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Optimal Combination between Concrete Strength and Sets of Forms in High-rise Building

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Abstract

Recently, construction of high-rise buildings is increasing in cities to maximize land usage in Seoul Korea. Since the structural framework in high-rise buildings requires the longest duration and the greatest cost among all component work, accelerating the schedule and reducing construction cost are important factors in structural framework. In addition, improving the durability of buildings is also an important factor because their durability influences their longevity. In Korea, for schedule acceleration, the cycle time of the structure work may be shortened by the following two methods: (1) forms are stripped early without damage, such as cracking the concrete or increasing the deflection of slabs or girders, by using higher strength concrete than the designed one and (2) the number of form sets is increased. Although using higher strength concrete and increasing the number of form sets increase direct construction costs, overall cost decreases because the cycle time of structural framework is shortened. Therefore, this study presented an optimal combination between concrete strength and slab form sets to reduce the cycle time of the structural framework, to minimize overall construction costs, and to improve the durability of high-rise building. The results of these case studies were that using 2 form sets and 35MPa concrete strength is efficient considering the duration, cost, and durability.

Keywords: high-rise building, formwork, cost, duration, durability

1. Introduction

Recently, high-rise building construction is booming in Korea and Korean clients increase interest in such buildings because high-rise buildings make it possible to maximize land usage (Shin, 2001). Since structural framework in high-rise buildings constitutes the longest duration and incurs the greatest cost among all other component work, accelerating the schedule and reducing construction cost are important factors in structural framework (Shin, 2002). In addition, improving the durability of buildings is also an important factor because their durability influences their longevity. However, satisfying all three factors is difficult in structural framework because they often conflict. Therefore, the tradeoff between duration and construction cost is necessary to complete a structural frame economically. Accelerating the schedule is more important than reducing construction cost in Korea because construction duration of high-rise buildings has to be limited by the needs of the housing market.

For accelerating the schedule, the cycle time of the structure framework is shortened by the following two methods in Korea: (1) forms are stripped early without damage such as cracking the concrete or increasing the deflection of slabs or girders by using higher strength concrete than the designed one and (2) the number of form sets is increased. These reasons are as follows: (1) the method using higher strength concrete than the designed one to slab make it possible to reduce the curing time to allow for a 28-day design strength; and (2) the method increasing the number of slab form sets allows an earlier starting time of the upper floor's formwork in a typical floor.

Although using higher strength concrete and increasing the number of slab form sets increase direct construction costs, the overall cost decreases because the shortened cycle time of the structural framework decreases the indirect costs. In addition, the durability of buildings is improved.

The object of this paper is to present an optimal combination between concrete strength and sets of slab forms to reduce the cycle time of structural framework and minimize overall construction cost in high-rise building structural frame construction and improve the durability of high-rise building. The next section briefly describes the factors, which influence the cycle time of structural frameworks. In section 3, durability, which influences the longevity of high-rise

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buildings, is considered by a study of previous research. Section 4 describes the variation of combination between concrete strength and sets of slab forms. In section 5, a case study is performed to verify the validity of the optimal combination, comparing the duration and cost with those of the initial combination and other alternative combinations.

2. Investigating durability of the slab concrete by using high strength concrete

Many researchers in Korea have concluded that the structural integrity derived from using upper level strength of concrete and shortening the stripping time is not significantly different from using the original design strength and maintaining the stripping time.

Oh et al. (2002) investigated the durability and allowede time of upper floor work when using the upper strength of concrete (35MPa) instead of using the design strength of concrete (24MPa) when shortening the stripping time of form. As a result, although deflection is higher than established cases, structural safety is satisfied because this deflection is lower than the allowed deflection. The resulting shortened time of upper floor work is satisfactory as well.

Kim et al. (2004) investigated the durability of concrete slabs from analytical modeling and mock-up test based on Oh's research. As a result, maximum deflection of the middle of the slab and moment are smaller than the allowed deflection and moment, leading to the conclusion that there are no problems about structural integrity.

This study aims to maintain high-rise building structural integrity and durability while reducing the duration of high-rise building construction by increasing the number of forms and applying upper strength concrete beyond the design strength of the slab in the framework.

3. Element concerned with Framework's duration

The framework of high-rise buildings has more typical floors than other low/middle-rise buildings because the numbers of floors are numerous (Ferguson, 1999). Therefore, the cycle time circulating all frameworks through one floor could be an absolute factor to control the total duration of the project (Kim and Kang, 2003). The cycle time concerned the schedule for constructing the column/wall and slab formwork, placing the column/wall and slab reinforcing bar, installing electrical and plumbing components, pouring of concrete, and the stripping time of form etc. Of these components, this study focuses on the stripping time of form. The others are assumed to be fixed.

(1) Form stripping time

The stripping time of form affects the schedule and cost of the structural framework because the stripping time influences the cycle time for a typical floor of a high-rise building.

Therefore, considering the number of slab form sets, which are determined previously, the cycle time of a typical floor is determined according to the stripping time. The standard for stripping form and support is regulated by the Concrete Standard Specification in Korea (Table 1) (Korea Concrete Institute, 2003).

Table 1. Allowed concrete strength for stripping form (MPa)

Type	Concrete strength (f_{cu})
Side wall of expanded base, side of beam, column, wall etc.	over 5Mpa
Underside of slab, beam, and arch	design strength×2/3 ($f_{cu} \geq 2/3 f_{ck}$), over 14MPa

In a case in the United States, the structural frame of a typical floor of a 70-story building was constructed in two days by using a pre-shoring support system (Yoon and Hong, 2000), and the total duration of this building was 24 months. This study does not consider the pre-shoring and re-shoring support system because there are no clear rules for these systems in Korea.

(2) Increasing the number of slab form sets

Increasing the number of slab form sets that shortens the cycle time for typical floor without decreasing the stripping time is considered. When one set of slab form is used, the upper slab form could be fabricated only after stripping the slab form. However, using several slab form sets makes it possible to work simultaneously on the upper floors without stripping the slab form of lower floors.

(3) Predicting the early strength of concrete

This study supposes that design strength of slab concrete is 24MPa and 27MPa because most of the high-rise buildings in Korea have adopted 24MPa and 27MPa as the design strength of slab concrete.

Many methods of predicting the early strength of concrete exist depending on the condition. This study proposed that equation (1), which was suggested by ACI 209 committee (Kumar, 1993), predicts the strength of concrete, which pouring the slab, based on 28 days strength.

$$f_{cm} = f_{c28}\left(\frac{t}{4 + 0.85t}\right) \qquad (1)$$

In equation (1), f_{cm} is the compressed strength of concrete over t days, f_{c28} is the strength of concrete over 28 days, and t is the curing period. In addition, equation (1) assumes that concrete curing temperature is 23℃±1.5℃ and a standard Portland cement is used.

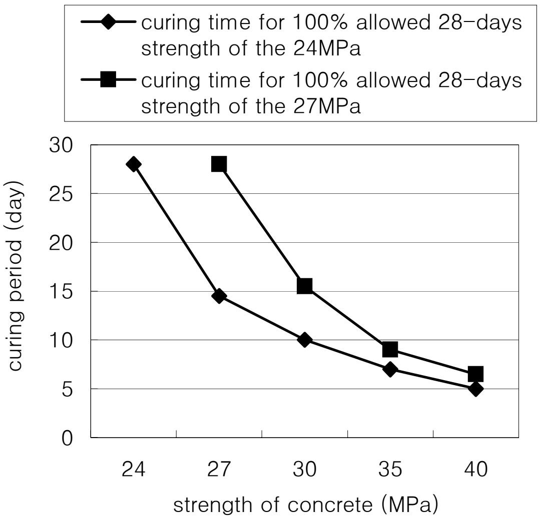

Fig. 1. Reducing the time for 100% allowed strength according to concrete strength

When using the 27MPa, 30MPa, 35MPa, and 40MPa concrete strength on the slab instead of the 24MPa and 27MPa design strength, the curing time for 100% allowed 28days' strength of the 24MPa and 27MPa is presented in Fig.1. by using equation (1).

4. Variations according to the strength of concrete and the number of form sets

(1) Combination of upper concrete strength and the number of form sets

Using the upper strength of concrete and increasing the number of form set are useful methods to shorten the cycle time of a typical floor, so that combining the two methods simultaneously in typical floor construction is possible for shortening the duration. Table 2 shows variations in the cycle time of a typical floor when using upper concrete strength and more form sets than designed. In these variations, the cycle time is calculated by focusing on the form stripping time; other elements related to the duration of the structural framework are consistent.

(2) Costs related to using upper concrete strength and increasing the number of form sets

Increasing the number of slab form sets means the increasing the quantity of slab forms and supporters. In addition, using upper concrete strength causes on increase in the material cost of slab concrete work, which directly relates to the structural framework cost. Nevertheless, it could shorten the duration of the structural framework, leading to a reduction in equipment cost such as tower crane, concrete placing boom and concrete pump, and indirect cost. For these reasons, comparisons between the increasing direct costs and decreasing indirect costs are considered.

Table 2. Cycle time of typical floor according to using the upper concrete strength and the number of form sets

Concrete strength \ Number of form sets		1set	2set	3set	4set
Design	Application				
24MPa	24MPa	8.0	4.0	3.0	2.0
	27MPa	7.0	4.0	2.0	2.0
	30MPa	6.0	3.0	2.0	2.0
	35MPa	5.0	3.0	2.0	2.0
	40MPa	4.0	2.0	2.0	2.0
27MPa	27MPa	8.0	4.0	3.0	2.0
	30MPa	7.0	4.0	2.0	2.0
	35MPa	6.0	3.0	2.0	2.0
	40MPa	5.0	3.0	2.0	2.0

5. Case study

(1) Case-1

The first case study building of this study is located in Yeongdeungpo-gu, a part of Seoul in Korea, and this building has 34 above-ground floors and 6 basement floors (Table 3). All slab concrete, from the 7th to the 34th floors, is designed with 27MPa concrete strength. The building's structural framework was processed with 5-day cycling and two sets of slab form. As mentioned in the previous section, though the cycle time of the structural framework is 4-day with two sets of slab form and 27MPa strength concrete when focused on the stripping time of slab forms, this case-1 processed 5-day for the cycle time of the structural frame considering the project's condition.

Table 3. Major features of case-1

Classification	Major subject	
Project name	○○ building project	
Location	Yeongdeungpo-Gu, Seoul, Korea	
Usage	Commercial and Residential building	
Duration	2000.07 ~ 2003.07. (37 months)	
Structure	Reinforcing concrete structure	
Design Parameter	Area of site	4,602 ㎡
	Gross floor area	68,143 ㎡
	Number of floors	34 above ground
		6 below ground

Table 4 hypothesizes construction cost, duration and typical floor cycle after considering the increased number of form sets, increased high strength concrete costs, decreased equipment cost, and reduced indirect cost.

Table 4. Construction cost when using upper concrete strength and number of form sets in the case -1

Concrete strength	Items \ Number of form set	1set	2set	3set
27MPa	Cost (million won)	2428	2309	2636
	Duration of framework 3rd-34th floors (month)	10	6	5
	Cycle time of a typical floor (day)	8	5	4
30MPa	Cost (million won)	2452	2185	2512
	Duration of framework 3rd-34th floors (month)	10	5	4
	Cycle time of a typical floor (day)	8	4	3
35MPa	Cost (million won)	2305	2187	2513
	Duration of framework 3rd-34th floors (month)	9	5	5
	Cycle time of a typical floor (day)	7	4	3
40MPa	Cost (million won)	2417	2249	2624
	Duration of framework 3rd-34th floors (month)	9	4	4
	Cycle time of a typical floor (day)	7	3	3

(2) Case-2

The second case study building of this study is located in Mapo-gu, a part of Seoul in Korea, and this building has 37 above-ground floors and 6 basement floors (Table 5). All slab concrete, from the 7th to the 37th floors, is designed with 27MPa concrete strength. The building's structural framework was processed with 4-day cycling and two sets of slab form as mentioned in the previous section.

Table 5. Major features of case-2

Classification	Major subject	
Project name	○○ building project	
Location	Mapo-Gu, Seoul, Korea	
Usage	Commercial and Residential building	
Duration	2001.12 ~ 2004.10. (35 months)	
Structure	Reinforcing concrete structure	
Design Parameter	Area of site	9,526 ㎡
	Gross floor area	120,544 ㎡
	Number of floors	37 above ground
		6 below ground

Table 6 hypothesizes construction cost, duration and typical floor cycle after considering the increased number of form sets, increased high strength concrete costs, decreased equipment cost, and reduced indirect cost.

Table 6. Construction cost when using upper concrete strength and number of form sets in the case -2

Concrete strength	Items \ Number of form set	1set	2set	3set
27MPa	Cost (million won)	2815	2415	2677
	Duration of framework 3rd-37th floors (month)	10	5	4
	Cycle time of a typical floor (day)	8	4	3
30MPa	Cost (million won)	2692	2460	2554
	Duration of framework 3rd-37th floors (month)	9	5	3
	Cycle time of a typical floor (day)	7	4	2
35MPa	Cost (million won)	2368	2299	2556
	Duration of framework 3rd-37th floors (month)	7	4	3
	Cycle time of a typical floor (day)	6	3	2
40MPa	Cost (million won)	2386	2317	2737
	Duration of framework 3rd-37th floors (month)	6	4	3
	Cycle time of a typical floor (day)	5	3	2

6. Discussion

All of these case studies actually applied 2 form sets and design concrete strength (27MPa). However, in these case studies, the lowest cost was acquired when using 2 form sets and 30MPa, 35MPa concrete strength, respectively.

We are convinced that using 2 form sets is better than using 1 or over 3 form sets in Korea. When using 1 form set, the cycle time is too long to increase the duration of framework because of the stripping time of form. When using over 3 form sets, overall construction costs are increased because the increasing the material cost of forms. In addition, we are convinced that using 35MPa strength is efficient with 2 form sets. Although a minimum overall cost of case-1 is when using 2 form sets and 30MPa concrete strength, the difference between overall cost using 2 form sets and 30MPa concrete strength and 2 form sets and 35MPa concrete strength is inconsiderable. This reason is the advantage of increasing durability when using the 35MPa concrete strength.

7. Conclusion

This study presented an optimal combination between concrete strength and slab form sets to reduce the cycle time of the structural framework, to minimize overall construction costs, and to improve the durability of high-rise building. Case studies were performed to verify the validity of the optimal combination, comparing duration and cost with those of the initial combination and other alternative combinations. The results of these case studies were that using 2 form sets and 35MPa concrete strength is efficient considering the duration, cost, and durability.

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