supply using the just-in-time (JIT) method according to the installation plan for the PC members. In this study, it was assumed that 100% of the in-situ production volume was produced. Thus, it was not a risk factor.

①In-situ production cost: The cost consists of the material cost, equipment cost, and labor cost, which are influenced by time and thus have a proportional relationship with the in-situ production time. Various influencing factors affect the in-situ production time and ultimately result in in-situ production costs. Among these, the time, quantity, and the number of molds have the most direct influences, and the cost required by the client should be considered when calculating.

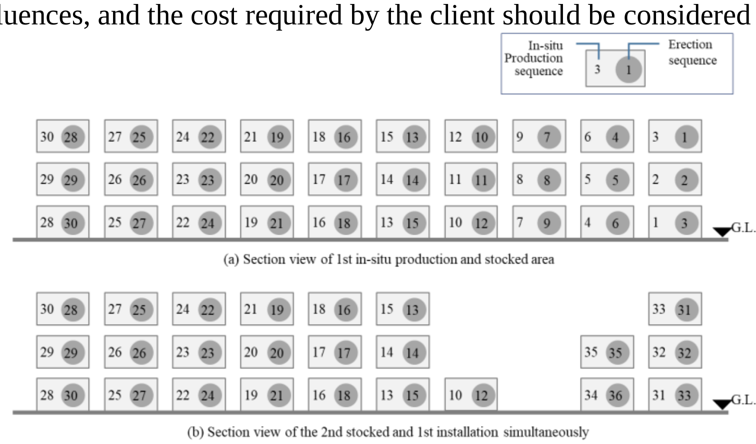

Fig. 5: Storage rules for field-produced PC members (loading and installation at the same time)

②In-situ production time: The production of PC members must be completed before installation. The in-situ production time is the total period from when PC member production starts to its completion. As the in-situ production time increases, the quantity that can be produced on-site in advance increases, and securing the lead-time is important.

③Lead time: This is an important factor that determines the in-situ production time. The lead time is the period of in-situ production before the PC member is installed, or it is the period from the start of the production of the PC member to the start of its installation [28]. Considering the curing period, all of the PC members cannot be produced during the installation period. Thus, the members must be produced in advance [28].

④Number of molds: As the number of molds increases, the production volume at one time increases, which has the significant effect of shortening the time, while increasing the storage area and sharply increasing the in-situ production This is because the cost of manufacturing a steel mold is high:

$$Q_{MOLDi} = \sum_{k=1}^{l} Q_{ij}(x) \quad , \qquad (2)$$

where Q_{moldi} is the in-situ production quantity of each mold type, $Q_{ij}(x)$ is the coordinate section quantity of the installation drawing, i is the number of the mold type (1, …, n), and k is the number of weeks from construction to completion (1, …, l).

⑤Yard stock area: In order to produce PC members on-site, an in-situ production area and yard area are required. The production area is the module area, and the storage area is the area where the PC members produced on-site are stored before being installed. Because the module area is small compared to the storage area, it is important to secure the storage area for the in-situ production of PC members.

$$A_{RYS} = A_{RT} - A_{RP}$$

$$\text{Subject to} \quad A_{RT} \leq A_A \quad , \qquad (3)$$

where A_{RYS} is the required yard stock area (m^2), A_{RT} is the required total area (m^2), A_{RP} is the required production area (m^2), and A_A is the available area (m^2).

⑥Yard stock layer: The storage of PC beams and the storage using the 4th floor are one-level storage. Thus, there is no need for a separate storage plan. The yard consisting of a $n \times m$ matrix can be expressed as Eq. (3), and the formula for the yard rule is expressed as Eq. (4).

$$f(x) = n \times m \qquad (4)$$

$$X(p_{ij}, e_{ij}) = \begin{pmatrix} (p_{11}, e_{11}) & \cdots & (p_{1j}, e_{1j}) \\ \vdots & \ddots & \vdots \\ (p_{i1}, e_{i1}) & \cdots & (p_{ij}, e_{ij}) \end{pmatrix}$$

$$= \begin{pmatrix} (n, 1) & \cdots & (nm - (n - n), nm - (n - 1)) \\ \vdots & \ddots & \vdots \\ (1, n) & \cdots & (nm - (n - 1), nm - (n - n)) \end{pmatrix}$$

(5)

5. Cost and Time Analysis of Field-Produced SCPC Members

Fig. 6 shows a construction status diagram for the in-situ production of SCPC members in the case project. The costs for the in-situ production of PC and SCPC members were compared and analyzed. The in-situ production costs of the PC and SCPC members were $5,141,723 and $4,480,751, respectively. In addition, the in-situ production time for PC members and SCPC members is 16 months and 4 months, respectively, and can be shortened by 12 months, reducing 70%.

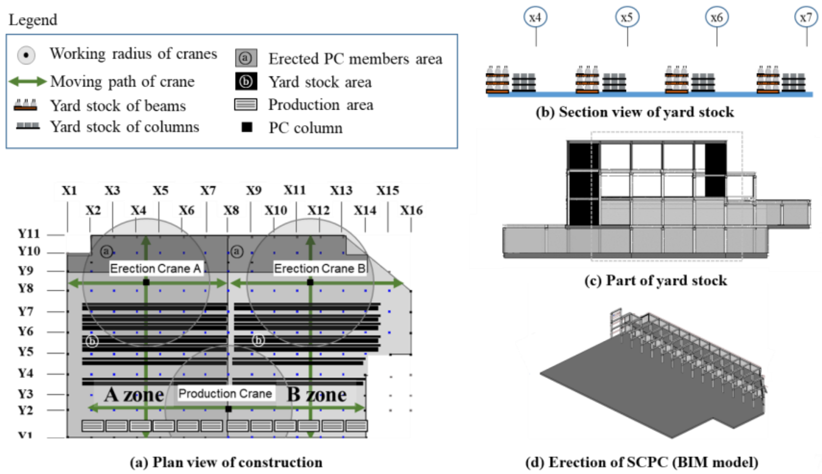

Fig. 6: Field application of SCPC member.

6. Conclusion

This study analyzed the risk factors affecting the storage area during the in-situ production of SCPC members and their application to a case site to analyze the cost and time. The conclusions drawn from this study are as follows. First, it was found that using the SCPC frame could shorten the installation time, increase the installation convenience, and secure space for construction compared to a general pin-jointed frame. Second, six major risk factors were derived: the in-situ production cost, time, number of molds, lead time, and yard stock area. Third, it was confirmed that the SCPC member had cost savings of 12.86% compared to a PC member, and the time could be shortened by 70%.

Green SCM (GSCM) could assist in reducing energy waste on construction sites, lowering carbon emissions, and keeping operations while considering environmental impact and resource efficiency [44]. Direct carbon emissions from the cranes used to move members are a major cause of CO_2 emissions. Thus, decisions about the supply lead time, reorder quantities, and storage equipment affect the costs and emissions [44]. Therefore, in future studies, it is necessary to study yard management considering CO_2 emissions from the GSCM perspective.

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