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COST ANALYSIS OF STRUCTURAL PLAN FOR REDUCING FRAMEWORK CONSTRUCTION DURATION OF REINFORCED CONCRETE RESIDENTIAL BUILDINGS

Seon-Woo Joo[1], **Moonseo Park**[2], **and Hyun-Soo Lee**[3]

[1] ph D. Candidate, Department of Architecture, Seoul National University, Korea
[2] Professor, Department of Architecture, Seoul National University, Korea
[3] Professor, Department of Architecture, Seoul National University, Korea
Correspond to qtsun@paran.com

ABSTRACT: Recently, the number of complex construction projects, such as high-density development and long-span mega structure construction, has been increasing globally. Therefore, the construction duration has become an even more important factor for success. Nevertheless, in domestic residential construction projects, it usually takes more time than twice as much as North American cases. The long construction duration causes a number of problems, for example growth of financial costs, fall in productivity, and weakness of competitiveness. If the framework construction duration can be shortened to 3 ~ 4 days, then it is also expected to complete the finish work of building in shorter duration, be led to reduce the entire construction duration, and eventually to save a great deal of indirect costs. For shortening the construction duration, previous researches pointed out that the development of simplified plan design should precedes. But, in reality, lack of experience of new design and innovative techniques tends to be the obstacle to wide adoption of the simplified plan design in construction fields. In this paper, a simplified structural plan design is proposed, and the construction cost is quantitatively compared between when traditional construction technique is applied to the traditional plan and when the duration-shortening key technique is applied to the developed plan.

Keywords: Framework, Shortening Construction duration, Construction Cost, System Form

1. INTRODUCTION

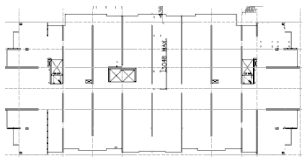
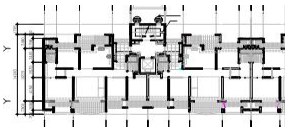
1.1 Background

All over the world, lately, it is obvious that the construction projects have been more complex and bigger than before, for example high-density development, long-span mega structure construction, high-rise building, etc. Especially, in Korea, it is noticeable that the number of projects, which are characterized by the mega-extensiveness and the sky-scratching height, is increasing. Such a project inherently requires a long construction duration, and also the duration has a strong impact on the success of the project. The long construction duration may cause the delay of operation of the facility, grow the financial costs, increase the gross construction cost, and reduce the benefit from the project. Furthermore, the long duration may cause some inconvenience around the construction site in respect of traffic and environment, so that the inhabitant's claim in the neighborhood can be another problem.

The average floor construction cycle for residential apartments, which holds the 92% out of the whole housing supply, is 8-10 days, 6 days when it is shortened as much as possible. It means that the construction duration of residential apartments is usually twice as long as the North American cases or Domestic high-rise building cases. Such a delay lowers the productivity of the project, causes further delay in finish work, grows financial costs, and weakens the technology competitiveness.

Park argued that large system forms and high early strength concrete should be widely adopted in daily practice to reduce the construction duration of residential apartment in domestic industry [1]. He also discussed that simplified plan design is indispensable for applying the new techniques above in construction practices. Kim et al. attempted to demonstrate the applicability of the duration-shortening construction techniques for domestic residential buildings through the mock-up test and the productivity analysis [2]. In the research, 3-day construction cycle per floor was expected to be able to be realized when the new techniques are applied.

Traditionally, under the Korean unique construction environment and regulations, it was possible for construction companies to manage the construction project financially with the money which had been prepaid by the owners. Following the traditional practice, the construction industry has had little concern about rapidly construction completing, and tends to adopt traditional construction techniques which is easy, familiar,

		Project A (North American case 1)	Project B (North American case 2)	Domestic Apartment
Size	Gross Area/ Stories	746 ㎡ / 43 storey	1400 ㎡ / 12 storey	543m2 (34PY 4SD) / 25storey
Structural Plan				
Floor Construction Cycle		2.5 days/floor	3 days/floor	6 days/floor
Form works	Inside Walls	Ganged Form	Ganged Form	AL Form
	Outer Walls	-	-	Ganged Form
	Slab	Table Form	Table Form	AL Form
Reinforcement	Method	Pre-fabrication(walls) On-site fabrication (Slab)	On-site fabrication	On-site fabrication
Concrete	Strength (for wall/ for slab) (kgf/cm^2)	500 / 300	350 / 250	240 / 240
	Early High Strength	O	O	X
Construction Planning	Concrete Installation Planning	VH Separate Installation	VH Separate Installation	T-type Installation
	Regulation on removal of forms	Walls: 18hr Slabs: 36hr	Walls: 18hr Slabs: 36hr	Walls: 2nd Day Slabs: 3rd Day
	Tower cranes (Average operation rate)	1 unit (80%)	1 unit (80%)	1unit for 2 buildings (32%)
	Concrete Installation Methods	Bucket	Bucket	Pump car

and little risky. However, nowadays the rate of housing to the population exceeds 100% (Statistics of Ministry of Land, Transport and Maritime Affairs, 2006) and the stagnation of the housing value by unsold apartments pressurize the construction industry to take the construction duration greatly into account [3]. Moreover, under the global misery of economic crisis, the importance of the discussion on issues related to construction duration cannot be emphasized enough.

1.2 Objective of the Study

There are insufficient studies on the duration-shortening construction techniques, and also the economic benefit of the methods is not proved yet. Thus, to catalyze the spread of new techniques, the demonstration of the applicability and benefit of the new ways should be test and verified.

This study proposes a prototype of simplified structural plan which is designed to acquire maximum constructability. Next, a comparative study is conducted quantitatively to verify the economic benefit of adopting duration-shortening methods for the framework construction, between when traditional construction technique is applied to the traditional plan and when the duration-shortening key techniques are applied to the suggested plan.

1.3 Scope and Methodology

This study focuses on the domestic mid-rise (15-25 stories) residential apartment buildings which have the reinforced concrete structure. The research is conducted following the flow as below

(1) Analyses of previous projects and previous researched, and proposal of a simplified structural plan for reducing construction duration
(2) Comparative study among the alternatives to select the most optimized structural plan in regard of constructability and duration
(3) Analysis of the construction cost, comparing the traditional practices and the duration-shortening ways.

The boundary of the comparative analysis is as the followings.

(1) Includes only the framework construction.
(2) Includes only direct costs

▪ **Table 19.**Comparison between Korean and North American construction sites

(3) Compares for the case for a building which consists of 4 households

2. PRELIMINARY STUDY

2.1 Comparative study on framework construction between the Korean and North American cases

With pursuing reduced duration of domestic framework construction, a comparative study is taken between the Korean and the North American cases, and the result shows some discriminating points (Table 1), (Table 2).

The North American case has a floor plan in which outer walls are open-type, and minimizes the amount of partitioning walls inside the building. In other words, it was the result of efforts to make the constructability of the architecture as high as possible, by eliminating the potential obstacles in the view of effective construction. With this type of structural plan, the duration-shortening construction techniques can be adopted as the followings: large system forms, early high strength concrete or high strength concrete, VH separate concrete installation or L-type installation, precast concrete for staircases, etc. Moreover, the North American maximizes the effect of the reduced duration, by using the effective zoning plan and optimized tower cranes operation.

Table 20. Comparison of floor construction cycle

Country	Structure	Key Technology	Floor Cycle (day)
U.S. (NYC)	Mushroom Structure	Handset Forms Shoring High Strength Concrete	2
U.S. (Chicago)	Mushroom Structure	Core-Preceding Technique VH Separate Installation High Strength Concrete Slab Post-tension	3-4
U.S. (Las Vegas)	Mushroom Structure	Core-Preceding Technique L-type Installation VH Separate Installation High Strength Concrete Slab Post-tension	3-4
Canada (Toronto)	Wall-Supported Structure	Synchronization of Core & Floor VH Separate Installation Table Form & Ganged Wall Form High-Quality Concrete High Early Strength Concrete	3
Korea	Wall-Supported Structure	Hand-set Form & GCS General Concrete	6-8

2.2 Previous research

Hanna and Senouci presented a design optimization method for all-wood concrete-slab forms, and compared the cost of each slab-form component to that of the traditional design method. They emphasized that the optimum design method for cost saving and constructability should be considered in design phase [4].

Recently there is a growing interest of shortening the construction duration and there is a diversity of approaches to address the problem. Lee et al. demonstrated that, if the architectural precast concrete is adopted, it leads an improvement in respect of the construction duration, construction operation conflicts, planning, safety, automation, etc [5]. Son expected that the industry would be inclined to use mushroom structure in the near future, which is led by the government's move to activate remodeling of old architectures [6].

3. DEVELOPMENT OF STRUCTURAL PLAN

Generally, when a structural engineer designs a reinforced concrete structure, he may want to find out the way to make the quantity of structure as small as possible, as long as the load not to exceed the maximum allowed strength of the structure. However, this type of approach may be prone to fall in ignorance of importance of the constructability. And also, the approach does not take it into account saving of costs produced by the shortened construction duration and improvement of constructability [7].

Thus, a reasonable process to address these issues – constructability and duration – has to be developed to reduce the construction duration of domestic residential buildings. In this paper, four alternatives are examined to look for the most desirable structural plan, focusing on the applicability to the large system form method. The four of them are these: Rectangle-shaped Mushroom Structure, Rectangle-shaped Open-type Wall Structure, Tower-shaped Structure, North-American One-way Wall Structure (Table 3). All these four are checked and examined thoroughly by criteria such as domestic traditional practice in the industry, structural stability, economic efficiency, extensibility to high-rise apartment, availability of remodeling, and suitability to Korean life style. Through this process, it is decided that the Rectangle-shaped Mushroom Structure is the most suitable option (Figure 1).

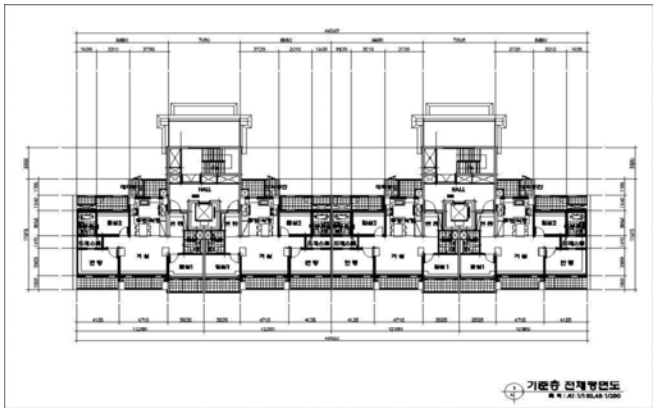


Figure 10. Simplified structural plan

4. ANALYSIS OF ECONOMIC EFFICIENCY OF REDUCED CONSTRUCTION DURATION

For a fair comparative study between the traditional way and the duration-shortening technique, the comparison is conducted based on two structural plans which have almost same space shape and same area.

4.1 Estimating of duration for framework construction

For estimating of the framework construction cost of the developed structural plan, a prototype, it should be calculated the period of time in which the formwork is rented and used. The estimation of the construction duration should be conducted to later analyze the economic efficiency of the suggested plan and method.

For the traditional wall-structure plan, when the floor construction cycle can be regarded as 6 days, the duration for the entire framework construction of 20-story apartment can be estimated as 254 days, including non-working days. On the other hand, the developed simplified structural plan is expected to yield 167 days for its framework construction because the floor construction cycle can be counted as 3 days. Therefore, it can be expected about 34.3% of the duration to be reduced if the simplified design and rapid construction techniques are adopted (Table 4).

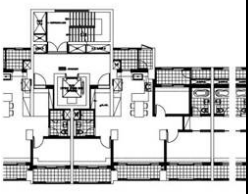
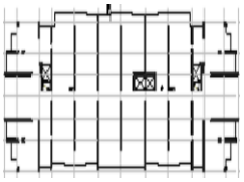
▪ **Table 22.** Comparison of construction duration

	Wall-support structure	Mushroom structure	Difference
Standard floor construction cycle	6 day cycle	3 day cycle	
Underground	45	45	-
1st Story	24	21	3 days
2nd~3rd Story	22	14	8 days
4th~20th Story	153	77	76 days
Top story	10	10	-
The entire duration	254	167	87 days

4.2 Economic analysis of traditional structural plan and technique

For estimating the economic efficiency, the most common estimating formula, which is based on the construction cost per unit area, is used. The comparative study of economic efficiency is conducted only about the

Table 21. Alternatives of structural plan.

Structural Plan	Features
	- Rectangle-shaped - Mushroom structure - Minimization of horizon-direction walls - supported partly by outlining beams
	- Rectangle-shaped - Open-type wall structure - Minimization of horizon-direction walls
	- Tower-shpaed - Open-type - Wall or Mushroom structure - Minimization of horizon-direction walls
	- Rectangle-shaped - North-American type one-way wall structure - Structural lateral supporting wall

construction above the ground. Also, the quantity takeoff is based on the quantity specification which is provided by the designer. In this study, due to the limited availability of hypothetical information, the analysis is conducted only on direct construction costs. Lastly, the cost data used in the analysis is acquired from the standard construction cost book.

Table 23. Quantity Analysis 1 - Wall-structure

	Concrete(M3)	Form(M2)	Reinforcement (Ton)
Quantity	6,976.606	48,409.45	496.994
Gross Area	M3/M2	M2/M2	Ton/M2
Per Pyung (Korean unit)	M3/Pyung	M2/Pyung	Ton/Pyung
Concrete		6.939 M2/M3	.071 Ton/M3

Table 6. Quantity Analysis 2 - Wall-structure

	concrete (M3)	%	form (M2)	%	M2/M3	reinforcement (Ton)	%	Ton/M3
Foundation	813.35	11.658	196.71	.406	.242	38.057	7.657	.047
Column	80.826	1.159	1,603.09	2.196	13.153	6.533	1.314	.081
Beam	71.2	1.021	692.36	1.43	9.724	16.752	3.371	.235
Slab	2,478.516	35.526	12,264.42	25.335	4.948	124.517	25.054	.05
Retaining Wall	3,287.502	47.122	32,303.78	66.73	9.826	267.462	53.816	.081
Staircase	169.219	2.426	1,135.89	2.346	6.713	29.181	5.872	.172
Else	75.992	1.809	753.2	1.556	9.912	14.491	2.916	.191

The result of the analysis is shown above (Table 5), (Table 6).

Based on the cost reference [8], the construction cost of concrete, reinforcement, and formwork of wall-structural plan is as following.

- Concrete work : 453,310,364 won
- Reinforcement work : 492,181,110 won
- Formwork : 1,985,481,914 won
- Overall cost: 2,931,344,127 won

4.3 Economic analysis of the simplified structural plan and duration-shortening technique

As in the estimation for the traditional ways, the result of the analysis for the simplified structural plan and duration-shortening technique is shown below (Table 7), (Table 8).

Table 7. Quantity Analysis 1 – Mushroom-structure

	Concrete(M3)	Form(M2)	Reinforcement (Ton)
Quantity	5,931.808	34,643.1	631.849
Gross Area	M3/M2	M2/M2	Ton/M2
Per Pyung (Korean unit)	M3/ Pyung	M2/ Pyung	Ton/ Pyung
Concrete		5.84 M2/M3	.107 Ton/M3

Table 8. Quantity Analysis 2 - Mushroom-structure

	concrete (M3)	%	form (M2)	%	M2/M3	reinforcement (Ton)	%	Ton/M3
Foundation	752.157	12.68	241.31	.697	.321	40.527	6.414	.054
Column	796.347	13.425	4,335.72	12.515	5.445	134.903	21.351	.169
Beam	95.9	1.617	949.68	2.741	9.903	52.261	8.271	.545
Slab	2,410.432	40.636	11,961.6	34.528	4.962	223.216	35.327	.093
Retaining Wall	1,707.754	28.79	16,018.9	46.24	9.38	151.761	24.019	.089
Staircase	169.219	2.853	1,135.89	3.279	6.713	29.181	4.618	.172
Else								

Based on the cost reference, the construction cost of concrete, reinforcement, and formwork of Mushroom-structural plan is as following (Table 9).

As it is shown in the table 9, the result demonstrates that, when the table-system form is applied to implement the simplified structural plan, it is expected as following

- Concrete work : 385,416,199 won
- Reinforcement work : 625,730,174 won
- Formwork : 1,244,546,521 won
- Overall cost : 2,255,692,894 won

Table 9. Analysis of construction costs

	Concrete		Reinforcement	Formwork			
	25-240-12	25-180-8		Veneer board	Euro form	Ganged form	Table form
Sum	383,030,763	2,385,436	625,730,174	72,461,774	43,789,397	840,854,822	287,440,528.4
Gross Sum	385,416,199		625,730,174	1,244,546,521			

If the system form is applied to the developed plan, the result yields 15% of reduction at the cost for concrete work and formwork, 27.1% of increase at the cost for reinforcement work. As a result, the overall cost is expected to be reduced by 23.5% for the entire framework construction.

5. CONCLUSION

Along with the rapid changes in the national economy, the construction industry also now is pressurized by the tide to adapt to the new construction environment and circumstances. One of the obvious changes occurring in the construction field is found in the structure of construction labor. Therefore, for the construction industry to handle the current challenges, one of the most critical areas is the management of the construction duration. Under more competitive environment and difficult economic circumstances, a key to solve the problem is developing new techniques to shorten the construction duration. If construction duration can be innovatively shortened, the industry can be little affected by the changed labor structure, also may be more free from the rapidly changing world economy.

As mentioned above, The average floor construction cycle for residential apartments, which holds the 92% out of the whole housing supply, is 8-10 days, which means that the construction duration of residential apartments is usually twice as long as the North American cases. Thus, in this paper, the study is conducted to find out a breakthrough to shorten the duration for the Korean residential building construction and verify its value.

For the purpose, some key technologies are used as some previous researches suggested. It includes the development of the new structural plan which is designed to maximize constructability and to reduce the duration as much as possible. The new plan has less walls inside of the building space and the non-structural components are designed to be assembled after the framework completed, so that the shortened duration of residential building can be realized, and bring a great deal of economic benefit.

The result of analysis demonstrates an obvious improvement by incorporating the simplified design and the duration-shortening technique. This is shown because the unit cost of the system form is much more expensive than of the traditional handset forms, but the productivity and reusability of the form is much greater. Therefore, the more storey the architecture has, the more improved is the productivity of the formwork. Also, the system form is operated mainly by equipments such as the tower crane, if the labor cost is rising, the benefit of system forms can be maximized.

However, the analysis does not include the consideration about non-structural walls. For more accurate analysis, the analysis for the mushroom structure plan should involve the additional cost for the quantity of those non-structural walls. Moreover, If the study includes complicated issues such as reduced indirect cost by shortened duration and additional reduction of duration by shortened finish works, it is expected that more realistic and reliable analyses can support the wide adoption of new structural plans and construction techniques for practitioners in fields.

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