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Reshoring effects on deflections of multi-shored flat plate systems under construction

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Abstract. RC flat plates that have no flexural stiffness by boundary beams may be governed by a serviceability as well as a strength condition. A construction sequence and its impact on the distributions of construction loads among slabs tied by shores are decisive factors influencing immediate and long term performances of flat plate. Over-loading and tensile cracking in early-aged slabs significantly increase the deflection of a flat plate system under construction. A reshoring work may be helpful in reducing slab deflections by controlling the vertical distributions of construction loads in a multi-shored flat plate system. In this study, a change of construction loads by reshoring works and its effects on deflections of flat plate systems under construction are analyzed. The slab construction loads with various reshoring schemes are defined by a simplified method, and the practical calculation of slab deflections with considering construction sequences and concrete cracking effects is applied. From parametric studies, the reshoring works are verified to reduce construction loads and slab deflections.

Keywords: flat plate; reshoring; deflection; construction load; reinforced concrete

1. Introduction

Although a flat plate system has many advantages such as a reduction of floor height, an increase of constructability, and an increase of space utilization, care must be taken with its use since, due to its low flexural stiffness, its structural design may be governed by serviceability as well as strength conditions. In particular, the flat plate system will be influenced by construction loads: the self-weight and construction load transferred through shores can damage immediate and long-term performances as well as structural safety when the early age slab is overloaded (Gardner *et al.* 1987, Hossain and Vollum 2002, Lee *et al.* 2007, Vollum and Afshar 2009). Because the initial damage that occurs in unhardened concrete remains even after the concrete has hardened, self-weights of slab, finishing material loads and live loads can influence long-term deflections as well as immediate deflections. Therefore, the key factors affecting construction loads, structural safety, or serviceability should be considered from the planning to the construction processes, and

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a continual control program for construction processes should be planned so that assumptions in design and analysis are effective. A careful plan is required for supporting and curing the slab concrete, in order to minimize cracking and avoid over-loading during construction. Also, the process of installation, removal, and reinstallation of shores should be balanced, in order to suitably distribute construction loads among slabs during the construction process.

Generally, the processes of shoring are classified into installing (preshoring), reinstalling and removing shores under the slab. Re-installing works are classified into reshoring and backshoring in accordance with the form-removed and shore-reinstalled area and the mechanism of load transfer (ACI Committee 347 2005). Backshoring is defined as a case in which shores have been removed and reinstalled in a small area at a time, without allowing the slab to deflect, thus the slab does not yet support its own weight or the existing construction loads from above. In this case, the effect of reinstalling is not considered and the load flow mechanism and the distribution of construction loads in each floor are the same as those in only-preshored floors without the reinstallation of shores. In contrast, when shores have been removed from a large area, the new slab deflects and supports its own weight. This process is defined as reshoring, where the load flow mechanism and the distribution of construction loads differ to those in only-preshored floors.

While in ACI-347 (ACI Committee 347 2005) it is mentioned that reshoring works could decrease the maximum construction load and deflection of a slab, analytical verifications were not performed. The aim of this study is to analyze the reshoring effects on the distributions of construction loads and deflections of slab. For this purpose, the construction loads for slabs with reshoring works are determined, and then the procedure of slab deflection calculation while considering the effects of construction sequences, concrete strength developments, and cracking is proposed.

2. Construction loads

2.1 Simplified method

The self-weight of placed slab concrete cannot be supported by itself for very long and should be transferred either entirely or partially to lower floors connected by shores, because unhardened slab concrete cannot sufficiently develop its strength and stiffness until it is hardened completely (Puente *et al*. 2007). During construction, slabs that have been placed at various times constitute a gravity-load resisting system, where adjacent slabs are connected by shores. Loads applied into the system are self-weights of connected slabs and construction live loads. These loads are distributed according to the relative stiffness ratio of slabs and applied to each slab as a construction load. According to a floor construction cycle or the number of shored floors, the construction load applied to the slab is determined through the relative stiffness ratio with the age of each concrete slab.

ACI-347 (ACI Committee 347 2005) presents a guideline determining the construction load of a slab by the "simplified method" (Grundy and Kabaila 1963). Fig. 1 shows a calculation procedure for construction load using a simplified method, for the cases of the 4-day floor construction cycle and 4-floor preshored system. Concrete stiffness with age is represented as a ratio to a modulus of elasticity of 28 days according to ACI-209 (ACI Committee 209 1997), and "DL" means a self-weight of one floor's slab. A construction live load of 0.5DL and a construction sequence whereby the lowest shores are removed on the 1st day after the top slab concrete is

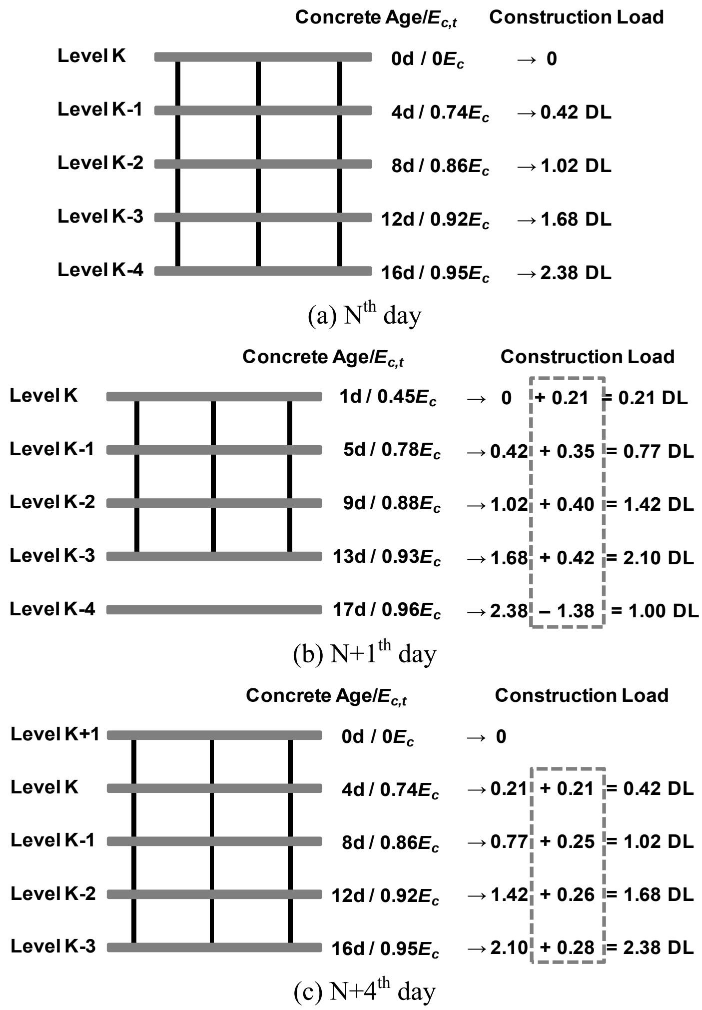


Fig. 1 Calculations of construction loads by simplified method

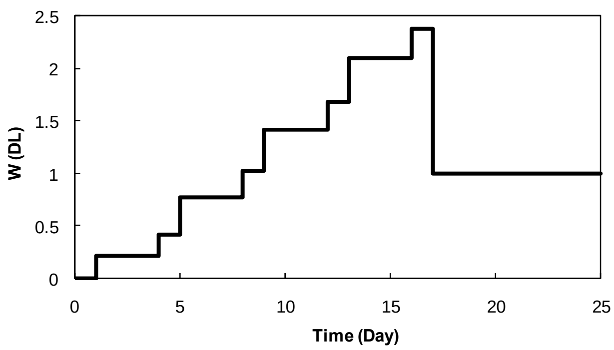


Fig. 2 Change of construction load with 4-day construction cycle and 4-story preshored

placed are assumed. The Level-K slab placed on the Nth day has not yet hardened directly after being placed, and it cannot support its self-weight. Therefore, the lower slabs (levels K-1~K-4) connected with shores support the self-weight of the level-K slab (Fig. 1(a)). By removing the lowest shores on the N+1th day, a construction live load of l.32DL that has been supported by the level K-4 floor is distributed to the upper 4 floors (levels K~K-3) according to the relative stiffness ratio (Fig. 1(b)). Similarly, 1.00DL, the load added by placing the level K+1 slab on the N+4th day (Fig. 1c), is accumulated with a distribution according to the relative stiffness ratio on the lower 4 floors (level K~K-3), with the exception of the level K+1 floor slab that does not yet have a load-supporting capacity. Summarizing the whole procedure of distributions of construction loads, Fig. 2 shows the change of construction load according to the concrete age. A larger construction load is applied on the lower floor in the slab system connected with shores, and the maximum load is presented immediately before the shore connected with the upper floors is removed. The value and the point of time of the maximum construction load might be changed according to the floor construction cycle and the number of shored floors.

In the simplified method, for convenience in calculations, it is assumed that the slab stiffness is elastic and the shores have infinite rigidity. To address the effect of shore's stiffness, several researches (Liu *et al*. 1985, El-Shahhat and Chen 1992) used finite element analyses. However, elaborate work is required to prepare the input data and to perform complicate numerical analyses. Since the simplified method is possible to be applied by hand calculations and preferable in practical structure designs, in this study, the simplified method is used for analyzing the reshoring effects on deflections of flat plates.

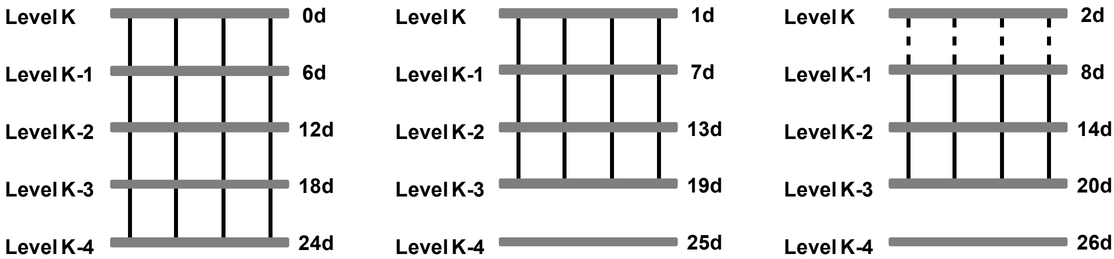
2.2 Construction loads including reshoring works

To analyze the effect of reshoring works on the construction load distribution, the parametric study is performed according to the factors of reshoring level and time. For a slab construction condition with a 4-floor shored system and a 6-day floor construction cycle, a total of 9 schemes with three conditions of reshoring levels – shores supporting top slab, 2nd top slab, and 3rd top slab – and three conditions for reshoring dates – 1st day, 2nd day, and 3rd day after removing lowest shores – are analyzed (Table 1). Fig. 3 shows the basic construction schedule for Scheme 1 where shores supporting the top slab are reshored on the 1st day after removing the lowest shores. On the Nth day, the level K slab is placed (Fig. 3a), and on the N+1th day, shores on the level K-4 floor are removed. On the N+2th day, the forms under the placed concrete are then removed and the supporting shores are reshored. For each scheme, the construction load is calculated by a simplified method, and the material stiffness according to slab concrete age is determined from ACI-209 (ACI Committee 209 1997). The calculation results of the construction load with the reshoring factors are compared with the result of only a preshored or backshored system without reshoring works.

Fig. 4 compares the results of the construction load with the slab concrete age for shoring systems with reshoring conditions ("Schemes 1~9"). By reshoring works, the maximum construction load is reduced during the construction, and especially in the case where reshoring has been performed at the upper level with the early aged slab concrete, the construction load decreases more. This is because by reshoring works, the construction load increases in the slabs over the reshored level and decreases in the slabs placed under the reshored level. Therefore, in the case of reshoring at the lower floor, a large construction load is already accumulated, so that the reshoring effect is not significant even though the construction load decreases by reshoring at the

Table 1 Reshoring models with 6-day construction cycle and 4-story preshored

Scheme	Reshoring floor	Reshoring date
Original	(Scheme without reshoring)	
Scheme 1	Shores supporting top slab	1st day after removing lowest shores
Scheme 2	Shores supporting top slab	2nd day after removing lowest shores
Scheme 3	Shores supporting top slab	3rd day after removing lowest shores
Scheme 4	Shores supporting 2nd top slab	1st day after removing lowest shores
Scheme 5	Shores supporting 2nd top slab	2nd day after removing lowest shores
Scheme 6	Shores supporting 2nd top slab	3rd day after removing lowest shores
Scheme 7	Shores supporting 3rd top slab	1st day after removing lowest shores
Scheme 8	Shores supporting 3rd top slab	2nd day after removing lowest shores
Scheme 9	Shores supporting 3rd top slab	3rd day after removing lowest shores



(a) Nth day (b) N+1th day (c) N+2th day

Fig. 3 Construction schedules with reshoring – scheme 1

upper floor. This phenomenon can be seen through comparisons of the tendency of an increase and decrease in construction loads in Schemes 1, 4, and 7. However, in the case of reshoring at the upper levels, the maximum construction load is applied to the earlier aged slab concrete, and a close examination of the safety of unhardened concrete is needed.

In the case of reshoring at the same level, the time of reshoring has an insignificant affect on the value of the maximum construction load: the maximum construction load is almost the same even though the date of reshoring changes with the 1st, 2nd, or 3rd days after removing the lowest shores. However, as the time of reshoring is delayed, the age of the slab concrete applied by a sharp increase of construction load by the reshoring works increases (compare Schemes 1, 2, and 3) and the material capacity resisting cracking can be increased. A decision for the time of reshoring in the case where the value of maximum construction load is not affected might be reasonable when the concrete strength development and construction conditions of the floor construction cycle are also considered simultaneously.

During construction, the slab concrete hardens and the concrete mechanical properties change, and slab damages therefore cannot be judged only from the amount of load. If the slab concrete age is greater, crack and deflection may decrease even for the same load because the strength and elastic modulus of concrete is greater. Slab damage caused by the smaller applied load on the younger slab might be greater than that caused by the greater applied load on the older slab. Therefore, to consider the effects of the number of shored floors and the floor construction cycle on slab deflections, the strength and stiffness according to the concrete age as well as the value of construction load should be considered. In order to determine a governing condition of

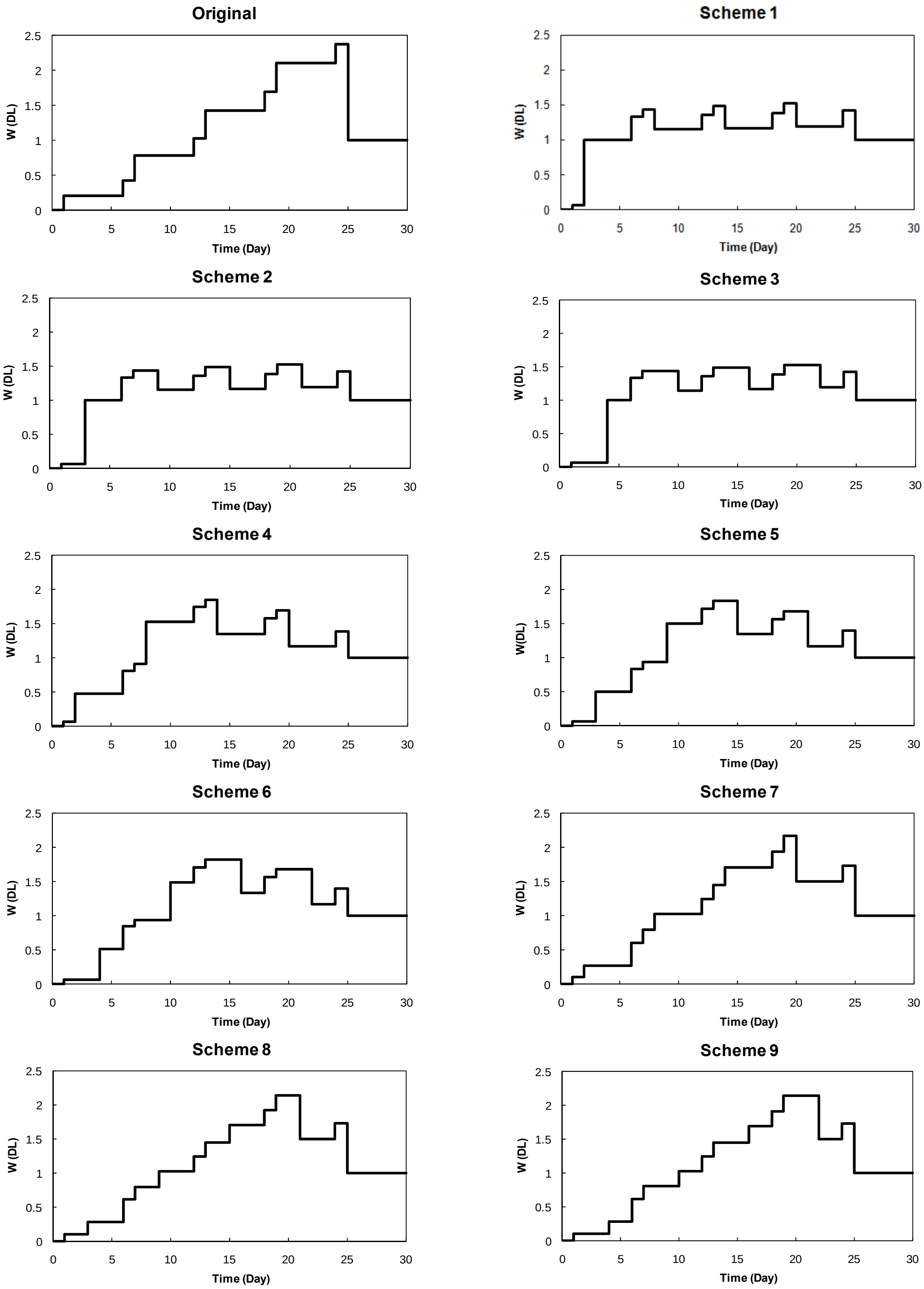


Fig. 4 Change of construction loads with time

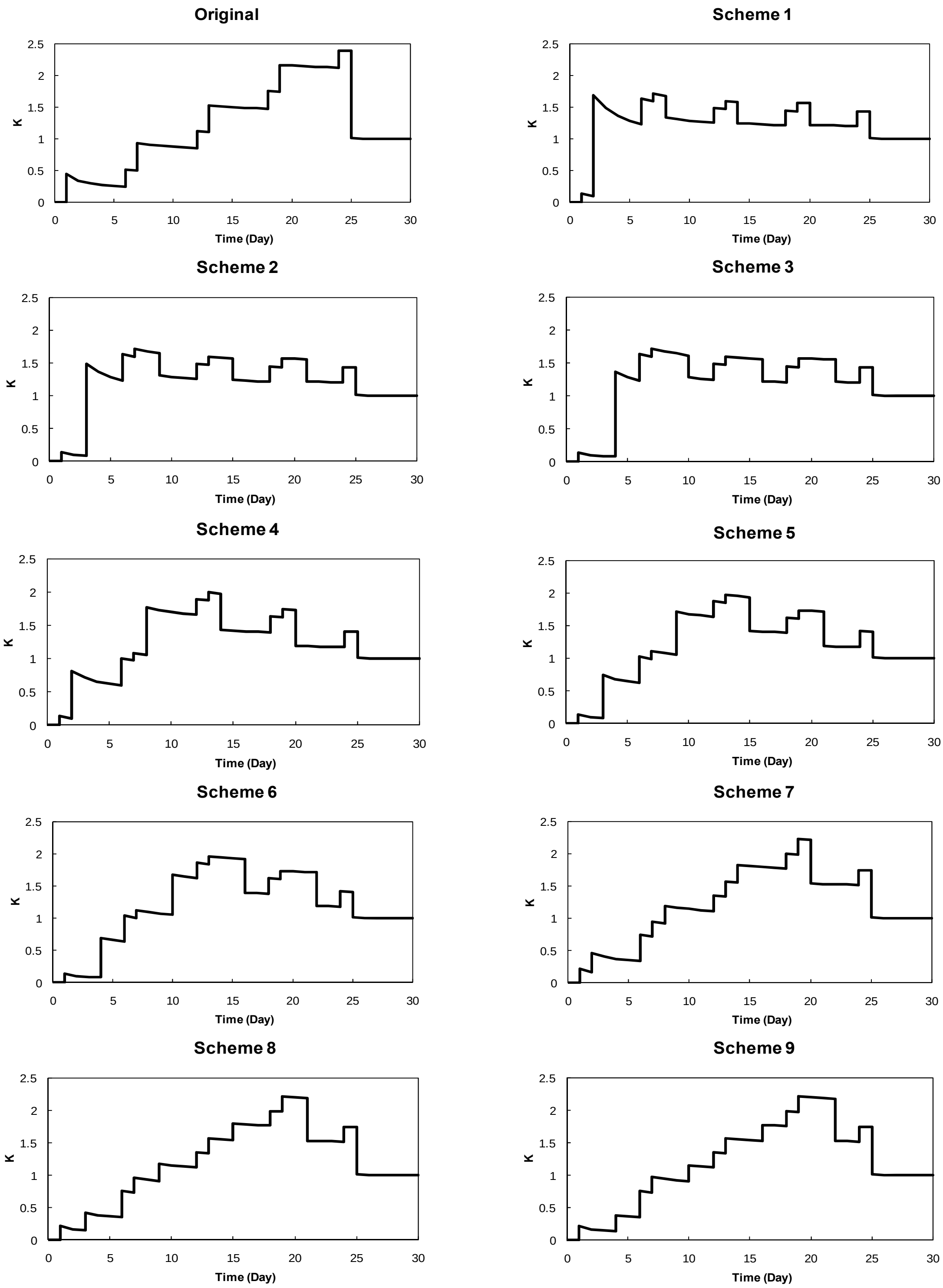


Fig. 5 Change of slab damage parameters with time

Table 2 Summary of maximum construction loads of reshoring models

Scheme	Maximum construction load		Maximum slab damage parameter		Maximum shoring force	
	Value	Ratio to original scheme	Value	Ratio to original scheme	Value	Ratio to original scheme
Original	2.37 DL	1.00	2.39	1.00	2.08 DL	1.00
Scheme 1	1.52 DL	0.64	1.72	0.72	1.50 DL	0.72
Scheme 2	1.52 DL	0.64	1.72	0.72	1.50 DL	0.72
Scheme 3	1.52 DL	0.64	1.72	0.72	1.50 DL	0.72
Scheme 4	1.85 DL	0.78	1.99	0.83	1.69 DL	0.81
Scheme 5	1.83 DL	0.77	1.97	0.82	1.67 DL	0.80
Scheme 6	1.82 DL	0.77	1.96	0.82	1.66 DL	0.80
Scheme 7	2.16 DL	0.91	2.22	0.93	1.90 DL	0.91
Scheme 8	2.14 DL	0.90	2.20	0.92	1.89 DL	0.91
Scheme 9	2.14 DL	0.90	2.20	0.92	1.89 DL	0.91

construction load for a flat plate system under construction, this study defines K, slab damage parameter (Hossain and Vollum 2002, Vollum and Afshar 2009), as follows

$$K = \frac{W_t / W_{DL}}{f_{t,t} / f_{t,28}} = \frac{W_t / W_{DL}}{\sqrt{f'_{c,t} / f'_c}} \quad (1)$$

Where W_t is the construction load of the slab according to concrete age of the tth day, and W_{DL} is the self-weight of one floor slab. Slab deflection is determined by occurrences of flexural cracks and effective moment of inertia of the slab section. Therefore, the ratio of construction load to square root of compressive strength is defined as the slab damage parameter because the tensile strength and cracking moment of concrete are proportional to the square root of compressive strength (ACI Committee 318 2008). In Eq. (1), the slab damage parameter K is calculated as 1.0, when the slab only supports its self-weight ($W_t = W_{DL}$) and the concrete age is over 28 days ($f'_{c,t} = f'_{c,28}$). As K increases, the possibility of the occurrence of slab crack damage may be greater and the deflection may be larger.

Since, as previously described, slab crack and deflection are affected by concrete age and material stiffness as well as construction load, the effect of each reshoring factor on slab deflection is examined by the slab damage parameter K from Eq. (1) (Fig. 5 and Table 2). In the cases of Schemes 1~3, a sharp increase of construction load is presented and the slab damage parameter increases significantly, because the shores supporting the early aged slab are reshored. When the date of reshoring works is later, the slab damage parameter K at the reshoring point decreases. However, in all of the cases of Schemes 1~3, the slab damage parameter at the early age (reshoring time) is smaller than the maximum slab damage parameter during construction. This is because an exaggerated increase of the slab damage parameter does not occur despite the sharp increase of the construction load by reshoring, since 50~60% of the 28 days stiffness is already represented at 2~4 days of concrete age (ACI Committee 318 2008), which is the time when the reshoring is in operation. Preferably, in the case of Schemes 1~3, peak values of the slab damage parameter are distributed almost equally from early age to final age. It is confirmed that the applications of construction load are accomplished efficiently with the change of material stiffness according to concrete age and a more efficient supporting system can be applied for the control of slab cracking and deflections through reshoring works.

Table 2 presents the summary of the maximum slab construction loads, the maximum slab damage parameters, and the maximum shoring forces of the original scheme without a reshoring work and 9 reshoring schemes. All results are presented in company with ratio to those of original scheme. From comparisons of results with or without a reshoring work, it is concluded that the reshoring works are helpful in reducing the maximum construction load of slabs under construction and the maximum force in shores supporting slabs.

3. Procedure of slab deflection calculation

3.1 Basic concepts

To analyze the effect of construction load including reshoring works on flat-plate deflection, the practical calculation method for slab deflections during construction is proposed based on design codes and guidelines (ACI Committee 209 1997, ACI Committee 318 2008). Differently to the existing methods (Ofosu-Asamoah and Gardner 1997, Chao and Naaman 2006, Kim and Abdelrazaq 2009) using finite element analyses, the proposed method can predict a midpanel deflection of flat plate by simple calculations. The section stiffness degradation of the slab by cracking due to over-loads during construction is considered and, to represent the continuous change of construction loads following the progress of construction work, a sequential procedure of deflection calculation depending on the change of applied load is applied. By applying pertinent factors to the elastic moment and deflection and defining the value of the effective moment of inertia with maximum moment, the procedure of the slab deflection calculation in each construction step is presented. Generally, the most influential factors on slab deflection are 1) the amount of construction load, 2) modulus of elasticity of slab concrete, and 3) slab cracks and effective section stiffness. The amount of construction load and modulus of elasticity of the slab are the values given as the input variable in each construction step. Slab cracks and effective section stiffness are determined by acting moments depending on applied load, concrete strength by slab age, slab thickness, reinforcement ratio etc., in each construction step. The deflection analysis method proposed in this study presents a direct procedure of slab deflection calculation by applying the sequential factor depending on applied load and modulus of elasticity in each construction step and the magnification factor by the effective moment of inertia to the elastic deflection. Because the effective section stiffness degradation by cracking is affected by the total construction load applied in each construction step, the accumulated elastic deflection value in each step is converted into the inelastic deflection by magnification as much as the effective section relative stiffness ratio $I_g/I_{e,i}$ of the relevant construction step.

$$D_i = \left\{ \sum_{k=1}^{i} \Delta D_{e,k} \left(\Delta W_k , E_{c,i} \right) \right\} \times \frac{I_g}{I_{e,i}} \tag{2}$$

Where $\Delta D_{e,i}$ is an incremental slab elastic deflection in step i calculated by the modulus of elasticity $E_{c,i}$, the moment of inertia of gross concrete section I_g, and the incremental load ΔW_i. The accumulated elastic deflection is converted to an inelastic deflection with an effective section stiffness ratio $I_g/I_{e,i}$ in the construction step *i*.

ACI- 318 (ACI Committee 318 2008) presents the equation of the effective moment of inertia, to consider the effective section stiffness degradation by cracking in the flexural members

$$I_e = \left(\frac{M_{cr}}{M_a}\right)^3 I_g + \left\{1 - \left(\frac{M_{cr}}{M_a}\right)^3\right\} I_{cr} \tag{3}$$

Where M_{cr} is the cracking moment of concrete, M_a is the maximum moment in the slab, I_g is the moment of inertia of the gross concrete section about the centroidal axis, and I_{cr} is the moment of inertia of the cracked section. However, through various experimental works, Bischoff and Scanlon (2007) suggested that Eq. (3) tends to overestimate the effective moment of inertia for flexural members that have a small longitudinal steel ratio. And alternative equation of effective section stiffness for a flexural member with less than a 1% reinforcement ratio such as a slab was proposed.

$$I_e = \frac{I_{cr}}{1 - \left(\frac{M_{cr}}{M_a}\right)^2 \left(1 - \frac{I_{cr}}{I_g}\right)} \tag{4}$$

For simply supported flexural members, the effective moment of inertia can be calculated directly by substituting the maximum positive moment to Eq. (4). However, for continuously supported members, each effective moment of inertia for a negative moment in both ends and a positive moment at midspan is separately calculated, and the effective moment of inertia (I_{ea}) of the whole slab is then calculated as an average (ACI Committee 318 2008)

$$I_{ea} = \{(I_{e1} + I_{e2})/2 + I_{ep}\}/2 \tag{5}$$

Where I_{e1} and I_{e2} are the values of the moment of inertia for negative moment in both ends, and I_{ep} is the value of effective moment of inertia calculated by substituting the positive moment at midspan to Eq. (4). ACI-209 (ACI Committee 209 1997) presents a guideline on how to use an average value of the effective moment of inertia for positive and negative moments for the longer direction column strip as the effective moment of inertia of the flat-plate system.

3.2 Calculation procedure

Based on assumptions presented in "3.1 Basic concepts", the procedure of slab deflection calculation during construction can be summarized as follows (Kim *et al*. 2009):

1) Define the construction steps and calculate the construction load in each construction step by considering the floor construction cycle and the number of shored floors.

2) Calculate the flexural moment by the slab self-weight (DL) in the flat-plate. The moment per unit width for each location of the flat-plate is defined by the direct design method (ACI Committee 318 2008)

$$M = \alpha \frac{w l_n^2}{4} \tag{6}$$

where l_n is a length of clear span in the direction that moments are being determined, and α is a factor decided on each location of the slab. If both the span lengths of the slab are the same, α can then be defined as shown in Table 3 (ACI Committee 318 2008).

3) Calculate the elastic deflection of the flat-plate applied by slab self-weight (DL) and 28 days concrete stiffness (E_c). The maximum slab deflection according to the moment of inertia of the gross concrete section (I_g) is defined by the crossing beam method (Rangan 1976, Scanlon and Murray 1982, ACI Committee 435 2003)

$$\delta_{mp} = \delta_c + \delta_m \tag{7}$$

$$\delta = \frac{5}{48}\frac{l_n^{\,2}}{E_c I_g}\{M_m + 0.1(M_1 + M_2)\} \tag{8}$$

where δ_{mp} is the deflection in the slab at midspan, and δ_c and δ_m are the maximum slab deflections of the column strip and middle strip, respectively. δ_c and δ_m are calculated by Eq. (8). M_m is the midspan moment per unit width in each strip, and M_1, and M_2 are end moments per unit width.

4) Calculate the incremental elastic deflection and the moment in each construction step. The value of elastic deflection is linearly related to the applied load and material stiffness, and the value of the elastic moment is linearly related to the applied load. Therefore, the incremental elastic deflection and the moment in each construction step are calculated by applying a construction load and modulus of elasticity of each construction step proportionally to the results by the slab self-weight (DL) and 28 days material stiffness (E_c)

$$\Delta D_{e,i} = D_e(DL, E_c) \times \Delta LF_i \times \frac{E_c}{E_{c,i}} \tag{9}$$

$$M_i = M(DL) \times LF_i \tag{10}$$

5) Calculate the effective moment of inertia ($I_{e,i}$) in each construction step by Eqs. (4) and (5), while considering the acting moment (M_i) calculated by Eq. (10) and the compressive strength and cracking moment of concrete.

6) Calculate the total elastic deflection ($D_{e,i}$) by accumulating the incremental elastic deflections ($\Delta D_{e,i}$) calculated by Eq. (9) in the previous construction steps.

$$D_{e,i} = \sum_{k=1}^{i} \Delta D_{e,k} \tag{11}$$

7) The total elastic deflection in each construction step is magnified to the total inelastic deflection by using the relation between the effective moment of inertia ($I_{e,i}$) and the moment of inertia of the gross concrete section (I_g):

$$D_i = \left(\sum_{k=1}^{i} \Delta D_{e,k}\right) \times \frac{I_g}{I_{e,i}} = \left\{\sum_{k=1}^{i}\left(D_e(DL, E_c) \times \Delta LF_k \times \frac{E_c}{E_{c,k}}\right)\right\} \times \frac{I_g}{I_{e,i}} \tag{12}$$

8) Repeat 4) – 7) in every construction steps.

Table 3 Factors for bending moments in flat plates

Location		Column strip	Middle strip
Interior span	Negative moment	0.49	0.16
	Positive moment	0.21	0.14
Exterior span	Interior negative moment	0.53	0.18
	Positive moment	0.31	0.21
	Exterior negative moment	0.26	0

Table 4 Material properties and reinforcements of sample model for comparisons of slab deflections

Concrete		Reinforcement		
Comp. strength (MPa)	Elastic modulus (MPa)	Yield strength (MPa)	Reinforcement ratio	
			Column strip	Middle strip
24	23,000	400	Top 1.04%/0.14% Bottom 0.43%	Top 0.32%/0.14% Bottom 0.28%

Table 5 Summary of maximum slab deflections of reshoring models

Scheme	Maximum slab deflection	
	Value	Ratio to original scheme
Original	16.5 mm	1.00
Scheme 1	7.60 mm	0.46
Scheme 2	7.21 mm	0.44
Scheme 3	7.01 mm	0.42
Scheme 4	9.93 mm	0.60
Scheme 5	9.29 mm	0.56
Scheme 6	8.94 mm	0.54
Scheme 7	13.9 mm	0.84
Scheme 8	13.5 mm	0.82
Scheme 9	13.4 mm	0.82

4. Effects of reshoring on slab deflections

To analyze the effects of reshoring works on flat plate deflections, a sample model of a flat plate system is used with a span length of 6,000mm × 6,000mm and a slab thickness of 170mm. The material properties and reinforcement information of the sample model are summarized in Table 4. For the sample model, the slab deflections during construction are calculated by the procedure in “3. Procedure of slab deflection calculation” and the construction loads in Table 2.

Fig. 6 shows the results of changes of slab deflections with time for all reshoring schemes, and Table 5 shows a summary of maximum slab deflections. In construction stages with decreased construction loads by reshoring works, it is assumed that the decrease of deflections is linearly proportional to the decrease of construction loads. The pattern of changes of slab deflections with time are similar to that of construction loads in Fig. 4, but the ratio of deflection changes between the construction stages differs. This is because inelastic deflections include the cracking effects of the slab concrete and are not linearly-proportional to construction loads. In particular, because after a slab moment exceeds a cracking moment the effective moment inertia is rapidly decreased

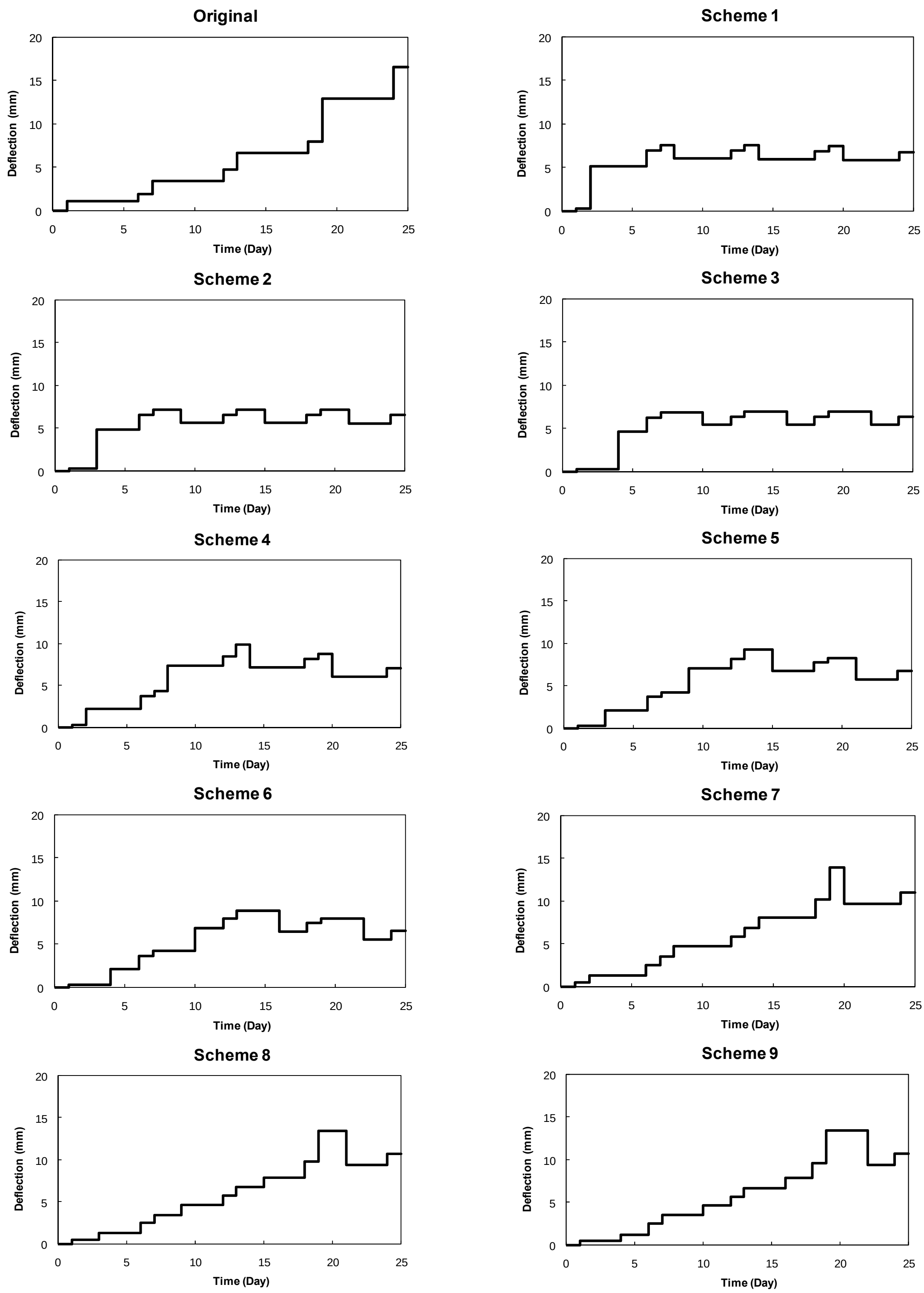


Fig. 6 Change of slab deflections with time

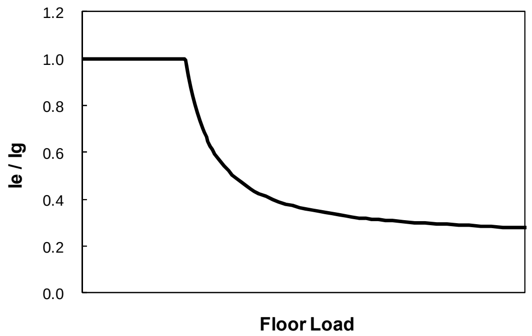


Fig. 7 Change of effective moment of inertia with floor load

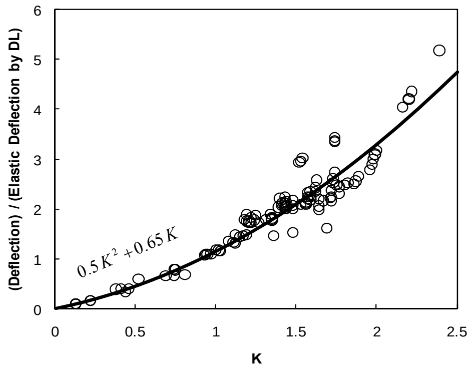


Fig. 8 Relations of slab damage parameters and slab deflections

with an increase of applied load (Fig. 7), whether or not cracking occurs is a decisive factor for slab deflections. While considering the cracking effects, the effects of reshoring works are more definite. For the original scheme, both the positive and negative moments exceed a crack moment and the deflection significantly increases at the stage of the 19th construction day. When the positive moment is less than the crack moment, schemes 1~6 do not show a sudden large increase of slab deflection. However, for schemes 7~9, the slab is reshored after undergoing both positive and negative moments that exceed the crack moment and a large increase of slab deflection. These results of maximum deflections are shown in Table 5, which shows that the ratios of slab deflections of schemes 1~6 to that of the original scheme are much smaller compared to the maximum construction loads shown in Table 2. This becomes clearer when we consider that, in the slab deflection calculations, the minimum I_e/I_g for the original scheme, schemes 1~3, schemes 4~6, and schemes 7~9 are 0.51, 0.80, 0.72~0.75, and 0.56~0.57, respectively. Also, since the damage in the section stiffness of the slab remains even after the completion of construction, the reshoring works might decrease long-term deflections. Fig. 8 shows the relations of slab damage parameters and slab deflections in all construction steps from the original scheme and schemes 1~9. The figure shows a strong correlation of slab damage parameters and slab deflections, and consequently the slab damage parameter can be utilized as a tool for evaluating slab deflections and damage during construction.

5. Conclusions

To analyze the reshoring effects on deflections of flat plates under construction, the construction loads for slabs with reshoring works were determined, and the procedure of slab deflection calculation while considering construction sequences and concrete cracking effects was proposed. Based on the analytical results with various reshoring conditions, the following conclusions are drawn:

1. The reshoring works are helpful in reducing the maximum construction load and the deflections of flat plates under construction and the maximum shoring force.
2. As reshoring works are performed at the upper levels, the maximum construction load and

slab deflection are smaller.

3. The point of time of reshoring works has little effect on construction loads and deflections.
4. Through a slab damage parameter, the construction loads can be evaluated in correlation with material strength or stiffness, and the slab damage parameter is strongly correlated with slab deflections

This study focused on the structural performances of flat plates during construction. But, the effects of reshoring works on the long-term behavior at a service stage as well as short-term behavior at a construction stage need to be clarified, and the procedure of slab deflection calculation needs be improved by including the long-term behaviors of concrete.

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