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Site Quality Evaluation Prototype for Building Deck-plate Construction

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Abstract

Deck-plates are widely used on construction sites, and have the advantage of enabling contractors to achieve a relatively uniform quality. But nevertheless, quality deviation in deck-plate construction can occur as the result of differences in site conditions and the experience of crew workers. In this study, the authors present a site quality evaluation prototype for building deck-plate construction. Through analyses of case studies and interviews with experts, standard quality check sheets and a quality management index were developed by estimating the importance of quality check items based on a Failure Mode and Effects Analysis (FMEA) method. The applicability and effectiveness of the prototype was evaluated through a case study and interviews with case participants. It was found that the prototype promoted an active quality management as a way of continuously improving quality management in deck-plate construction instead of passive quality inspection practice.

Keywords : deck-plate, standard quality check sheet, quality management index, quality evaluation prototype

1. Introduction

1.1 Research objective

Slab work is one of the main building processes between structural work of beams and columns and finishing work. Because of performing same activity repeatedly, the quality of the slab work generally has a great impact on a succeeding work and constructability as well as the entire construction duration and cost. Recently, deck–slab have been widely used in reinforced concrete and steel–frame structures due to their advantages, such as being easy to handle and conducive to reducing construction duration[1]. In deck–slab construction, the use of factory–manufactured deck–plates provides a relatively uniform quality, but construction quality of the deck–slab can still be affected by the worker' s skill and the site condition. A further problem is the lack of a distinct division of tasks between participants. As well, the quality criteria have been fragmented due to their dispersion in different construction documents, which increases the difficulty in managing the site quality of the deck–slab. In addition, the conventional quality inspection using a checklist has limitations in terms of reflecting the quality performance in the construction process[2].

In this study, to perform quality management of deck–plate construction in a more effective and efficient manner, the authors present a site quality evaluation prototype based on a standard quality check sheet and quality management index. With this prototype, construction quality managers can continuously perform quantitative quality control by comparing the quality of distinct work stages within one construction site or the quality of whole deck–plate construction among different sites.

1.2 Research scope and method

The deck–plate subject to quality management in this

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study is a structural part supported by steel beams, and is applied only to large-sized commercial and office facilities in medium or high-rise buildings classified by Article 3 Clause 4 of the Enforcement ordinance of the Building Law (Types of Building Structure by Usage). The scope of deck-plate construction is the process from carrying-in of the deck-plate to a construction site to placing and curing of the concrete on the floor. The quality management period begins after the design documents are reviewed and a specialty contractor is selected, and continues to the completion of the deck-plate construction.

First, we performed a literature review to investigate deck-plate construction quality management, and the importance evaluation methods for quality management items. Second, the current status of deck-plate quality management is analyzed through case studies and interviews with deck-plate experts to derive problems and identify improvement directions. Third, quality check items for each work stage of the deck-plate construction process are derived through interviews with experts, and the importance of each item is evaluated using the FMEA method. Fourth, a standard quality check sheet and a quality management index are proposed to be generally applied to construction sites using deck-plates, and a site quality management operation process is additionally presented based on the site quality evaluation prototype, which consists of the sheet and the index. Fifth, the applicability of the prototype is validated through a case study and interviews with practitioners.

2. Literature review

2.1 Deck-plate construction

The deck-plate slab is defined as a floor system combining in-situ concrete and a metal plate called a 'deck-plate' as a mold or slab tension member. The deck-plate slab consists of deck-plate, supplementary hardwares (concrete stoppers, reinforcing angles, etc.), deformed steel bars, and concrete. The deck-plates can be categorized by function, section, and processed shape into form and composite decks, corrugated and flat decks, and rebar integrated and steel wire integrated decks.

Figure 1 summarizes the deck-plate construction process based on the particular specification, construction plan, and quality management plan of the specialty contractors in producing or installing the deck-plates. Deck-plate construction is carried out in the following sequence: pre-work phase, deck-plate work, rebar work, and concrete work, each of which is divided into 2 through 6 detailed steps.

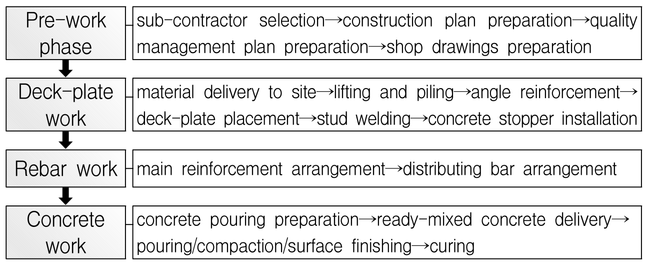


Figure 1. Deck-plate construction process

2.2 Construction quality check items

Quality management has conventionally been considered as checking whether a work was done appropriately, putting an emphasis on the appropriateness of the method[3,4]; however, it can be also defined as a method of attaining and maintaining high-quality output that satisfies customer demands[5]. Unlike cost management and process management, which are actively and voluntarily performed by a contractor, quality management in Korean construction projects is carried out to meet the minimum level specified in related laws and regulations. Therefore, the Ministry of Land, Transport and Maritime Affairs (MLTMA) promulgated "Construction Quality Management Guidelines" (MLTMA Notification No. 2010-1043) based on the Construction Technology Management Law, and specified the establishment of quality management plan and quality test criteria.

To turn the basic quality management based on regulations and guidelines into practical quality management, all of the diverse quality factors depending on site condition and construction resource should be included in the managed object list. But construction project managers inevitably focus on the factors with high priority to secure construction quality and minimize quality deterioration and its influence, due to realistic restrictions[6]. Failure Mode and Effects Analysis (FMEA), which has been presented as an analysis method to assess importance, elicits critical management factors based on the Risk Priority Number (RPN) calculated by multiplying the occurrence, severity and detection of a potential risk factor[7].

With FMEA, a general risk analysis method, potential risks can be reviewed quantitatively and qualitatively within a relatively short period of time[8], and the opinions of site managers can be reflected. Many efforts have been made to accurately derive key risk factors and the critical management items using FMEA in each sector of the construction management. The management sectors include safety management[8,9,10], process management[11,12,13], and cost management[7,14,15]. The usage of FMEA has also been expanded to the business level of a construction company[12] and the design phase of a project[16]. In the previous studies, however, FMEA was used to prioritize risk factors and management items based on calculated RPN values, and thus failed to provide a practical utilization of FMEA into the later stage of the construction process and following construction projects. In this study, FMEA was used to calculate the importance of quality check items of the deck–plate construction. Occurrence, severity and detection were replaced with defect frequency, quality criticality, and quality impact to correspond to the context of construction quality management.

3. Current quality management of deck–plate construction

3.1 Outline of the current status analysis

Case projects were analyzed and interviews with deck–plate experts were conducted to investigate the current status of quality management and derive improvements in the deck–plate construction. Two projects were scrutinized based on construction plan, quality management plan, detailed shop drawings, and the specifications of the projects. To complement the generality of the detailed case studies, interviews were carried out with experts on the current problems of deck–plate construction and improvement directions of the quality management. Target buildings analyzed in the case study were composite and commercial facilities, and the deck–plate was applied to all of their ground and underground floors (refer to Table 1).

Table 1. Overview of case projects

Item	Project A	Project B
Construction period	2005.3.1～2007.11.30	2008.2.20～2011.12.20
Gross floor area	305,934㎡	59,484.35㎡
Floors	40, basement (7)	5, basement (3)
Type of building	office facility	commercial facility

7 executive–level interviewees with more than 10 years of experience as sub–contractor, general contractor, and supervisor were selected (refer to Table 2). The interviews were conducted through personal visits to interviewees' offices for about one month, from October 27 through November 30, 2009.

Table 2. Composition of Interviewees

Group	Position	Number
Sub–contractor	• executive • deck designer • construction • supervisor	1 1 1
General contractor	• project manager • construction manager	1 1
Construction supervisor (construction manager)	• chief supervisor • supervisor staff	1 1

3.2 Problems by construction phase

To analyze causes and results of quality management problems by specific phase, deck–plate construction was divided in four phases: pre-work, deck–plate work, rebar work and concrete work. Construction of the deck–plates complying with the Korea Standard (KS) is performed by a manufacturer after getting a sub–contract from a general constructor. The intention of designers and site conditions are not fully reflected in construction shop drawings and construction plan made by the manufacturer. A hastily-made construction plan and a lack of ability and time on the part of reviewers often compromise the completeness of the construction plan. When the deck-plate and supplementary hardware are brought into the site, inappropriate materials can be used if they are not inspected thoroughly. If the materials are not installed promptly and left in an open field, they are subjected to be exposed to moisture, or damaged in the handling process, causing early rust. The studs are installed to secure the incorporation of the deck-plate with steel beams. If studs are installed at an arbitrary interval or negligently handled in the welded parts, the strength of the deck-plate structure can be decreased.

In rebar work, if the distributing bars are combined inappropriately, the rebars will lose their proper arrangement in the middle of concrete placement, and shrinkage cracks may even occur on the perimeter of slab concrete after the placement. Since the completeness of the previous work can have a direct impact on quality and constructability of the following works, applicable shop drawings are imperatively required. In practice, however, crew workers in deck-plate contractors have frequently omitted the construction shop drawings, and arbitrarily executed each work based on their previous experience. Ill-managed concrete work incurs diverse problems, including sink cracks from excessive slump, cold joints of successive pouring, strength deterioration and early cracks of wet curing.

Through the current status investigation, it was found that deck-plate quality management had a great impact on the entire construction in terms of cost and duration. In particular, quality defects have even resulted in construction delays, safety accidents and rework. The experts interviewed noted that there are few clauses or guidelines related with a quality management plan in a specification. In terms of sub-contractor's work, sufficient precautions have not been provided for defect prevention. Next, defects in deck-slab cannot be detected with naked eyes, because the rebar and concrete of the deck-slab is covered with the deck-plate panel and finishing materials. It was found that the quality management items should be derived and managed by their importance level. Also, a method to quantitatively measure construction quality should be developed.

3.3 Improvement direction of quality management

Through the case study and interviews, the current status and problems of deck-plate construction were analyzed, and improvement directions of the quality management were derived. The main quality issues derived through the interviews can be classified into 5 categories: (1) share of quality management items among participants, (2) analysis of quality defect types, (3) clear definition of critical quality management items, (4) development of a evaluation method to measure work quality conveniently in, and (5) reflection of the process and procurement package of deck-plate construction. Based on these issues, the improvement directions of quality management were summarized into the following three.

First, there are no concrete standard specification for deck-plate construction, and as the quality-related documents are informal and differ depending on a participant, and they are rarely applied at a site practice. Therefore, quality items that are omitted or repeated in existing quality-related documents can be complemented by developing a quality check sheet that can be utilized at sites as a standard. By using the quality check sheet, the construction participants can carry out standard checking activities based on prioritized quality check items. Second, by applying a differential weight depending on the evaluation score of the quality check item, the management efficiency can be improved. Through the quality management according to importance of the item, cost increase and time loss resulting from defects can be prevented. Third, for the quantitative evaluation of construction quality, a method of calculating a quality management index needs to be developed. Existing quality evaluation is conducted by checking O/X in the inspection process, and it is impossible to express quality quantitatively. A quantitative index of construction quality enables quality managers to compare the quality of a work to others in terms of element and space (floor), work crew, or construction phase.

4. Quality factors and quality check items

4.1 Analysis of quality factors

Factors influencing the quality of deck–plate construction were classified by product component and participant, and defined as 'quality factors'. After the analysis of quality factors and their impacts, quality check items were derived.

An analysis on the components of the deck-slab system, including panel, supplementary hardware, and truss-girder are executed, quality factors and impacts as results are indicated in Table 3. The deck–plate becomes a finished product by combining semi-finished products, deck–plate panel and truss girder, using welding. Quality factors of the deck–plate include the welding quality of deck–plate panel and truss girder and the welding quality of end vertical rebars. When the quality factors are not managed appropriately, it ultimately has an adverse impact on structural integrity and end bearing capacity of the deck–plate.

Table 3. Quality factors of deck components

Material Composition	Quality factors	Quality impacts
Galvanized steel	• coating weight • mechanical properties • dimensions • shape, weight, appearance	• corrosion resistance • form stiffness • thickness, width, length • flatness, density, beauty
Deck-plate panel	• forming quality of surface • forming quality of welding rib • quality of interlocking parts • accuracy of cutting	• exposed surface, concrete adhesion • corrosion resistance of welded joints • water-tightness of joints • safety of spanning length
Smooth/ deformed wire	• mechanical properties • nominal linear diameter • nominal cross sectional areas • weight per unit length • depth of surface dumps	• tensile force • tensile force • tensile force • density of structural steel • concrete adhesion strength
Truss girder	• tolerance of placement • lifting-up height	• construction load & structural resistance • deflection of floor slab
Deck-plate	• welding of panel and truss girder • welding of end vertical bars	• structural integrity of deck-plate • end bearing capacity of deck-plate

As the construction quality of the deck-slab can vary depending on participant skill, in order to achieve a consistent level of quality, the quality factors related to each participant should be analyzed. Based on the content of quality-related documents and the party responsible for the document, the quality management tasks and quality factors related to each participant were derived. As shown in Table 4, there are about 10 documents stipulating deck–plate construction quality, including structural drawings.

Table 4. Content of quality related documents

Type	Contents	Ⓟ	Ⓡ	Ⓐ
Structural drawings for construction	• floor plan, • structure detailed floor plan, structural section details • schedules of slabs	①	⑤	⑤
Construction specifications	• description of construction plan • description of shop drawings • check list of pre/under construction • site work-conditions, continuity with adjacent activities • criteria of materials, work preparations	①	⑤	⑤
Structural design reports of deck-plate	• structural analysis of deck-slab • deck type: combination types of top, bottom, distributing, lattice bars • design criteria and design load for deck types • design conditions: deck-plate span, concrete strength, thickness of concrete cover and etc. • work load, slab design load, review of deck-plate deflection/stress, natural vibration frequency, embedment/splice length of bars	②	③	④
Deck-plate design manuals	• summary of deck-plate product • KS measurement per material, allowable clear span • structural design for deck-plate • standards for deck-plate construction, shop drawing standards	②	-	-
Construction shop drawings	• structural detailed floor plans • section details per deck-plate type, member lists • tables for embedment/splice length of bars, details of bar placing	②	③	④
Construction plans	• organization, human resources and equipment plan • construction process plans • checklists for inspection	②	③	④
Supply request form	• business license and factory registration certificate • material test reports, mill sheets	③	④	④
Special specifications	• general descriptions, order/manufacture/processing/inspection • storage, transportation, delivery to site • safety plans, construction standards	②	-	-
Other documents	• supervision execution guide • standard specification for building construction • Korea Standard (KS)	⑥	-	-

Ⓟ: preparation, Ⓡ: review, Ⓐ: approval
①: designer, ②: sub-contractor, ③: contractor, ④: construction supervisor, ⑤: owner, ⑥: etc.

Quality management-related participants are divided into sub–contractors in charge of initial construction quality, general contractors in charge of managing the quality of the work, and supervisors who supervise to determine whether the work is done according to the design documents and overall regulations. The sub–contractors are responsible for making most of the documents, and the documents are reviewed by a general contractor and approved by supervisor and the owner. Table 5 shows quality management tasks and quality factors related to each participant.

Table 5. Quality factors of stakeholders

Stakeholders	Quality factors
Sub-contractor • project manager • foreman • worker	• construction experience, headquarters' support • quality management organization structure • responsibility and leadership of project manager • craftsmanship and awareness level of work crew • possession and proper operation of construction equipment • preparation and understanding of construction shop drawings
General contractor • project manager • quality manager • construction manager	• understanding of design documents (drawings and specifications) • organization of quality management • ability to manage sub-contractors, construction experience • preparation quality management plans • review of construction plans and shop drawings • feedback on quality defects
Construction supervisor • chief supervisor • supervisor staff	• review of construction plans, drawings, shop drawings • review of quality management plans • understanding related regulations and field application • quality inspection ability • corrective order for quality defects and confirmation

4.2 Derivation of quality check items

Based on the quality factors of deck components and participants, we revisited the deck-plate experts listed in Table 2, and derived detailed quality check items and types of defects for each step of deck-plate construction process. According to the construction procedure stipulated in a specification, the deck-plate construction was composed of 3 phases: deck-plate work (D), rebar work (R), and concrete work (C). More specifically, the 3 phases are divided into 10 steps in total: 5 steps in the Deck-plate work including deck-plate delivery (D1), 2 steps in the Rebar work including placement of main rebars, and 3 steps in the construction work including concrete curing (C3). Concrete check subjects and methods were presented as detailed quality check items. The types of quality defects are materialized instances from ill-managed effect of the quality factors enable the quality managers to prepare appropriate measures for preventive quality management. Similar or redundant items were combined, while different contents were excluded after reviewing coincidence with the reasons for selecting the quality check items. As shown in Table 6, 41 detailed quality check items were derived from the 10 steps of the construction process.

5. A prototype for site quality evaluation

5.1 Importance evaluation of quality check items

The critical check items were selected based on their importance, and contributed to improvement of management efficiency at construction sites. Through a survey, the importance of quality check items was determined. Respondents to the survey were 10 site practitioners with more than 10 years of work experience related with deck-plate construction, and the survey was conducted from April 30 through May 25, 2010. Risk

Table 6. Quality check items for building deck-plate construction

Construction steps		Quality check items	Detailed quality check items	Type of defects
Deck-plate work (D)	D1 deck-plate delivery	• delivery time • delivery inspection	① delivery in rainy weather ② inspection omission/error	• steel corrosion of plate/wire • use of inadequate material
	D2 lifting & piling	• lifting work • piling place	③ non-application of sleepers ④ deck piling error ⑤ poor protection for piling	• steel plate deformation • field processing/minor transport increase • steel corrosion of plate/wire
	D3 deck-plate placement	• spanning length of both end portions • surface adherency • cutting/boring • vertical post fixing • fixing deck-plate	⑥ shortage of spanning length ⑦ excess of spanning length ⑧ adhesion defects ⑨ oxygen welding use ⑩ omission of vertical welding post ⑪ point welding defects	• separation during placement • field processing (cutting) increase • cement paste escape • durability decrease of processing part • deck-plate separation during pouring • poor deck adherency
		⋮	⋮	
Concrete work (C)	C3 concrete curing	• wet curing • warm/heat curing	㊵ poor curing and omission ㊶ poor heat keeping/heat supply in cold weather	• aquation rate/strength decrease • initial frost damage

Table 7. Standard quality check sheet

Construction steps		Quality check items	Detailed quality check items	Importance of quality check items: Defects frequency [1]	Quality criticality [2]	Quality impact [3]	RPN [4]=[1]×[2]×[3]	Rank	Quality check levels
Deck-plate Work (D)	D1 deck-plate delivery	• delivery time	① delivery in rainy weather	2.5	2.2	2.1	11.6	39	III
		• delivery inspection	② inspection omission/error	2.4	3.1	3.1	23.1	22	II
	D2 lifting & piling	• lifting work	③ non-application of sleepers	1.9	2.5	2.4	11.4	40	III
		• piling place	④ error in stacking decks	2.0	2.7	2.6	14.0	36	III
			⑤ poor protection for stacking	2.8	2.8	2.9	22.7	23	II
	D3 deck-plate placement	• spanning length of both end portions	⑥ shortage of spanning length	2.7	4.1	4.0	44.3	3	I
			⑦ excess of spanning length	1.9	2.3	2.2	9.6	41	III
		• surface adherency	⑧ adhesion defects	3.1	2.7	2.9	24.3	19	II
		• cutting/boring	⑨ oxygen welding use	2.6	2.7	2.8	19.7	27	III
		• vertical post fixing	⑩ omission of vertical welding post	2.2	3.2	3.2	22.5	24	II
		• fixing deck-plate	⑪ point welding defects	2.3	3.0	2.7	18.6	30	III
			⋮				⋮		

Priority Number (RPN) ([4] of Table 7) was calculated by multiplying defect frequency ([1]) by quality criticality ([2]) and quality impact ([3]) for each detailed quality check item1), which were obtained based on a 5-point scale.

A sustainable quality evaluation method for the deck-plate construction was proposed. Composed of the standard quality check sheet, quality checking score (QCS) and quality management index (QMI), the proposed quality evaluation prototype can support quality evaluation and control by check item and construction phase.

5.2 Standard quality check sheet

Based on the result of importance analysis on each quality check item, the standard quality check sheet was presented for the deck-plate construction to help conduct site evaluation. The standard quality check sheet shown in Table 7 can be utilized in various ways in the process of deck-plate construction. Before construction, the standard quality check sheet can make workers and quality managers aware of the critical check items by presenting potential defect factors and preventive measures for each item. In the middle of construction, it can help quality stakeholders to manage quality efficiently by applying a differentiated priority depending on the importance of each quality check item. After construction, the sustainability of site quality evaluation can be improved by recording the quality management indexes reusing them as fundamental data for the evaluation and management of a new construction project.

To efficiently utilize the standard quality check sheet, it is important to select the critical check items among 41 detailed quality check items. 9 top items were classified as Level I, which showed a relatively greater change of ratio on the curve of the RPN accumulative graph, meaning they were prioritized management items (Figure 2).

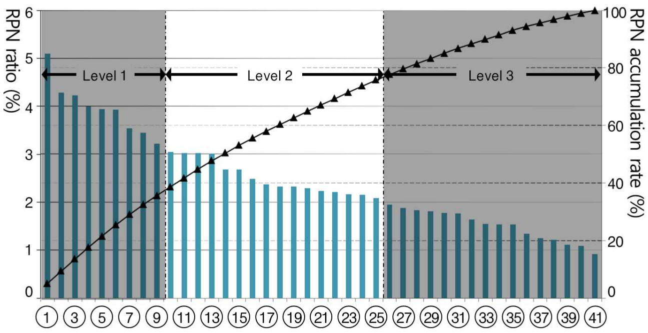


Figure 2. Level classification of quality check items

1) Defect frequency means the probability of a defect occurrence, and quality criticality is the difficulty of treatment and its cost when the defect occurs. Quality impact explains the degree of a defect influence on succeeding activities or quality of the final product.

Items other than the critical check items can be applied flexibly depending on diverse site conditions. 16 items with the RPN ratio of 2% or lower were classified as Level III, and the others were classified as Level II. The classification of detailed quality check item is applied to the standard quality check sheet as quality check levels to provide efficiency and convenience in the site quality evaluation. The quality management activity may differ according to the classified level. Table 8 shows examples of quality management activities that can be differently composed depending on the importance level.

Table 8. Quality management activities according to levels

Level	Quality education	Quality meeting	Attendance	Check	Measurement
I	○	○	●	●	●
II	×	×	×	○	●
III	×	×	×	×	●

●: essential ○: select by need ×: skip

5.3 Quality management index

The current status of site quality management of the deck-plate construction was evaluated with Quality Checking Score (QCS) and Quality Management Index (QMI). QCS was derived based on a 5-point scale to evaluate the appropriateness of the construction carried out by the worker in terms of each detailed quality check item. QMI represents percentage value of a quality management status according to the phase of construction progress, and enables the quality stakeholders to continuously evaluate the quality of the deck-plate construction. As shown in Equation (1), QMI is calculated by comparing a Weighted Quality Score (WQS: RPN × QCS) to the maximum WQS of ideally managed quality status in terms of the quality check item. Based on the QMI, the construction quality of check items within a project can be compared. In addition, a relative increase and decrease in degree of quality can be expressed against the previous and/or the next projects.

t^{th} quality management index during deck-plate construction process is calculated as in Equation (1).

$$QMI_t = \frac{\sum_{i=1}^{n}(RPN_i \times QCS_i)}{\sum_{i=1}^{n}(RPN_i \times 5)} \times 100 \qquad (1)$$

QMI_t : tth quality management index QCS_i : quality checking score item i
t : time-point of evaluation i : quality check item

5.4 Quality management operation process

Based on the developed quality evaluation prototype, a quality management operation process was presented as shown in Figure 3 to help quality practitioners to analyze the current status of quality management and to keep sustainable quality improvement. The basic framework of the operation process observed the successive 4 step process of the PDCA Deming cycle. In addition, the framework presented core work tasks and precautions in each phase of the deck-plate construction including feedback of improvements.

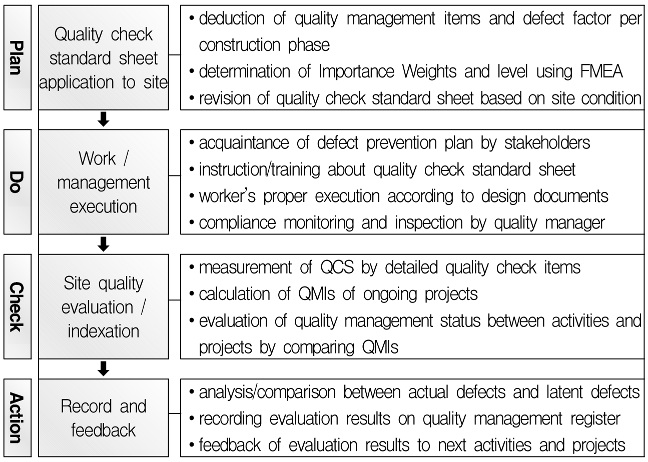


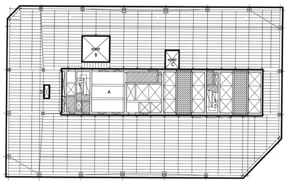
Figure 3. Quality management process of deck-plate construction

6. Case study and verification

6.1 Case study

The site quality evaluation prototype was applied to a case project of the deck-plate construction to verify its applicability. The case project was a 32-story office building, and deck-plates were used on each floor. In the typical floor construction process, the deck-plate construction was performed after the reinforced concrete core was constructed and surrounding steel beams were installed. Three consecutive floors (17th~19th), among the typical floors were analyzed based on the prototype, and the floor plan was as shown in Table 9.

Table 9. Overview of case project

• Site area	33,058㎡	
• Gross floor area	509,525㎡	
• Building area	15,272㎡	
• Building coverage ratio	46.2%	
• Floor area ratio	922.8%	
• Structure	SRC/steel	

The evaluation was conducted after the completion of deck-plate construction and rebar work but before the start of concrete work, at which point a quality supervisor performed an inspection. According to the quality management operation process presented, the standard quality check sheet was filled out, sub-contractor's work and management was conducted, the quality checking score was measured, the quality management index was calculated and recorded, and feedback was given. The quality check was conducted according to the order of construction from 17th floor to 18th floor and then to the 19th floor. Figure 4 and Table 10 provide a summary of the evaluation results. RPN ([1] of Table 10) was multiplied by QCS ([2], [4], [6]) to calculate WQS ([3], [5], [7]), and then finally QMI for each floor was derived using Equation (1).

At the case site, a QMI-based quality comparison for construction process could be performed, and it was found that sustainable quality management could be achieved. The QMI was calculated as 59.9 for the 17th floor, 55.4 for the 18th floor, and 70.2 for the 19th floor. Based on the increase and decrease in QMI from 17th floor to 18th floors derived in a quantitative manner, a quality evaluation basis could be established for the 19th floor. Second, WQS for each detailed quality check item could be evaluated and compared, on which basis the problems could be analyzed more accurately and could be effectively complemented. For example, '⑥ shortage of span length' at 'deck-plate placement' was an item that greatly decreased in the WQS (25%) in the 18th floor work, and it's WQS was recovered in the 19th floor work due to intensive management.

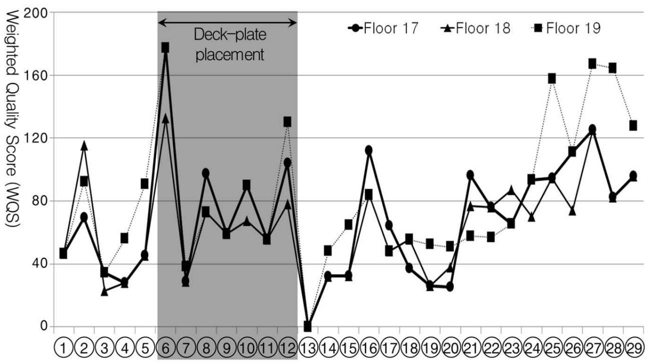


Figure 4. Comparison of weighted quality scores

Table 10. Analysis of case study

Construction steps		Quality check items	Detailed quality check items	RPN	Floor 17(1st)		Floor 18 (2nd)		Floor 19 (3rd)	
					QCS	WQS	QCS	WQS	QCS	WQS
				[1]	[2]	[3]=[1]×[2]	[4]	[5]=[1]×[4]	[6]	[7]=[1]×[6]
Deck-plate work (D)	D1 deck-plate delivery	• delivery time	① delivery in rainy weather	11.6	4	46.4	4	46.4	4	46.4
		• delivery inspection	② inspection omission/error	23.1	3	69.3	5	115.5	4	92.4
	D2 lifting & piling	• lifting work	③ non-application of sleepers	11.4	3	34.2	2	22.8	3	34.2
		• piling place	④ error in stacking decks	14.0	2	28.0	2	28.0	4	56.0
			⑤ poor protection for stacking	22.7	2	45.4	2	45.4	4	90.8
	D3 deck-plate placement	• spanning length of both end portions	⑥ shortage of spanning length	44.3	4	177.2	3	132.9	4	177.2
			⑦ excess of spanning length	9.6	3	28.8	3	28.8	4	38.4
		• surface adherency	⑧ adhesion defects	24.3	4	97.2	3	72.9	3	72.9
			⋮				⋮			
Rebar work (R)	R1 main bar	• dowel bar	㉘ shortage of embedment depth	41.1	2	82.2	2	82.2	4	164.4
	R2 distributing bar	• distributing bar assembly	㉙ inadequate assembly spacing	31.9	3	95.7	3	95.7	4	127.6
Quality management index (QMI)					59.9		55.4 (▼4.5)		70.2 (▲10.3)	

6.2 Face-to-face interview

To get opinions on the verification and adjustments to the site quality evaluation prototype, interviews with participants of the case projects were conducted. 7 interviewees were composed of one quality supervisor, and 6 from a general contractor and sub-contractors in charge of deck-plate work, rebar work, and concrete work. Interviews responded to the effectiveness of the standard quality check sheet, adjustment for optimization to the site, and frequency and scope of the quality evaluation.

The effectiveness of the standard quality check sheet was examined in 7 specific categories: quality check items, quality defect factors, quality impact, importance evaluation, preventive measures, quality managing stakeholders, and construction quality evaluation. In addition, it was evaluated to be an effective tool for workers or managers with less years of work experience, since precautions were provided in advance of construction. Advance deliberation or agreement should be made regarding the roles of participants in the site correction of the standard quality check sheet. It was found to be effective for the sub-contractor to make a suggestion, the general contractor to review it, and the supervisor to determine its practicability. For an efficient quality evaluation, the frequency of evaluation could be determined based on the management capacity. When a building is 50 stories in height or less, it is appropriate to conduct evaluation at every 5th floor. If the building is 50 stories or higher, it is appropriate to conduct evaluation at every 10th floor. In addition, the scope within which the prototype could be utilized most was found to be the comparison between buildings in a construction site. Since in large construction sites, multiple work crews are operated in each work zone, and if the quality management of each crew or building is evaluated, visible and comparable management effort will make results of good-will competition.

7. Conclusion

A quality evaluation prototype was presented in consideration of practicability using a sustainable quality evolution tool in the process of construction, as well as for preventive quality management. Through the two case studies and the interviews with experts, the challenges of deck-plate construction were analyzed, and the direction for quality improvement was presented.

To develop the quality evaluation prototype, interviews were conducted with 7 experts with more than 10 years of work experience on construction sites to determine quality check items for each construction phase. Using the FMEA, the importance of each item was evaluated. Second, based on the quality check items derived, the standard quality check sheet was developed. Third, WQS was calculated taking QCS and RPN into account, on which basis the QMI was derived. To verify the applicability and effectiveness of the proposed prototype, follow-up interviews with experts were held after the site application. It was found that the prototype was more effective for workers or managers who had less years of experience in the field. In addition, the prototype is expected to induce a shift from the current passive quality management based on inspection, to active quality management for the prevention of defects.

For general application and enhancement of quality check items and detailed quality check items of deck-plate construction, the prototype needs to be applied to more construction sites. Further studies should be conducted to secure the objectivity of the importance evaluation of each quality check item and to provide a more systematic plan that will increase its applicability to practical construction.

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