고층벽식구조 아파트에서 골조공사 공기단축을 위한 바닥 슬래브 및 지주의 해석

Analysis of Floor Slab and Support for the Shortening of Construction Time in High-Rise Wall-Type Apartment Building

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Abstract

국내 주거의 주종인 아파트의 구조형식은 벽식 철근콘크리트조로 경제성 때문에 대부분 고층으로 지어지고 있다. 철근 콘크리트조 건물의 구체공사비중 상당부분이 거푸집공사에 투입되고 있다. 구체공사의 공기(工期)는 층당 소요일수로 산정할 수 있는데 공사비 절감 및 공기단축을 통한 시공효율성의 향상을 위해서는 지주시스템의 효율적인 전용(轉用)이 필수적이라 할 수 있다. 본 연구에서는 벽식구조 아파트의 현장조사를 토대로, 현재 사용되고 있는 지주시스템 및 바닥슬래브에 대한 응력해석을 수행하고, 이를 분석하여 공기단축의 가능성을 검토하였다.

keywords : RC Wall-Type Apartment, Formwork, Shore, Reshore, Construction Rate

1. 서 론

Currently major structural system for domestic housing is a wall-type reinforced concrete structure which rises up to 30 stories. Formwork is the major factor for construction time and cost in concrete construction. Hence, construction efficiency can be improved by optimally operating shore-slab system. The disasters in RC construction are mainly due to excessive load applied to false work and premature removal of support. For the early striking of forms, sufficient compressive strength of early-concrete is essential for the safety of structure during construction.

Most of studies on the construction-load distribution referred to a simplified method

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suggested by Grundy and Kabailia in which the infinite stiffness of supports and time-independent stiffness of floor slabs are assumed. Taking more realistic assumpions in analysis model, Liu et al concluded that the simplified method is appropriate in predicting maximum slab moment and shore loads, but it is necessary to introduce modification coefficient to assess accurate load distribution. Stivaros and Halvorsen analyzed the construction-load distribution of multistory buildings by applying equivalent frame method to multibay model, finding that the most significant factor in distributing construction loads to slabs and supports is the shoring-system stiffness. El-Shahhat and Chen presented a complex procedure to improve the shore-slab interaction by utilizing deflection approach for the steps of removing shores and reshores.[1),2),3)]

In this paper, based on the field survey of wall-type apartment buildings during construction, stresses in floor slabs and supports and slab deflection during construction are examined. The feasibility of shortening construction rate from the stand point of structural safety is studied by changing construction cycle and support system.

2. Parameters Influencing Construction -Load Distributions

The main parameters influencing load distributions in slab and support during construction are construction load, concrete placement path, slab support condition, shoring system, construction rate, and the properties of concrete.[2)]

Construction loads can be classified into dead load due to concrete slab and formwork system and live load due to workers, equipment, and impact. In addition to these loads, horizontal load due to concrete placement should be considered in the design of formwork system. However, in this study, as the lateral stability of slab formwork is constrained by the wall, the effect of horizontal load is not included. The loads applied during construction is shown in Table 1. The impact load is considered only during concrete pouring while the construction live load is considered during concrete pouring and curing.

Table 1 Construction load

Dead Load	Concrete slab	2.400 kgf/m^2
	Form	40 kgf/m^2
	Support	30 kgf/m^2
Live Load	Impact Load	50% of slab weight
	Live Load	150 kgf/m^2

The joints between walls and slabs are rigid-ended because the concrete are poured simultaneously. As the end of support is not completely fixed on the upper and lower of slabs, the joint between slab and shore is regarded as a hinge.[1),2),5)]

The rate of the concrete strength development depends mainly on the concrete age, cement type, and curing temperature. In this study, the compressive strength of concrete is determined using the maturity method4). To take into account the time-dependent slab stiffness the modulus of elasticity of slab concrete is estimated using eq.(1) which showed a close relationship with the experimental result.[5)] The development of compressive strength and modulus of elasticity are shown in Fig. 1.

$$E_c = 10458.8\sqrt{f_{ct}} + 63000 \quad (kgf/cm^2) \qquad (1)$$

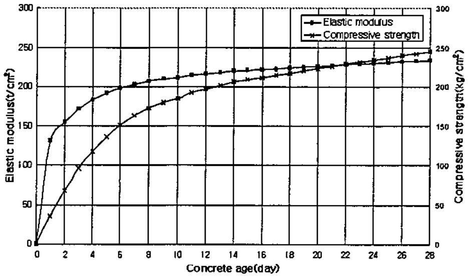


Fig. 1 Development of compressive strength and modulus of elasticity

In addition to these factors, nonlinear behavior of shores and concrete creep may affect on the load distribution but, the effect was found to be practically insignificant[1]

3. Survey of Construction Sites

Two construction sites are surveyed to prepare data on slab-support system. The rate of construction and shoring system were 10-day per story and 1-shoring with 2-reshoring for both sites, respectively. The size of the living room was 4.2×4.3m(site 1) and 5.8×7.5m(site 2). Concrete design strength was 240 kg/cm^2. The materials for formwork and dimensions are shown in Table 2.

4. Modeling according to Construction Sequence

In the modeling of story unit, living room and kitchen area are selected because this area is the largest one surrounded by walls for both cases. Based on the previously mentioned factors, the assumptions introduced in the modeling are as follows:

(1) Slabs behave elastically, and their stiffnesses are time-dependent.

(2) Shores and reshores act as continuous uniform elastic supports and behave elastically.

(3) The foundation is rigid and unyielding.

(4) The joints between the slabs and walls are rigid-ended and the wall is rigid.

(5) Joints between slabs and shores are pin-ended.

The plate element and truss element of MIDAS were utilized to model slab and support, respectively. The evaluation of stresses in the slab was done according to the construction sequence and rate illustrated in Table 3.[7]

Table 2 Dimension of building and formwork

		Site 1	Site 2
Story height		250	230
Slab thickness		13.5	16
Support (steel pipe)	External Diameter	6.05	
	Pipe thickness	0.21	
	Spacing	60 ~ 120	90 ~ 110

Note: unit cm

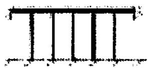
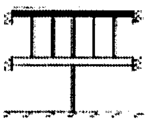
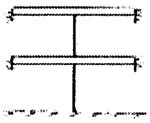
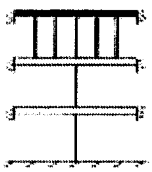
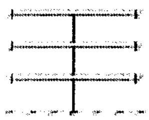
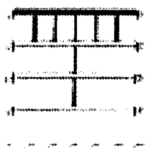
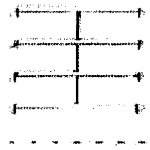
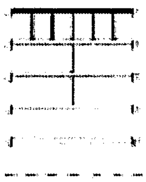
4. Analysis Results

4.1 Stresses

For the two cases maximum values of stresses are traced at the second and third floors according to construction sequence. The rate of construction was 10-day per story.

The allowable compressive and shear stresses are $0.3\,f_{ck}$ and $0.53\sqrt{f_{ck}}$, respectively. The maximum compressive stress is shown in Fig. 4. As the site 2 has the larger slab, peak stress also much higher than that of site 1 when fresh concrete was poured on the upper floor. Locals

Table 3 Modeling Unit and Concrete Age

Stage	Structure Status	Age(day) 7-day cycle	Age(day) 10-day cycle
1		0	0
2		4	5
3		0 7	0 10
4		4 11	5 15
5		0 7 14	0 10 20
6		4 11 18	5 15 25
7		0 7 14 21	0 10 20 30
8		4 11 18 25	5 15 25 35
9		0 7 14 21 28	0 10 20 30 40

Note : ■ : fresh concrete
□ : partially hardened concrete

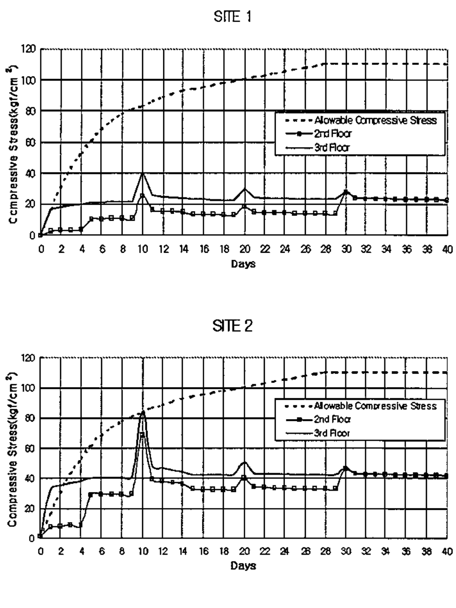


Fig. 4 Maximum compressive stress

peak stress values in the 3rd floor decreased as concrete hardened.

It is noticeable that the stress at the stage of removing reshore from the ground in the 2nd floor of site 1 exceeded that at the stage of concrete pouring on the 3rd floor, which was not true of site 2.

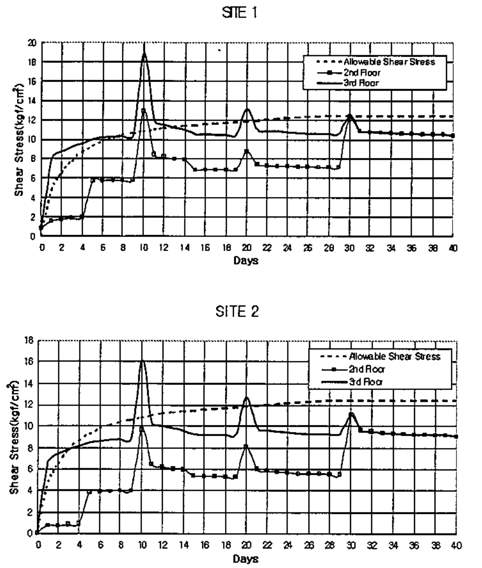


Fig. 5 Maximum shear stress

In Fig. 5, the shear stress exceeded the allowable one by 80% in the 3rd floor of site 2. The gap of the maximum shear stress between 2nd and 3rd floors are much higher than that of the compressive stress.

4.2 Axial force in support

The axial force in support is shown in Fig. 6. The force in the 1st level support exceeded the allowable value by 97%, while in the 2nd level it was acceptable. It is noticeable that the gap of the axial force in the 1st and 2nd levels increases as slab concrete hardens and the 1st level shore becomes reshore, relieving the load from the 2nd level shore. As the overload of shore can cause the collapse of the shoring-system, placing horizontal bracing in the 1st level may reduces the possibility of the collapse.

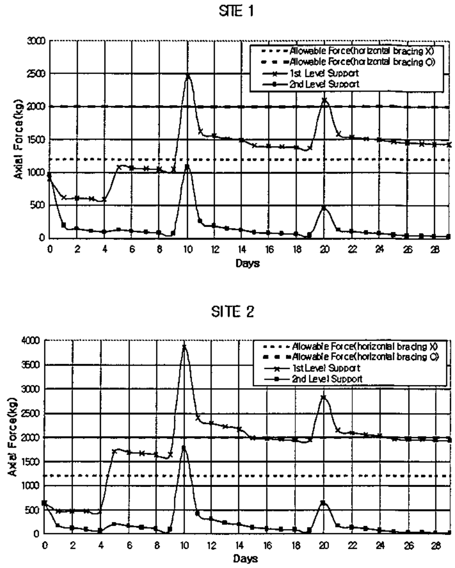


Fig. 6 Maximum axial force in support

4.3 Slab Deflection

The maximum vertical deflection of the slab was 0.18cm for the site 1 and 0.26cm for the site 2(Fig. 7). This is far below from the allowable value which is based on the limit of span/360.

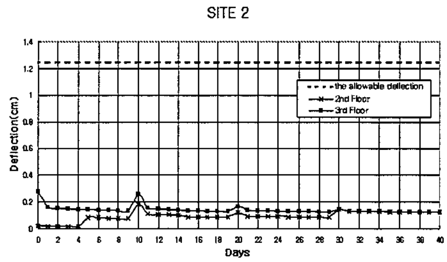


Fig. 7 Maximum slab deflection

4.4 Effect of Construction Rate and Shoring System

One of a way to operate construction site economically is to shorten construction time with maintaining structural safety. Analysis with 7-day cycle is done to find out the effect of early form striking.

In Fig. 8, compressive stress at the 3rd floor is compared. The peak points shifted horizontally, exceeding the allowable value slightly in site 2. Also, horizontal shifting of peak points can be found in the case of shear stress(Fig. 9), deflection(Fig. 10). However, the peak of axial force in the shores is increased about 2% in site 2(Fig. 11). This is due to insufficient slab stiffness.

Premature removal of forms leads to cracking in the slab, causing subsequent defects. Reinforcing reshoring can be a possible solution to this problem.

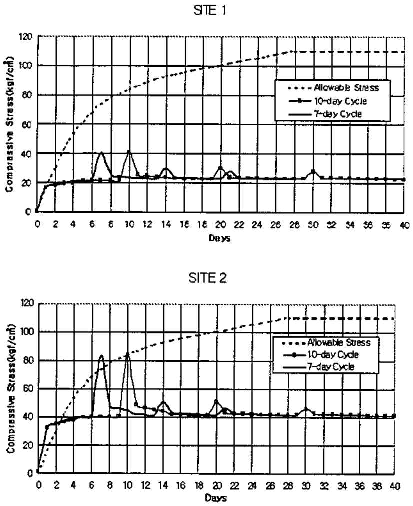


Fig. 8 Maximum compressive stress(3rd floor)

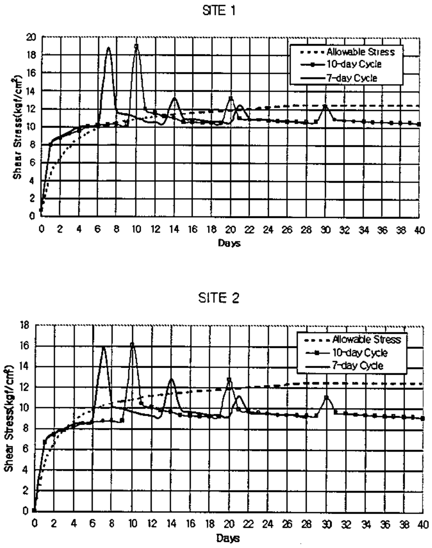


Fig. 9 Maximum shear stress(3rd floor)

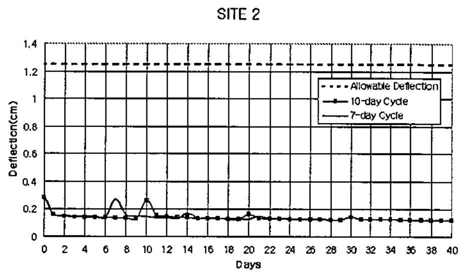


Fig. 10 Maximum deflection(3rd floor)

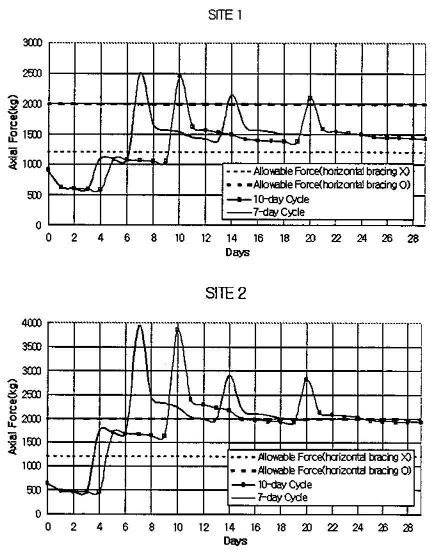


Fig. 11 Maximum axial force (1st level)

Hence, two types of reshoring with 7-day cycle for site 1 is examined: reshoring type 1-current system, reshoring type 2-doubled amount of reshore. The maximum compressive and shear stress, axial force are compared in Table 4. The effect of increasing reshoring is well reflected in the 1st level shore, relieving axial force by 30%. The second floor rather than the third floor is benefited by the reshoring reinforcement.

Table 4 Comparison of reshoring type.

	Type 1		Type 2		Ratio	
	2F(1L) (a)	3F(2L) (b)	2F(1L) (c)	3F(2L) (c)	c/a	d/b
Compression	24.7	40.3	19.4	38.2	0.78	0.95
Shear	12.8	13.8	11.0	13.1	0.86	0.96
Axial force	2494	1114	1732	762	0.69	0.68

Note: unit kgf/cm², kg, 2F(1L) 2nd floor slab or 1st level shore.

5. Conclusion

Based on the field survey of construction sites, the structural behavior of floor slab and shoring system, and the effect of changing construction rate and reshoring are examined. The findings of this study can be summarized as follows:

1) The compressive stress in the larger and thicker slab was higher than in the smaller and thinner one, but, this is not true of the shear stress.
2) The difference of the shear stress in the second floor and third floor was much higher than that of compressive stress. Shear stress in the third floor exceeded the allowable one at the early ages, and therefore, shear stress can be a cause for falsework failures in concrete structure during construction.
3) Horizontal bracing or reducing the spacing of reshore at the 1st level is instrumental in lessening axial force in reshore.
4) The change of construction rate from 10-day to 7-day cycle brought only minor variation in the peak of stress. However, feasible cracking of slab concrete due to early removal of formwork should be examined.

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