

**PRODUCTIVITY ANALYSIS OF THE TABLE FORMWORK METHOD
FOR MAKING A COST-EFFICIENT EQUIPMENT INPUT PLAN**

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ABSTRACT

For improvement in the productivity of tall building projects, table formwork is one of the main methods that have been adopted for slab formwork. Because the table formwork method is an equipment-oriented construction method, the type of lifting equipment and method of operation considerably affects the productivity and cost of the table formwork. It is also important to make an equipment input plan for completing the table formwork within the time given, according to the structural construction cycle. For performing the table formwork, a tower crane or an independent lifting system, and shifting trolleys, are required. However, if an inefficient equipment input plan is made, exorbitant cost may be incurred. Therefore, the purpose of this study is to analyze the productivity of a table formwork, considering the type and number of lifting equipment and the number of trolleys inputted, and to suggest quantitative data for making a cost-efficient equipment input plan within the construction duration given. It is expected that the results of this research will be utilized as a basis for cost-efficient equipment input planning.

KEYWORDS

Tall building, Tower crane, Independent lifting system, Productivity analysis, Simulation, CYCLONE

INTRODUCTION

For improvement in the productivity of tall building projects, table formwork is one of the main methods that have been adopted for slab formwork. Because the table formwork method is an equipment-oriented construction method, the type of lifting equipment and method of operation considerably affect the productivity and cost of the table formwork. It is also important to make an equipment input plan for completing the table formwork within the time given, according to the structural construction cycle.

The table formwork method generally requires a Tower Crane (T/C) or independent lifting system for lifting the table form, and shifting trolleys for moving the table form. The table formwork with T/C will increase the lifting load of the T/C. However, when using an independent lifting system, more efficient lifting will be possible, in spite of the expensive cost. Consequently, the table formwork requires an equipment input plan that considers the cost and duration adequate to the table formwork. However, due to the lack of performance-data, it is difficult to figure out its quantitative effect and cost. Thus project managers have difficulty in deciding the type and number of lifting equipment input following the formwork.

The purpose of this study is to analyze the productivity of table formwork considering the type and number of lifting equipment, and the number of trolleys inputted, using Web-CYCLONE, and to suggest quantitative data for making a cost-efficient equipment input plan within the construction duration given. The targets of the analysis are the table formwork method with T/C, using the loading platform, and the table formwork with Table Lifting System (TLS), as developed by DOKA GmbH. It is expected that the results of this research will be utilized as a basis for cost-efficient equipment input planning.

LIFTING EQUIPMENT FOR TABLE FORMWORK

Tower crane

A table formwork with T/C lifts the table forms by loading them onto a loading platform, located on an external wall of the building (Fig. 1). It is necessary to use a shifting trolley that can strip and install the table forms on the stripping floor. To maintain the balance of the table form, wire should be tied to the four corners of the table form. The table form tied with wire is quickly lifted to the place of installation through the T/C, and additional equipment for installing the table form is not required.



Figure 1 – Lifting and installing work with T/C

However, this lifting method requires additional time for tying the wire, and work skill of the T/C driver in using the table formwork (Kim, 2013). Furthermore, higher heights of buildings lead to more difficulty in the lifting work, due to the effects of wind. The installation time of the next table form is also delayed, because the T/C should be used during the installation duration of the table form.

TLS (Table Lifting System)

The Table Lifting System (TLS), developed by DOKA GmbH, is a system for the vertical lifting of table forms, with no need for a T/C (DOKA GmbH, 2011). The system can lift the table form at a speed of 10 m/min, through an independent deck that is supported by two masts, between the stripping and installing floors. For use in a building of any height, the system can automatically raise itself using hydraulic power on the external wall of a building, and can run at high wind loads (of up to 20 m/sec).



Figure 2 – Table Lifting System developed by DOKA GmbH

The table formwork with TLS, in contrast to the table formwork with T/C, requires one or more shifting trolleys on the installing floor. The system can lift the next table form, because of the shifting trolley on the installing floor, regardless of travel or the installation time of the table form. Therefore, the stripping and installing work of a table form is conducted separately. This formwork method can improve the productivity of table formwork, and reduce the lifting load of the T/C.

CYCLONE MODELING BY LIFTING EQUIPMENT

Project overview

To measure the productivity of the table formwork method by applying two different items of lifting equipment, a case site of a tall building construction project was considered, where table formwork was being used. The case site was a construction field in Busan, Korea, for a high-rise 63-floor office building, where table formwork lasting 18 months was planned. The table formwork was conducted by dividing the construction site into zones A and B for a 4-day cycle, and a total of 99 table form units were used, which were composed of 48 and 51 table form units for each zone, respectively, to form three floors. One TLS was used for lifting the table form in each zone, and two shifting trolleys were installed on each stripping and installing floor.

CYCLONE model for table formwork with T/C

The table form process with T/C was investigated through a progress schedule corresponding to the case site, and with interviews with the project manager. The table formwork process with T/C was categorized into stripping work using a shifting trolley, and installing work with the T/C. In the stripping step, the table form is stripped, and shifted to the loading platform, using a shifting trolley. The table form is loaded onto the loading platform, and then tied to the wires of the T/C. After the tying work, the shifting trolley is returned to the stripping spot, for stripping the next table form. In the installing step, the table form is lifted to the installing spot, using the T/C. An installation crew conducts the positioning, installing, and untying work. After the untying work, the T/C is returned to the loading platform, to lift the next table form. The details of the simulation model are shown in Figure 3.

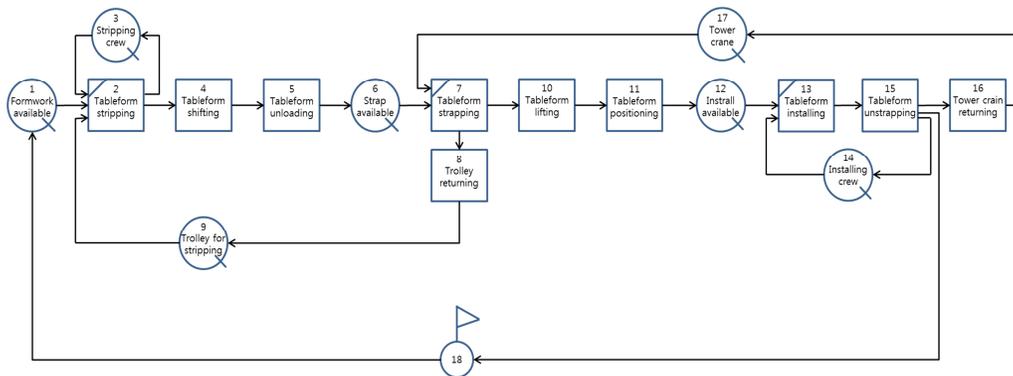


Figure 3 – Simulation model for table formwork with tower crane

The resources for each activity were input on the basis of data collected from the case site. The resources that were input were defined as fifty-one table form units, a pair of installation crews, a pair of stripping crews, a T/C, and two shifting trolleys for stripping table forms. The work time for the simulation was input on the basis of data collected from cameras at the case site. However, since a T/C was not used for lifting the table forms, the lifting time was calculated by the Hook Travel time suggested by Zhang et al. (1999). Also, the travel time of a shifting trolley was calculated by the average duration of table form unit shifting suggested by Lim et al. (2013). Each work time required is described in Table 1.

The work time of installing and stripping the table form were input as triangular distributions, with actual measurements. The lifting and traveling duration of the table form, and the returning duration of the shifting trolley, were input as uniform distribution, according to the distance of traveling and lifting of the table form. The duration for loading, unloading, and tying were defined as deterministic values, because of the almost fixed durations, with little variation.

Table 1 - Duration input data of Table formwork with T/C

Node	Work task	Value type	Duration (min)		
			Min	Mean	Max
2	Table form stripping	Triangular	1	2.24	3.83
4	Table form shifting	Uniform	0.488		5.126
5	Table form unloading	Deterministic		1	
7	Table form strapping	Deterministic		1.5	
8	Trolley returning	Uniform	0.488		5.126
10	Table form lifting	Uniform	0.36		0.721
11	Table form positioning	Deterministic		1.5	
13	Table form installing	Triangular	3.65	4.88	6.33
15	Table form unstrapping	Deterministic		1	
16	Tower crane returning	Uniform	0.36		0.721

CYCLONE model for table formwork using TLS

In order to analyze the productivity of the table formwork process with TLS, the CYCLONE model suggested by Lim et al. was used (2013). Figure 4 describes the formwork process. Two shifting trolleys were input, both in the installing and stripping steps, and the process was classified into stripping, lifting, and installing steps. In the stripping step, the table form process and the stripping process with T/C were the same, and the tying work of the table form was replaced by fixing work, which is a simpler process. In the lifting step, the table form was lifted with the TLS to the installing floor. After the table form had done the unfixing work, the TLS was returned to the stripping floor, for lifting of the next table form. In the installing step, the unfixing table form traveled, and was unloaded at the installing spot by the shifting trolley. When the unloading was complete, the table form was installed by the installation crew, and the shifting trolley was returned to the TLS, for loading the next table form. The details of the simulation model are described in Figure 4.

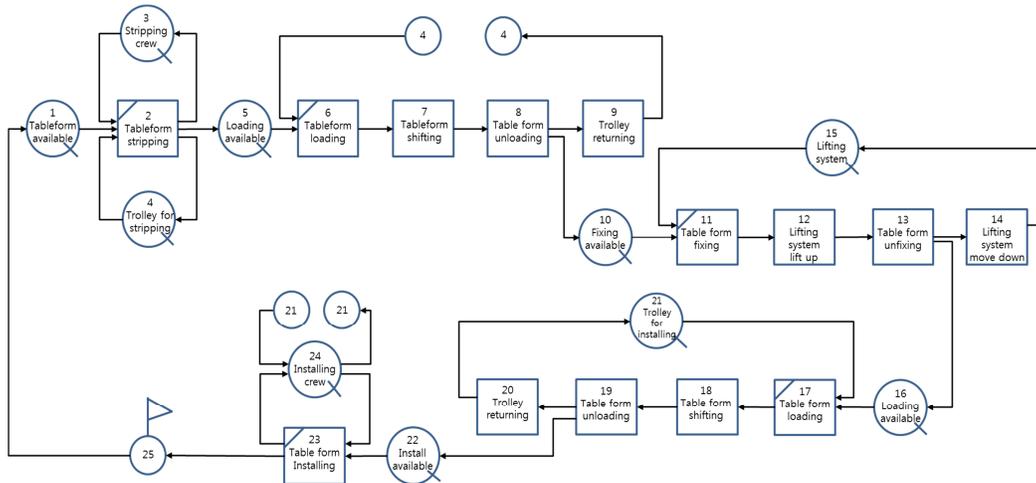


Figure 4 - Simulation model for table formwork with TLS

The resources invested in each activity were input on the basis of data collected at the case site. Fifty-one units of table forms, a pair of installation crews, a pair of stripping crews, a TLS, two shifting trolleys for stripping, and two shifting trolleys for installation were put into the case site, according to zone A. For the working duration for this simulation, data was collected from cameras at the case site. The durations are shown in Table 2.

Table 2 - Duration input data of Table formwork with TLS

Node	Work task	Value type	Duration (min)		
			Min	Mean	Max
2	Table form stripping	Triangular	1	2.24	3.83
6	Table loading	Deterministic		0.1	
7	Table form shifting	Uniform	0.488		5.126
8	Table form unloading	Deterministic		1	
9	Trolley returning	Uniform	0.488		5.126
11	Table fixing	Deterministic		0.5	
12	TLS lift up	Deterministic		1	
13	Table form unfixing	Deterministic		0.5	
14	TLS move down	Deterministic		1	
17	Table form loading	Deterministic		1	
18	Table form shifting	Uniform	0.488		5.126
19	Table form unloading	Deterministic		0.1	
20	Trolley returning	Uniform	0.488		5.126
23	Table form installing	Triangular	3.65	4.88	6.33

Stripping, shifting, installation, and the returning time for the trolleys are input with the same values as in the CYCLONE model of the table formwork with T/C, since the only change was in the lifting equipment. Also, the loading, unloading, fixing, and lifting times with the TLS, which have almost fixed durations with little variation, were input as deterministic values.

RESULTS

Comparative analysis of productivity

For sufficient convergence of the result values of the simulation, the simulation was performed for 1,000 cycles. The results of the analyses of table forms with T/C and TLS are described in Table 3. For the formwork with TLS, on the basis of productivity of 0.169947cycles/min, the whole simulation time was 5884.2 minutes, and the installation time for each table form was 5.9 minutes. Thus, the productivity of the table formwork with TLS increased by 170.68%, compared to the table formwork with T/C, and the whole installation time of fifty-one table forms decreased by 3.53 hours.

Table 3 – Results of the comparative analysis of the productivity

Equipment	Total simulation time (min)	Cycle number (time)	Productivity per time unit (cycle/min)	Total installation time (hour)
Tower crane	10043.2	1000	0.099569	8.53
TLS	5884.2	1000	0.169947	5.00

The idle state analysis of the two items of lifting equipment is described in Table 4. In order to analyze the reason for the productivity change between the two items of lifting equipment, a comparative analysis was performed, with work that showed the highest idle state in the table formwork with T/C, and work in the same class in TLS. In the table formwork with T/C, the idle state of tying preparation (node 6) was the highest at 89.01%, and in the equivalent node with TLS, the idle state of fixing preparation (node 10) was 0.0%. According to the result of the analyses, it is considered that the tying preparation with T/C caused the idle state, because of the T/C being occupied, until the installation of the table form was done. In contrast, the tying preparation with TLS was able to have a shorter idle state for lifting the next table form, since the TLS was not occupied during the installation time, and the table forms were lifted independently.

Table 4 - Idle state analysis of the two items of lifting equipment

Equipment	Node	Name	Idle state (%)	Average waiting time (min)
Tower crane	6	Strap available	89.01	9.6
TLS	10	Fixing available	0.14	0.0

Sensitivity analysis

Sensitivity analyses of the two different formworks were conducted, to analyze the total installation time and lease fees, according to the change of equipment. The leasing fees for the trolley and TLS were calculated through interviews with construction-equipment experts. The leasing fee for T/C was also estimated, by applying the lifting load factor for the table form, based on the leasing fee at a construction site where table formwork with a T/C was performed. The leasing fee for one T/C was 11,400,000 won for one month. However, the leasing fee for the T/C was estimated as 4,332,000 won, because the lifting load factor was calculated as 38%. The leasing fees for the equipment are described in Table 5.

Table 5 – Lease fee of equipment

Equipment	Lease fee per month (won)	Period (month)	Total lease fee (won)
Trolley for installation (E_{ti})	450,000	18	8,100,000
Trolley for stripping (E_{ts})	450,000	18	8,100,000
T/C (E_{tc})	4,332,000	18	77,976,000
TLS (E_{tls})	7,000,000	18	126,000,000

Based on the leasing fees for the equipment in Table 5, sensitivity analyses were conducted, by changing the number of trolleys for installation (1-4), trolleys for stripping (1-3), T/C (1-2), and TLS (1-2). The construction duration for a single floor was also classified into 3-day cycles and 4-day cycles. According to analysis of the tall building construction report and progress schedule, the total installation time of a table form in a 4-day cycle was variable, but within one day (6-10 hours). The installation time in the 3-day cycle was also variable, but within a half-day (4-6 hours). The results of the analysis are described in Table 6.

Table 6 – Comparative result of the sensitivity analysis

Cycle	Time (hour)	Table formwork								
		Table formwork with T/C				Table formwork with TLS				
		[T/C (N_{ts}, N_{tc})]		[TLS (N_{ti}, N_{ts}, N_{tls})]						
N_{ts}	N_{tc}	Total installation time (hour)	Total Cost (won)	N_{ti}	N_{ts}	N_{tls}	Total installation time (hour)	Total Cost (won)		
4-day cycle	8~10	1	1	9.37	86,076,000	1	1	1	10.01	142,200,000
		2	1	8.53	94,176,000	2	1	1	9.93	150,300,000
		3	1	8.51	102,276,000	3	1	1	9.94	158,400,000
	6~8					1	2	1	7.56	150,300,000
						1	3	1	7.57	158,400,000
						1	3	2	7.54	284,400,000
3-day cycle	4~6	2	2	5.13	172,152,000	2	2	1	5.00	158,400,000
		3	2	5.06	180,252,000	3	2	1	4.99	166,500,000
	4~8	2	2	5.08	188,352,000	2	3	1	4.23	166,500,000
						2	3	2	4.24	292,500,000

N_{ts} = number of inputted trolleys for stripping; N_{ti} = number of inputted trolleys for installation; N_{tc} = number of inputted T/Cs; N_{tls} = number of inputted TLSs.

The productivity of the table formwork with T/C was greatly influenced when the number of T/Cs and trolleys for stripping was equally increased (i.e. T/C (1, 1) versus T/C (2, 2)). On the other hand, the productivity of the table formwork with TLS was substantially influenced by the number of trolleys for installation and stripping (i.e. TLS (1, 1, 1) versus TLS (2, 2, 1)). The number of trolleys for stripping had a great effect on the productivity (i.e. TLS (1, 1, 1) versus TLS (1, 2, 1)).

Considering the economic feasibility, the table formwork with T/C, in the case of the 4-day cycle process, was more economical than the table formwork with TLS (i.e. T/C (1, 1) versus TLS (1, 1, 1)). Additionally, the table formwork with TLS, when the 3-day cycle was conducted, was more economical than the table formwork with T/C (i.e. T/C (2, 2) versus TLS (2, 2, 1)).

CONCLUSIONS

This study suggested quantitative data for cost-efficient equipment input planning, by using Web-CYCLONE. Also, to draw the objective productivity, data from a case site was used. The simulation values determined the selection of lifting equipment according to the progress schedule. The results of this research will be utilized as a basis for cost-efficient equipment input planning.

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