Inhibiting Factors and Improvement Plan of Table formwork Method in High-Rise Building Construction

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Abstract –

The table formwork method for high-rise building formwork can shorten the construction time and reduce manpower through machine- and equipment-based automation. However, this method is not used as much as other system formworks. Various studies have been conducted to activate the table formwork method; but, the problems in associated with the automation work of table formwork are not understood, because researchers are focusing on improving efficiency through new technology development. As a basic study of the activation of the table formwork method, this study proposes an improvement plan after analysing the problems and satisfaction level according to the detailed process of the table formwork method. The results of this study are expected to expedite the process improvement and activation of the table formwork method.

Keywords –

Table formwork; Automation; IPA; Delphi; High-rise building

1 Introduction

Recently, the application of system forms, used to compensate for the disadvantages of traditional manpower-dependent forms, is increasing in high-rise building formwork. The table formwork method in particular is a large system form method with an integrated joist and sleeper on the bottom plate. It is recognized as an advantageous method for reducing labor and construction costs through machine- and equipment-based automation (automation machine and equipment). In spite of these advantages, however, the table form method is not applied as often as other system forms in the construction of high-rise buildings, except for in some Asian regions.

In the past, researchers have focused on activating the table formwork method. For example, studies have aimed to evaluate the productivity of the table formwork method[1], supplement the element technologies[2], and automate the layout and operation plans for table forms[3, 4]. Even though these studies increased the completeness of the table formwork method, improving work efficiency, they failed to understand the problems arising from the actual table form construction process, and could not propose improvement directions. Thus, as a basic study supporting the activation of the table formwork method, this study proposes an improvement plan. This plan is proposed after analysing the problems and satisfaction levels associated with the detailed processes of the table formwork method. Thus, as a basic study supporting the activation of the table formwork method, this study analyses the problems and satisfaction related to the detailed process of the table formwork method and suggests an improvement plan accordingly.

The scope of this research is the RC frame slab table form, a major application part of the table form. This study is limited to analysing the importance and present satisfaction level of each major process during table form construction in high-rise building. To analyse importance and satisfaction levels, a survey was conducted to practitioners who had experience using the table formwork method and expert consulting was carried out with eight experts who had at least ten years of experience. Furthermore, the importance-performance analysis (IPA) method was applied to evaluate the importance and satisfaction levels for the evaluation items by task obtained through the survey. After using an IPA to derive the problem factors for each task and items requiring improvement, we found an improvement plan by conducting a Delphi process with a group of experts, who performed the table formwork method many times. This study aims to contribute to the activation of the table form method, by identifying inhibiting factors and proposing improvement plan. In the future, the results of this study will be used to investigate the development of element technologies and process improvements for the table formwork method.

2 Literature review

2.1 Current table formwork

A table form is a large system form for pouring concrete floor slabs. A table form is composed of a form board, joist, sleeper, and support, and can move

horizontally and vertically through a crane. Table forms are used in high-rise building construction mainly because the associated installation, disassembly, lifting, and reinstallation work is performed by machines. This shortens construction time and reduces labor costs.

The table formwork method is generally carried out through installation, disassembly, transportation, and lifting processes. First, during the installation process, the floor form is completed by supporting the bottom shore after the table form is placed in its designated position. Next, during the disassembly and transportation process, a separate transport device such as a trolley is placed at the bottom of the table form, where it can be removed and then dropped by a certain height before being transported. Finally, in the lifting process, the table form is pushed to a lifting deck such as a super-deck and is then lifted to the upper floor by a tower crane. The detailed process of the table formwork method is shown in Fig. 1. Typically, a table form unit for 2−3 floors is manufactured and used repeatedly[5].

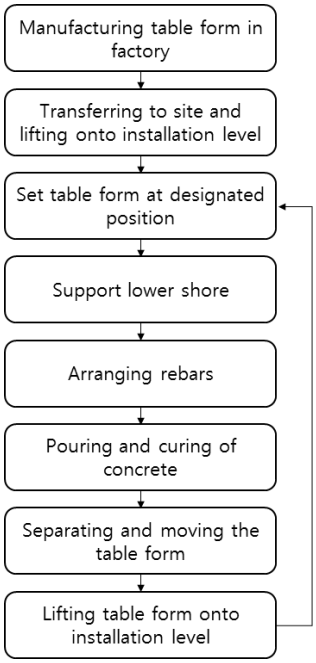


Figure 1. Table form installation procedure

2.2 IPA analysis for improvement of table form work method improvement

IPA is a method that simultaneously compares the relative importance and performance of each property, in order to measure the importance and performance of users for products or services. It is primarily used in the business administration field, but has been widely used in the machinery, construction, and transportation fields in recent years. To use IPA, a questionnaire is distributed to users, who are surveyed on a five-point or seven-point scale. Then, the average value of each attribute is calculated and marked on a four-quadrant grid, with the vertical axis representing importance and the horizontal axis representing performance[6]. The IPA method is used in many studies because it is useful for finding factors for inputting limited resources, and identifying key improvement factors and over-investment factors.

In this study, importance and user satisfaction (performance) are analysed for the detailed processes of the table formwork method; improvement and activation plan are then proposed. Among the many research methods for analysing user satisfaction, an IPA method was applied, to derive the factors that inhibit the activation of the table formwork method because of low satisfaction relative to importance.

3 Method

3.1 Questionnaire development

To identify inhibiting factors associated with the activation of the table formwork method, a questionnaire survey was conducted involving various construction companies, including constructors, specialty contractors, construction management(CM) companies, and design companies(Table 1). The respondents were limited to those who had experience with the table formwork method, to obtain practical opinions based on experience. A total of 40 questionnaire sheets were distributed through e-mail and field visits, and 36 sheets were recovered. A total of 33 questionnaire sheets were used in the analysis (three questionnaires were excluded because of omissions). The questionnaire examined the importance and satisfaction for each evaluation item using a five-point likert-type scale.

Table 1. Experience with table formwork method by company

Types of construction companies	Experience with table formwork method			
	1 time	2 times	3 times	more than 4 time
Constructors	8	5	1	-
Specialty contractors	1	2	2	5
CM	3	2	-	-
Design companies	4	-	-	-

3.2 Derivation of evaluation items

Prior to the creation of the questionnaire survey, several experts were interviewed to derive the evaluation items included in the questionnaire(Table 2): the field manager of a high-rise construction project applying the table form, a person who had worked with many table forms, two table form developers, and two formwork experts. The evaluation items were composed of the structural and operational features of the table form
In order to identify problems that may occur during the selection process and construction process of the table form construction. The detailed evaluation items are listed below in Table 3.

Table 2. The experts who participated in the interview for the evaluation item

Classification	Persons	Experience
Field manager applying the table form	1	More than 10 years
Person who had worked with many table forms	1	More than 20 years
Table form developers	2	More than 5 years
Formwork experts	2	more than 10 years

3.3 Data analysis

3.3.1 Derivation of evaluation items

A reliability test was conducted for the collected questionnaire sheets by applying Cronbach's alpha coefficient, which is the most frequently used reliability coefficient, using the commercial software application SPSS Statistics 22.

When analysed by the internal consistency method, a Cronbach's alpha value of 0.7 or greater indicates reliability. The Cronbach's alpha value of the questionnaires collected in this study was analysed as 0.974 for importance and 0.956 for satisfaction. Therefore, the questionnaire data collected in this study was found to be reliable.

3.3.2 Evaluation using Importance Performance Analysis (IPA) method

The importance and satisfaction of each evaluation item were determined through the survey and evaluated using the IPA method. Importance in this study determines whether each evaluation item is an important factor for the given work. The higher the number on the Likert 5-point scale, the higher is the importance. Satisfaction determines whether each evaluation item is satisfactory at the time of the work. Likewise, the higher the number on the Likert 5-point scale, the higher is the satisfaction level.

Table 3 Detailed evaluation items by task of table formwork method

Task	Features	Division	Evaluation Items	Task	Features	Division	Evaluation Items	Task	Features	Division	Evaluation Items
Selection of the table form work method	Structural features	A1	Weight	Table form horizontal transportation	Structural features	B1	Weight	Table form disassembly	Structural features	D1	Weight
		A2	Size			B2	Size			D2	Size
		A3	Shape			B3	Shape			D3	Shape
		A4	Unit price		Operational features	B4	Safety		Operational features	D4	Safety
	Operational features	A5	Exclusivity			B5	Work experience			D5	Work experience
		A6	Assembly			B6	Manpower			D6	Manpower
		A7	Procurement			B7	Transportation equipment	Table form lifting	Structural features	E1	Weight
		A8	Compatibility	Table form installation	Structural features	C1	Weight			E2	Size
		A9	Concrete quality			C2	Size			E3	Shape
		A10	Safety			C3	Shape		Operational features	E4	Safety
		A11	Constructability		Operational features	C4	Safety			E5	Work experience
		A12	Work experience			C5	Work experience			E6	Manpower
		A13	Manpower			C6	Manpower			E7	Lifting equipment

The X and Y axes of the two-dimensional graph were assigned to satisfaction and importance, respectively by applying the IPA technique. The scores of the evaluation items determined through the survey were plotted on the graph. Each item is analysed according to the quadrant in the graph, and the quadrants are classified as maintenance area, priority improvement area, progressive improvement area, and over-investment area. The maintenance area is an area where both importance and satisfaction are high and where items required to constantly maintain the current level are located. The priority improvement area is an area where the importance is high but the satisfaction is low and where items that require urgent improvement and have the greatest improvement effect are located. The progressive improvement area is the area where both importance and satisfaction are low and where items that have low need for improvement are located. The over-investment area is where the importance is low and the satisfaction is high and where the invested resources need to be redistributed because the satisfaction is unnecessarily high. This study focused on analysing the items in the priority improvement area and proposed improvement methods for them.

4 Results and Discussion

4.1 Analysis of IPA results

The results of the survey on the importance and satisfaction of each evaluation item are outlined in Table 4, and the results of applying the IPA method to analyse them are shown in Fig. 2.

Table 4. Average value of importance and satisfaction by evaluation item

Division	Importance	Satisfaction	Division	Importance	Satisfaction
A1	3.879	2.939	C1	4.091	3.242
A2	3.970	3.303	C2	4.121	3.152
A3	4.031	3.152	C3	3.909	3.394
A4	4.000	3.091	C4	4.182	3.303
A5	3.909	3.455	C5	3.879	3.061
A6	4.394	3.364	C6	4.000	3.030
A7	3.909	3.333	D1	4.000	3.091
A8	3.848	3.061	D2	4.152	3.182
A9	3.848	3.212	D3	3.970	3.273
A10	4.121	3.333	D4	4.182	3.303
A11	4.091	3.242	D5	3.970	2.879
A12	4.030	2.970	D6	3.970	3.000
A13	3.818	3.273	E1	4.091	2.939
B1	4.000	3.152	E2	4.030	3.030
B2	4.061	3.212	E3	4.121	3.000
B3	3.848	3.333	E4	4.242	3.061
B4	4.030	3.152	E5	3.970	3.000
B5	3.879	3.030	E6	3.939	3.061
B6	3.727	3.030	E7	3.970	2.879
B7	3.818	3.091			

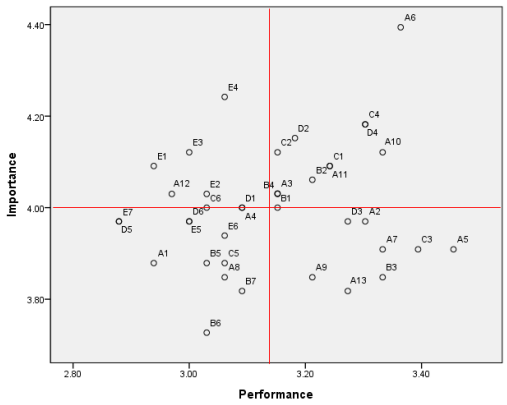


Figure 2. Results of applying IPA method

Following the analysis, items A4, A12, C6, D1, D6, E1, E2, E3, and E4 were included in the priority improvement area where urgent improvement is required. Even though these items are important factors in each work process, they are considered factors that inhibit the activation of the work method by lowering the preference for the table formwork method and hindering the reuse of the method owing to their low satisfaction. Furthermore, as a result of analysing the satisfaction of each work compared to importance, the satisfaction of the lifting work was lowest among the selection, transportation, installation, disassembly, and lifting works. When the importance and satisfaction of the 39 evaluation items were analysed and the top five items were derived, it was found that 80% of the top five items were pertained to the lifting task(Table 5). Therefore, this study determined that it is urgent to improve the items included in the table form lifting task among the various items in the priority improvement area, and to provide an accurate analysis of this items and improvement plans preferentially.

Table 5. Top 5 of importance/satisfaction values

Division	Task	Evaluation items	Importance/ Satisfaction
E1	Table form lifting	Weight	1.392

E4	Table form lifting	Safety	1.386
D5	Table form disassembly	Work experience	1.379
E7	Table form lifting	Lifting equipment	1.379
E3	Table form lifting	Shape	1.374

4.2 Analysis of problems through the Delphi method and proposal of improvement plan

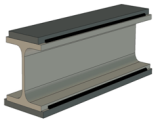
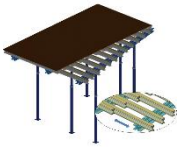
Among the items included in the priority improvement area through IPA, those corresponding to the lifting task were the weight, size, shape, and safety of table form. In addition, among the five items with the lowest satisfaction compared to importance, there is an equipment item for lifting work. This item is important for the lifting work of the table formwork method but actually shows low satisfaction. This study, therefore, performed qualitative evaluation of five items through Delphi method which is conducted as a panel survey composed of experts. Then, an improvement plan was proposed after analysing the effects of these item on the activation of the table formwork method.

As a result of the survey through two Delphi rounds with 11 table form experts, including workers who have experience with table formwork more than five times, table form developers, and table form researchers, all the factors showed correlations, In particular, the limitation of lifting equipment seems to be a critical factor that inhibits the activation of the table formwork method. This is because the table form lifting is done by a tower crane in current high-rise building construction projects, which reduces the operation time of the tower crane and consequently delays the construction time. Moreover, owing to the nature of construction of high-rise buildings, the influence of wind is much greater on higher floors. Thus, it takes more time to lift a table form that is heavy and large, and the probability of accidents increases. In addition, with the shape of the existing table form, it is difficult to flexibly cope with the increasing number of atypical high-rise buildings, and this causes additional work owing to the planar changes that occur as the number of floors increases, thus delaying the construction time and increasing the construction cost. Therefore, the existing table form method requires the development of separate lifting equipment, weight reduction of the table form, and a flexible change of shape.

In this study, one more Delphi round was performed to solve the aforementioned problems and suggest improvement methods, and the following improvement methods have been suggested. First, in future high-rise building constructions, a separate automatic lifting equipment such as automatic lifting system[7] combined with lift system and table lifting system[8] should be installed to increase the operation time and improve the safety of tower cranes. Furthermore, the weight of the table form should be reduced to decrease the burden of lifting and the effect of winds. This problem can be solved by replacing the existing materials such as aluminum, steel, and lumber with plastics and composites. Plastics and composites are frequently used recently for lightweight forms because they are lightweight and have high rigidity, making them suitable for table forms as we ll. Finally, flexibility should be added to table forms so that they can respond to the changing planes by the number of floors. This technology is being researched currently, and a product called flexible table form[7] has been developed. However, this technology has a limitation because the table form must be fixed in advance in accordance with the plane shape before the table form can be used. Therefore, additional technical development is required to enable the immediate change in the shape of table forms.

The improvement plan proposed in this study are outlined in Table 6. The overall efficiency and safety of the table formwork method can be improved by applying these techniques. Furthermore, automation technology can be added to the existing lifting decks so as to reduce the weight burden for the table form transportation equipment and minimize the effects of winds.

Table 6. Improvement plan for activation of table formwork method

Division	Improvement plan		Effect
Table form	Composite		- reduce the weight - improve the safety
	Flexible Table Form		- can respond to the changing planes - can be possible to resize
Lifting equipment	Table lifting system		- increase the operation time of tower cranes - minimize the effects of wind - reduce construction period - improve the safety
	Automatic lifting system		

5 Conclusion

The inhibiting factors for the activation of the table formwork method were identified through the IPA method. Furthermore, the effects of these inhibiting factors on the table formwork method were analysed through the Delphi method and improvement methods were proposed.

The analysis results showed that the weight, shape, size, safety, and lifting equipment of the table formwork method were the representative factors that inhibit the activation of the table formwork method. These factors cause workloads in the tower crane and increase the probability of accidents. In addition, with the conventional shape of the table form, it is difficult to respond to the atypical shape of high-rise buildings. This causes additional work, thus delaying the construction time and increasing the construction cost. To solve the analysed inhibition factor, separate automatic lifting equipment such as an automatic lifting system and a table lifting system is required for high-rise buildings, and the weight of the table form should be reduced by using lightweight materials such as plastics and composites. Furthermore, the existing flexible table formwork method needs to be improved to develop table forms that can flexibly change their shape.

In this study, the problems and satisfaction levels of the detailed processes of the table formwork method were analysed and future improvement and activation methods were proposed. Among the many improvement items found through the IPA method, however, the items corresponding to lifting task were analysed first. Thus, additional research is required for other items than those of the lifting task among the improvement items derived in this study. In the future, the results of this study could be used to develop element technologies of the table formwork method and improve user satisfaction. It is expected that this will enable the process improvement and activation of the table formwork method.

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