Lee et al. Int J Concr Struct Mater (2019) 13:2
https://doi.org/10.1186/s40069-018-0309-9

International Journal of Concrete Structures and Materials

RESEARCH Open Access

# Assessment of Delay Factors for Structural Frameworks in Free-form Tall Buildings Using the FMEA

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**Abstract**

There are many factors in a common building project that are not relevant for free-form tall building projects, for example, the free-form planes or various shapes of buildings. Among the many risks present in particular in structural frameworks, the risk of delays is an important one and has a considerable effect on the entire project performance. Generally, a delay causes a decrease in constructability and an increase in cost, so eventually the productibility of the structural framework would decrease. Delay management of structural frameworks in free-form tall buildings is currently performed by project managers based on personal experience and intuition. This nonsystematic management results from the lack of data that are essential for the planning construction process reflected in the particular considerations of the free-form tall building. This study identified the delay factors that can occur in the structural framework of free-form tall building projects and analyzed priorities for delay management. First, the scope of free-form tall buildings was identified, and particular considerations for the structural framework in their construction were determined, such as plane, elevation, floor height, and structure. Delay factors for each category were recognized through interviews with experts with experience in such projects. To prioritize the delay factors, the occurrence and severity of each factor were surveyed. A risk priority number was calculated from the survey results, and the priority was analyzed. The results of this study could serve as preliminary data for the planning construction process of structural frameworks in free-form tall buildings.

**Keywords:** delay factor, free-form, tall building, structural framework, FMEA

## 1 Introduction

Free-form tall building projects are more significant than general projects due to their complicated structure with various forms. Thus, high-speed construction is required for achieving the construction of such buildings in an appropriate period. Any delay which frequently occurs in structural frameworks can adversely affect subsequent processes, thus lowering the efficiency of construction and increasing construction cost (Callahan et al. 1992; Lee and Kim 2010, 2011). Therefore, management of delay factors must be considered in advance in free-form tall building structural frameworks (Elinwa and Joshua 2001; Larsen et al. 2016).

However, the management of delays in free-form tall building construction has not been systematically or quantitatively dealt with because of the lack of experience in such projects and the lack of primary data necessary for establishing a plan (Hong et al. 2004; Lee and Kim 2011). These problems exist because management of delays depends on the experience of managers of tall building projects and the intuition of project participants without taking into account characteristics of free-form tall buildings such as planar free formalities, planar changes, and structural stability. Therefore, in this study, delay factors were derived considering characteristics of the free-form tall building. Results of this study suggest that factors that can be managed quantitatively in the

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Journal information: ISSN 1976-0485 / eISSN 2234-1315

planning and execution stages of structural frameworks should be prioritized.

In this study, factors of delay were derived from characteristics of free-form tall buildings. First, relevant factors were selected based on characteristics of structural frameworks of free-form tall buildings. Delay factors were then derived from these factors. Second, to evaluate the importance of derived factors, we conducted a questionnaire survey of experts who had experience in free-form tall building projects on the frequency and degree of influence of delay factors. Third, the frequency and effect of each factor were analyzed based on results of the questionnaire. Finally, a risk priority number (RPN) was calculated by using the frequency and the degree of influence. Delay factor was considered to be a priority factor in the construction of free-form tall building frameworks based on RPN value.

## 2 Review of the Literature

### 2.1 Studies on Delays in Construction Projects

Extensive research studies have been conducted on causes of delays in construction, process risk, and other influential factors. Delay factors in tall building projects have also been studied (Kang et al. 2001). Specifically, delays occurring in the process stage of tall building projects such as finishing work and curtain wall construction have been analyzed (Kang et al. 2005; Cho et al. 2012). In addition, delays caused by structural frameworks that occupy a significant portion of tall building projects have been evaluated by means of surveys of relevant parties within the construction industry (Kim et al. 2008).

However, few studies have analyzed delay factors considering the characteristics of free-form tall building construction projects. In this study, the delay factors that occur in the construction of a free-form tall building frame were derived from relevant factors that can be considered in a free-form tall building. The frequency and the degree of influence were analyzed by means of the Failure Mode and Effect Analysis (FMEA).

### 2.2 Risk Analysis Methodology

Although there are many risk analysis methods, FMEA is generally used in the risk factor analysis of delays. FMEA has been widely applied to construction projects in recent years. It has been used for risk management of tall building projects that contain repetitive characteristics of the same work (Hong et al. 2004; Kim and Kim 2007; Lee and Kim 2011). If possible delay factors are managed according to priorities determined by FMEA, the project is expected to achieve a high process rate.

When failures occur because of latent risk factors, FMEA can classify them into occurrence, severity of failure, or detection. FMEA predicts and eliminates potential risk factors (Joo et al. 2008). After evaluating occurrence, severity of failures, or detection, the risk priority is evaluated by calculating the RPN.

RPN is a value obtained by multiplying the occurrence frequency, influence degree, and detection degree. In turn, RPN determines the priority for improvement. In general, the evaluation score of the items is given in the range 1–10, and corrective action is required when the frequency, the degree of influence, and the degree of detection are scored at $\geq 8$. If the influence is high regardless of the RPN value, need the correction action. The criteria for the score vary depending on the degree of industrial development and the nature of the industry in question.

The purpose of this study was to evaluate the importance of delay by using FMEA. The frequency of occurrence is the degree to which a failure can be caused by a potential risk factor, and the degree of detection is defined as the degree to which a failure that has occurred can be found. However, the meaning of the possibility and the degree of detection of the factors of delay occurring in the construction of a tall building is considered to be highly redundant. In this study, we considered that the risk factor is the factor causing delay, and the degree of failure can be found to mean the frequency of delay. Therefore, two scales were integrated because it was judged that it was meaningless to separate and analyze the two scales. In case of delay, there is a need to understand the degree of impact on the construction unit process. Therefore, the incidence frequency and the degree of detection are integrated into the frequency, and the criterion is changed to influence the selection of two evaluation items (Table 1).

To evaluate the importance of the delay factor in the construction of a free-form tall building, we used the RPN value, which represents the priority of the existing FMEA. The RPN is calculated by multiplying the frequency of the evaluation item and the degree of

**Table 1 FMEA evaluation items for this research.**

| Rating scale | Content |
|---|---|
| Occurrence | Extent to which failures can be caused by latent risk factors |
| Influence | Criticality of the result in case of failure |
| RPN | Occurrence × influence |

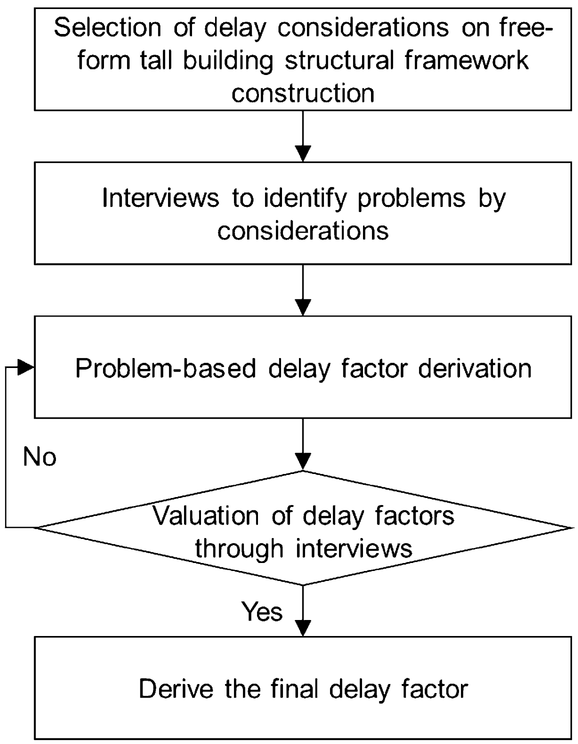


**Fig. 1** Derivation process of the delay factor.

influence. In free-form tall structural frameworks, the delay factor is more critical with higher RPN values.

## 3 Delay Factors in Free-form Tall Building Structural Framework Construction

### 3.1 Process of Deriving Considerations and Delay Factors

The process of deriving the delays of free-form tall building structural frameworks is as follows (Fig. 1). First, four items, namely plan, elevation, storyboard, and structure, are selected as the factors to consider in the construction of the free-form superstructure. We interviewed domestic experts with experience in free-form tall building projects and the delay factors were derived based on the identified problems. Finally, the delay factors of free-form tall building structural frameworks were derived through expert judgment.

The factors to consider were selected by considering the relevant characteristics in the construction of a free-form tall building compared with structural frameworks of an existing construction project and standardized tall building structural frameworks (Fig. 2).

First, considering the free form of the flat shape, the changes in floor area, elevation, floor height, structure, and construction components, we integrated the elements that are considered to be highly related to each other according to interviews with six experts. For example, a change in the floor area is associated with both

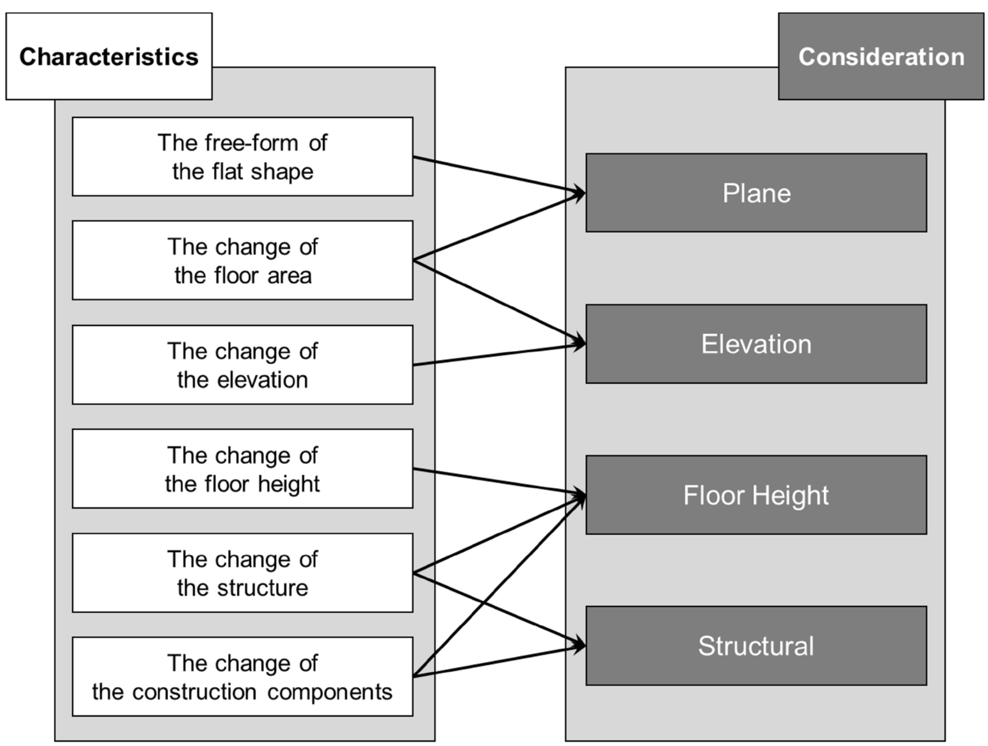


**Fig. 2** Selection process of consideration.

the plane and the elevation. This is because the size and shape of the plane can change through the change in area, and the shape of the elevation can also change.

The definition of the final consideration factor is as follows. The elements of the planar are the elements to be considered in the structural frameworks and the elements to be considered in the continuous change of the area of the planar in the shape of the free-form plane such as a circle or a polygon instead of a square in the form of a plane. The elevation elements are those that should be considered in the structural frameworks at the elevation of the building such as the 3T (twisted, tapered, tilted) shape. The floor height is a factor to consider in the framing construction because of the difference in floor height due to different uses. Finally, the structural elements considered are those structural systems such as outrigger and belt truss, mega column, and truss tube used to secure the structural stability of tall buildings.

### 3.2 Delay Causes by Consideration

To derive the factors of delay, the causes of delay were identified. First, the plane element is the most frequent cause of delays in the construction of an atypical superstructure. The plane elements were found to delay numerous activities such as the planar zoning plan, rebar work, formwork, and the auto climbing system (ACS) climbing work.

The planar zoning plan increases the number of zones, which increases the number of construction joints, resulting in a delay. The reason for this is that the structural stability of the building is first taken into consideration rather than the existing quantity of concrete. Also, rebar construction, formwork construction, concrete construction, and material piling work by zone are delayed because of planning errors of the unit process.

The formwork is delayed because of an additional mold production period, mold installation and disassembly, and fluctuation of the layout plan. The length of the rebar depends on the shape of the free-form plane. This increases the work on reinforcing steel joints and causes delays. ACS, which is installed on a free-form plane, increases the number of units compared with a regular plane; in turn, this increases climbing work on the ACS, installation, and disassembly time.

Other causes of delays include the installation of additional crash prevention networks for safety, changes in material quantity, and worker composition because of changes in the plan area, lack of skill of operators, and a lack of understanding of the design drawings by field managers.

Second, the cause of delays in the elevation elements arise from the fact that it is difficult to install and climb construction equipment due to the shape of the building being narrowed or twisted upward, and it is also difficult to construct sloped columns installed outside the building.

The tower crane (T/C) and lift car (L/C) installed outside a free-form tall building cause delays as the installation work of the additional construction material increases during the climbing work. In addition, delays occur because of wrong planning of the type and number of T/Cs and installation location.

Other causes of delay are difficulties in setting up rebar corresponding to the inclination of the columns, difficulties encountered by the laying workers, considerable difficulties involved in the mold setting work, and the lack of skill of operators.

Third, there is a difference in stratification according to the use of the floor height element in a tall building, which causes delays. If the height of the stratification is higher than that of the existing layer, an additional formwork is required when constructing a vertical member such as a column. In addition, because of the height difference, the ACS installed on the outer periphery has to be installed with additional construction material. This additional work creates a delay compared with existing plans. Moreover, the difference in the number of materials because of the difference in the height of the floors, errors in the importing section, errors in the design of the piping, and the lack of skill of operators are all causes of delay.

Finally, a delay due to structural elements can occur when constructing systems for structural stability of buildings such as outrigger, belt truss, and special structures such as mega column and truss tube. When the structure becomes large and super-high-rise, consideration is also given to the assembled state of reinforced concrete (RC) beam, the state of the reinforcement, and static load depending on the structure. Improvement of seismic resistance and collapse resistance of RC structures are also carried out. RC structures can affect the construction of skyscraper buildings (Kim and Choi 2015; Rashidian et al. 2016). Structural changes such as when changing from a RC structure to a steel structure can also cause delays.

The causes of delays in the special structures installed to secure the structural stability of the buildings vary. For special structures, a thicker rebar is used compared with existing structures, and a large amount of reinforcement is installed. Because of this, the difficulty of the reinforcement work is increased, and the working time is extended. The joining of a zone that changes from a RC structure to a steel structure can take more time than planned. In addition, it is necessary to select a suitable workgroup, a material transfer plan, and a quantity plan for the changed structure. There is also a delay in working time because of insufficient preparation schedule.

Delays are also caused by the difficulty in placing the rebars at the time of constructing diagonal members, and there are delays due to the installation work of the additional construction material to support the installed formwork. Delays are also due to a lack of skill of the workers who install the special structures and diagonal members and a lack of understanding of the field manager's drawings.

### 3.3 Delay Factor Derivation

Table 2 shows the delay factors by consideration derived. The delay factors were summarized by a process of integration and deletion through interviews with experts from Korea; they were finally selected through three processes of feedback. The delay factors were derived by integrating items that were considered to correlate highly with the causes of delays and we excluded items that were less likely to occur in practice. The initial delay factors were 39 factors, and the last 27 factors were selected through three feedbacks.

First, in the planar element (A), nine delay factors were derived from 15 delay causes. The causes of delays in reinforced concrete work and formwork due to irregularities in the plane were derived from each factor. The delay caused by the increase in the section of free-form plane zoning was integrated into the increase in the operation of the construction joint and derived as a factor. In addition, delays due to errors such as form layout planning, input quantity planning, and workgroup selection were found to be insufficient factors in the change of the plan area. In this consideration, eight delay factors were integrated and presented as three, and one factor was excluded because it was considered to be irrelevant. For example, factors related to insufficiency of the preliminary preparation work were derived by integrating the delay factors caused by the change of the order of the formwork installation and dismantling work, the delayed factors due to the change of the input quantity and the work structure. This is because these factors were judged to occur because they were insufficient in the pre-work planning stage. The delay caused by installation of an additional fall prevention network due to a difference in

**Table 2 Delay factors.**

| Consideration | Delay factor | |
|---|---|---|
| A. Plane | A-F1 | Increased rebar installation work |
| | A-F2 | Construction joint work increase |
| | A-F3 | Increased production and installation/disassembly of nonstandard formwork |
| | A-F4 | Increase in ACS installation/dismantling time |
| | A-F5 | Increase in production time of nonstandard formwork |
| | A-F6 | Increased worker transit time due to split L/C zoning |
| | A-F7 | Lack of a preparatory plan |
| | A-F8 | Lack of worker skills |
| | A-F9 | Lack of understanding by the field manager of the design drawings |
| B. Elevation | B-F1 | T/C and L/C increase, additional material installation work |
| | B-F2 | Tilt adjustment operation when the ACS climbs |
| | B-F3 | Tilted reinforcement work |
| | B-F4 | Formwork work corresponding to the slope of the elevation |
| | B-F5 | Lack of worker skills |
| | B-F6 | Lack of understanding by the field manager of the design drawings |
| C. Floor height | C-F1 | Additional formwork installation for vertical member construction |
| | C-F2 | Additional scaffold installation work when the ACS is applied |
| | C-F3 | Install additional form after ACS climbing |
| | C-F4 | Lack of a preparatory plan |
| | C-F5 | Lack of worker skills |
| D. Structural | D-F1 | Reinforcement work with high difficulty |
| | D-F2 | Selection error of construction order of special structure and slab layer |
| | D-F3 | Additional temporary material installation work |
| | D-F4 | Additional joining operations for additional structures |
| | D-F5 | Lack of a preparatory plan |
| | D-F6 | Lack of worker skills |
| | D-F7 | Lack of understanding by the field manager of the design drawings |

the shape of the floor planes was considered less frequent in the field and was excluded from the factors.

Second, in the elevation factor (B), six of the eight causes were derived as delay factors. In the elevation factor, more work was carried out depending on the type of building, and the factors causing delay were derived. According to the shape of the elevation, delays due to additional materials in the installation of T/Cs and L/Cs were found as the main factors. In addition, the installation, dismantling, and climbing work of the ACS were identified as major factors. In this consideration, two factors were judged to be irrelevant and were excluded. The excluded factors are delays caused by the improper planning of the T/Cs and delays in securing the safety of the ACS. These delay factors were excluded because they were considered to be less frequent due to delayed frame construction.

Third, unlike other considerations, the cause of each delay was derived as the factor of the delay. It was concluded that the effect of the elevation work and the ACS climbing work on the construction period during the frame construction was significant. It was also determined as a delay factor because it was considered that errors in preparation work such as the plans for material introduction and pumping had a strong influence on the occurrence of delays in the elements.

Finally, the delay factors derived from the structural factor (D) incorporated six factors from among 11 causes. All delay factors identified in the structural elements were considered to have a strong effect on the construction and the period of frame construction and were derived as delay factors. In particular, free-form plane and structure ware integrated as a factor of insufficiency of the preliminary preparation plan because delays occurred in the equipment operation plan such as the selection of workers, a working group, material introduction, and removal of the ACS bottom scaffold when constructing a diagonal member and a special structure. In this consideration, six delay factors were integrated into two. In particular, the delay factors of the Lack of a preparatory plan were integrated into the planning of additional work, the planning of materials, and the planning of equipment. In the structural consideration, the need for preliminary preparation is high and it can be judged that there is a great relation with the delay of construction of free-form framework.

# 4 Assessment of Delay Factors

## 4.1 Survey Outline and Reliability Analysis

Table 3 shows the reliability analysis of the delay factors by consideration. The survey was conducted to investigate the incidence and influence of each factor. The survey was conducted by field managers and workers who had participated in free-form tall building projects. The survey period was divided into two, from November 24, 2014 to December 8, and from April 2, 2018 to April 13, 2018. A total of 60 questionnaires were collected. Approximately 80% of all respondents had more than 10 years of construction experience, and more than 50% had experience with more than one skyscraper project. The reliability of the questionnaire was analyzed using Cronbach's α coefficient (the minimum value of the α coefficient was 0.727) (Nunnally 1967).

**Table 3 Reliability analysis of the delay factors by consideration.**

| Consideration | Rating scale | Cronbach's α | Case valid | | Number of items |
|---|---|---|---|---|---|
| | | | N | % | |
| Plane | Occurrence | 0.850 | 60 | 100 | 9 |
| | Influence | 0.736 | | | |
| Elevation | Occurrence | 0.787 | 60 | 100 | 6 |
| | Influence | 0.734 | | | |
| Floor height | Occurrence | 0.741 | 60 | 100 | 5 |
| | Influence | 0.745 | | | |
| Structural | Occurrence | 0.868 | 60 | 100 | 7 |
| | Influence | 0.727 | | | |

## 4.2 Analyzing the Importance of the Delay Factors

As a result of analyzing the importance of the delay factors of the planar elements (Fig. 3), the frequency and influence of Increased production and installation/disassembly of nonstandard formwork (A-F3) and Increase in production time of nonstandard formwork (A-F5) factors were higher than those of other factors. It can therefore be concluded that their importance was high.

Delays in structural formwork, which account for a large percentage of the critical path (CP) of the structural formwork, have a significant adverse impact on the overall structural formwork, including subsequent processing. Therefore, it is essential to identify and manage the delay factors that can occur in the formwork in advance. However, according to result of survey, it understood that the free-form plane formwork. This delay factor is due to the increased amount of nonstandard formwork, which increases the formwork installation and dismantling time, and also increases the time and cost of making nonstandard formwork. To solve this problem, it is necessary to find ways to reduce the amount of nonstandard formwork when planning the form layout. However, if the number of nonstandard forms is large, one solution might be to shorten the working time by increasing the

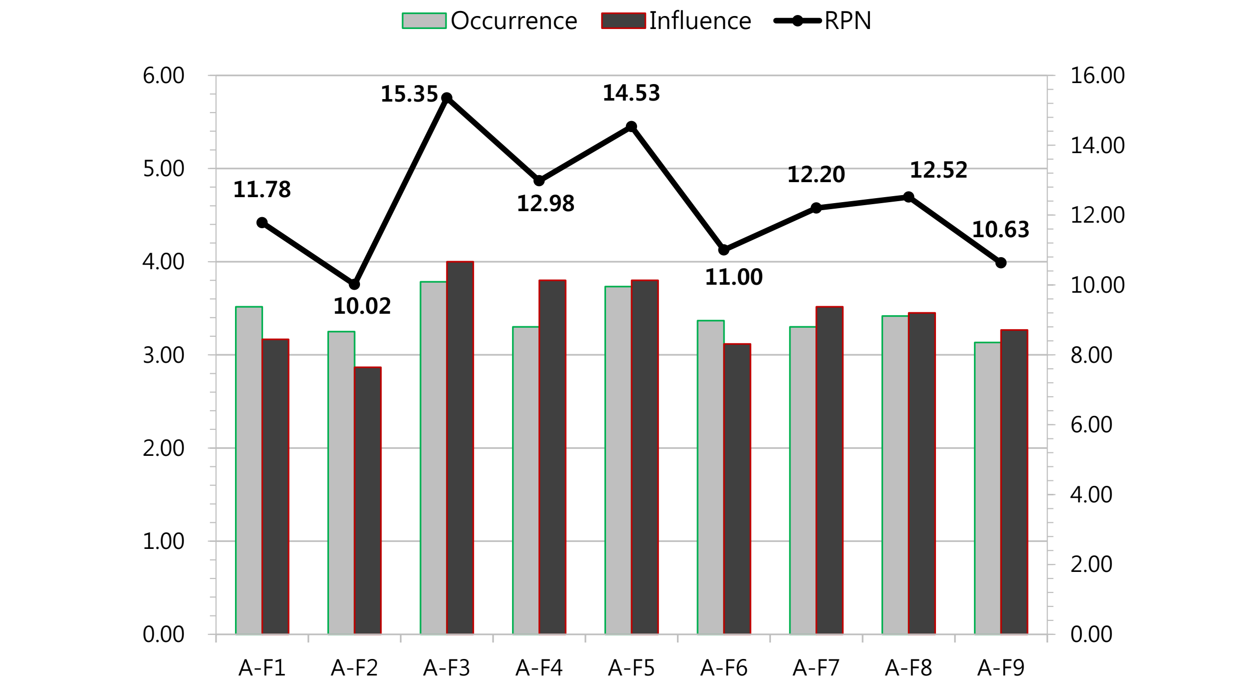


**Fig. 3** Result of delay factors of the plane element.

number of workers. In addition, it is necessary to anticipate the changing quantity of the mold and the time taken for the required amount and to consider these factors beforehand when planning the T/C.

In addition, it was clear that the maintenance of a delay due to the lack of skills of the workers was more important than the increase in the ACS installation/dismantling working time. It is therefore necessary to plan to minimize the quantity of ACS installed in the outer periphery;

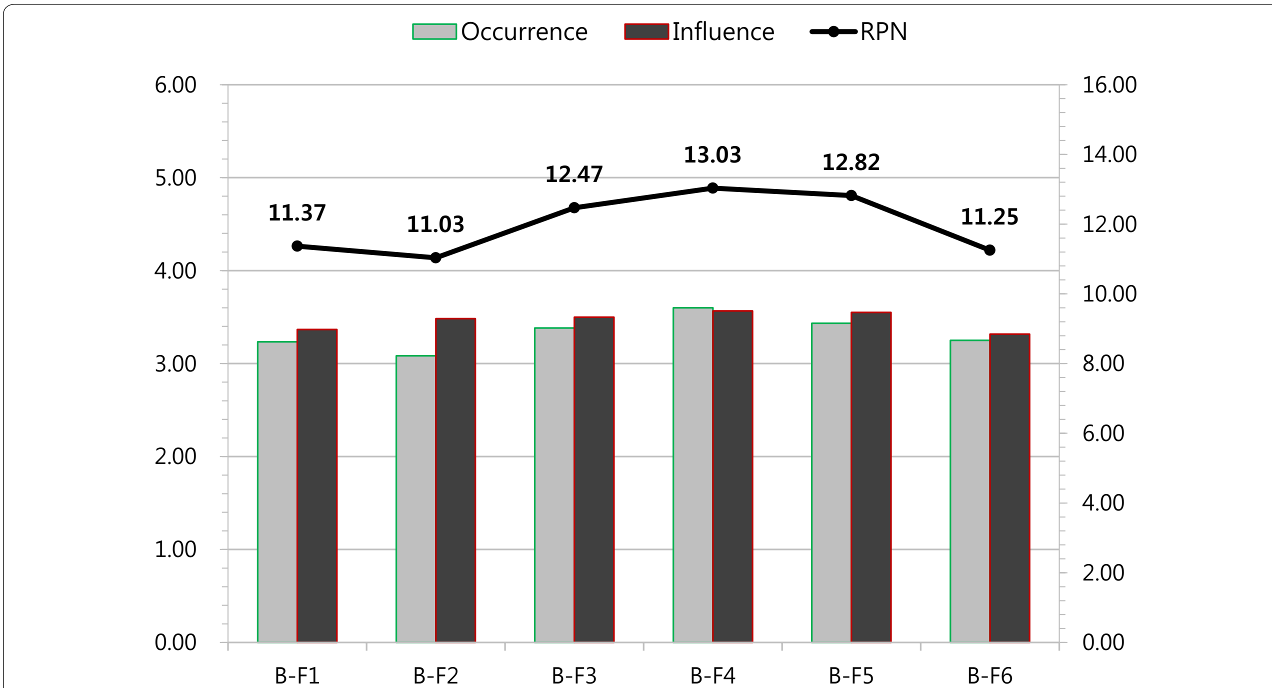


**Fig. 4** Delay factors of the elevation element.

it is also necessary to take measures such as the employment of experienced workers or preliminary training of the required skills for workers at the beginning of frame construction.

The RPN value of the delay caused by the formwork installation work (B-F4) corresponding to the slope of the elevation of the elevation factor was the highest at 13.03, followed by the lack of skill of workers in the elevation construction of the sloped building (B-F5), and difficulty of reinforcement work (B-F3) in the construction of sloped columns (Fig. 4).

For the formwork and reinforced concrete construction at the time of constructing the outer pillar of a twisted-shape building among the free-form tall building buildings, delay management was of high importance. This delay factor results from difficulties in forming and installing the formwork when a tilting or bending pillar is constructed, and it is considered essential to manage these tasks because of the difficulty in setting up and installing rebars according to the slope. Also, according to the analysis, the delay caused by the construction sequence of the slab layer that should have a high work connection and the order error of the column work is due to the lack of continuity of the work due to the construction plan which does not sufficiently consider the conditions of the site.

The importance of delay on the increase in equipment operating in the frame construction, such as the additional building material installation work (B-F1) for T/C, L/C climbing, and the slope adjustment work (B-F2), was lower than the other factors. In addition, according to the analysis, the importance of delay management due to the lack of understanding by the field manager of the design drawings (B-F6) was not high.

In the delay factor of the elevation element, the delay was more significant in the formwork and reinforced concrete construction when the column of the slanted building was constructed. A new method of formwork and reinforced concrete work corresponding to the inclined column needs to be developed. It may also be necessary to anticipate avoiding delays that can occur by employing experienced workers for these tasks.

All the delay factors of floor height were less likely to occur in the tall building elements than in the other considered elements, and the effect on the unit process was also low (Fig. 5). Because of the difference in the height of the material, the factors of delay affect the follow-up process. The preliminary planning, such as that involved in the quantity of material and the lifting of material that changes according to the difference in height, is essential to the execution of the frame construction. Therefore, a precise understanding of the factors related to the quantity of materials in general and of those factors involved in the frame construction of the stratified layer is required, and these should be reflected in the frame construction process plan.

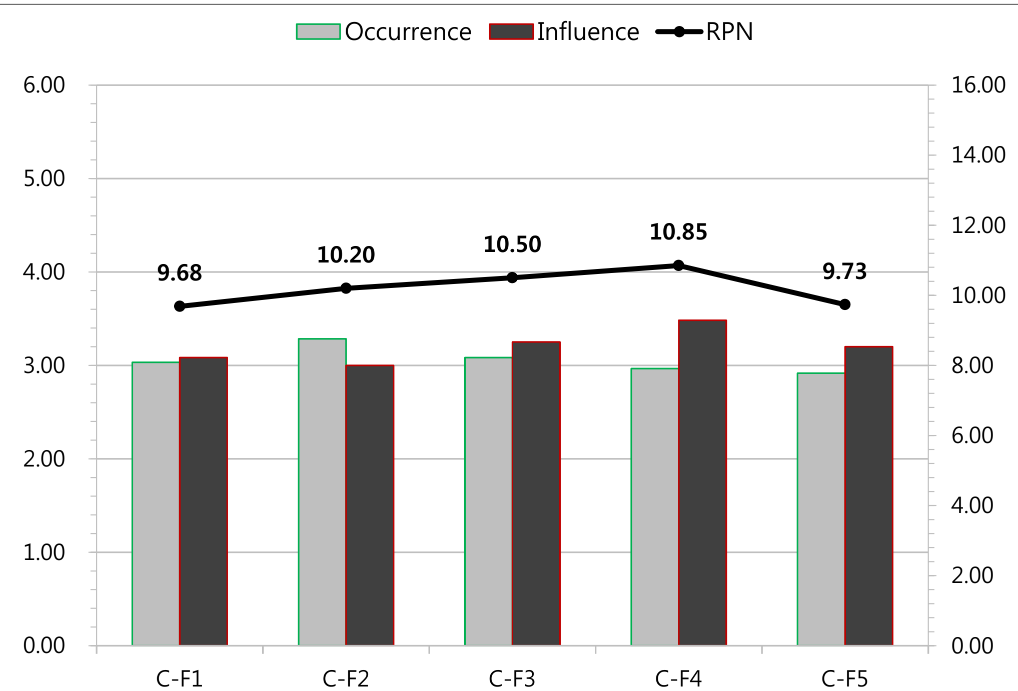


**Fig. 5** Delay factors of the floor height element.

In addition, the delay factors additional scaffold installation work when the ACS is applied (C-F2), and install additional form after ACS climbing (C-F3) that occur when the outer circumference ACS climbing have a low effect on the frequency of delay and the process of the frame construction. Additional formwork installation for vertical member construction (C-F1) was not significantly affected by the work delay.

Therefore, although it can be seen that there is a possibility of delay because of the stratification factor, it does not have a significant influence on the frame construction process. It can be understood that the delay factor caused by the difference in the height of the roof is fully considered in advance and is reflected in the process plan. Also, floor height elements are characteristic in ordinary tall buildings including atypical tall buildings, and thus it is considered that systematic management is possible by referring to existing examples and data.

For the delay factors of the structural elements, many factors with high importance were found (Fig. 6). The mega column and mega truss tube are the most critical factors in the management of delays because of the difficulty of reinforcement work (D-F1) in the construction of particular structures installed for the structural stability of buildings. In addition, the RPN values of D-F5 and D-F1 were higher than those of other structures before the construction of diagonal members and particular structures.

For D-F1, the size of rebars used in particular structures considering the structural stability of buildings was larger than that used in general structures. It was seen that delays frequently occur in the reinforcement work of these particular structures and the delay of work because of the difficulty of the work has a significant influence on the subsequent process. Also, before the construction of particular structures and diagonal members, the preparation of materials and the selection of work groups must be thoroughly carried out before the construction can be carried out according to the planned process. However, it can be concluded that delays are frequent because of the lack of construction experience and errors in the intuition-determined plan; in the case of D-F2, the construction of appropriate structures and slab layer construction are determined according to the conditions of the site. If the selection of the construction sequence is incorrect, the construction of particular structures and slabs has a significant influence on the construction progress, meaning that delays could occur in the subsequent processes.

Next, it was found that delay factors such as lack of skill (D-F6) and lack of understanding by the field manager of the design drawings (D-F7) are of high influence in the case of additional joints (D-F4) between the particular structure and the slab layer.

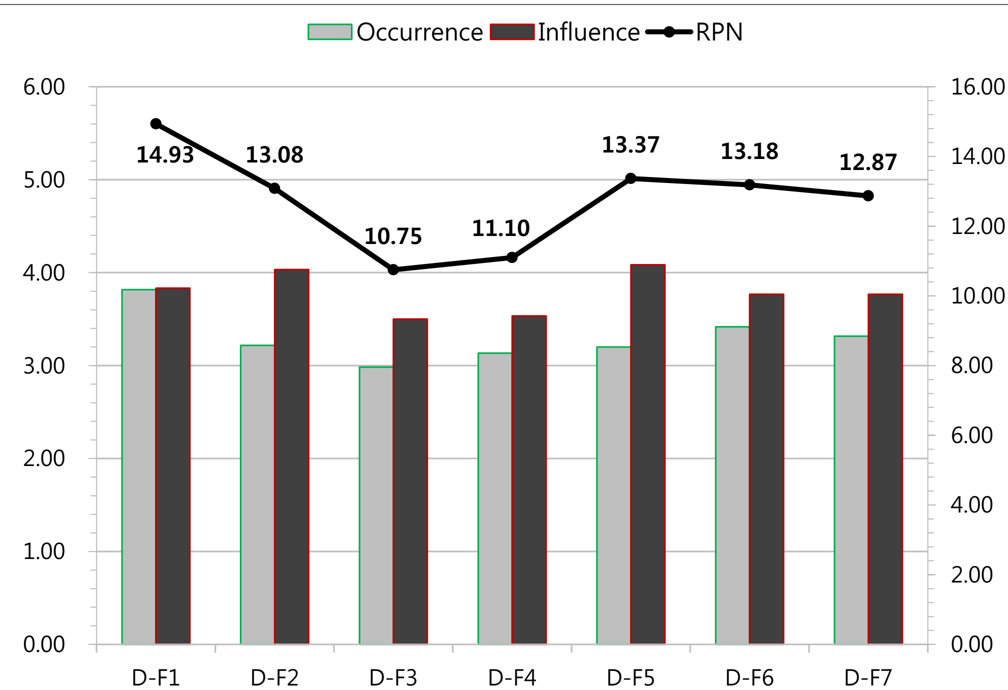


**Fig. 6** Delay factors of the structural elements.

The delay factors of structural elements were seen as highly significant for the reinforcement work in particular structures, preliminary preparation plans for particular structures, diagonal element construction, and the construction order of particular structures and slab layers. Since it is a particular structure to construct considering the stability of the building, a careful process plan is needed compared with a general structure, and thorough preparation is required in selecting the workgroup, bringing in materials, and ordering the construction processes. Moreover, it is necessary to refer to the data from similar projects in the process planning because there are cases where delays occur due to lack of experience in Korea.

## 5 Conclusion

There are limitations in the management of delays in free-form tall building construction projects because of factors such as a lack of experience and a lack of data necessary for establishing construction plans, depending on the experience and intuition in existing projects. Therefore, the delay factors from the construction planning stage need to be identified and systematically managed.

To overcome these problems, this study analyzed the occurrence frequency and the degree of influence of delay factors in framework construction of free-form tall buildings. Delay factors were derived from selected factors based on the characteristics of the free-form tall building and final factors derived through interviews with domestic experts on free-form tall buildings projects. The frequency and effects of the delay factors were analyzed, and the importance of each factor was evaluated by calculating the RPN value.

First, there is a high probability of delays in formwork and rebar construction in the free-form plane area in the planar element; according to the analysis, these factors have a significant influence on other processes. The importance of delay factors was high because the amount of additional formwork and installation work in the free-form plane increases and additional reinforcement work is generated.

Second, the delay factors in the elevation elements are trying to work in formwork and reinforced concrete construction because of sloping elevation columns, as in the case of the plane elements. Moreover, the frequency and influence of delays because of lack of skills of workers were analyzed.

Third, according to analysis, the delay caused by an insufficient preparation plan such as material procurement and material procurement among delay factors of the floor height factor has a significant effect on the subsequent processes. However, the remaining factors were less important than the delay factors of other items.

Finally, in the case of structural elements, a delay factor is highly likely to occur, and the effect on the unit process is also high. The delay factors caused by the difficulty of the reinforcement work when there are particular members and diagonal members installed were very frequent and influential. The process plan of a particular member and the diagonal member was inadequate because of the lack of experience in construction work and insufficient preparation schedule. Therefore, if the process plan was established with sufficient reference to the performance of similar projects, delay management can be efficiently performed.

The delay factors outlined in this study were derived from selected consideration factors based on the characteristics of the free-form tall building structural frameworks, and it is expected that the delays that can occur in construction works can be manages in advance. This analysis can also be used as essential data for planning the structural framework process. However, only the delay factors that occur during the construction phase in the construction of a free-form tall building frame were analyzed, and we did not examine factors such as the level of the country and local companies, the client–consultant management system, or design errors. Therefore, in future research, risk analysis such as delays in the overall process and increase in construction costs should be derived, and additional risk analysis also should research.

**Authors' Contributions**

DL carried literature study and drafted the manuscript. HL analyzed the test results and revised the manuscript. DL derived the factors for the survey and conducted a survey. HC have carried the literature study and participated in discussing the results. K-IK provided some advices on the manuscript. All authors read and approved the final manuscript.

**Acknowledgements**

This research was supported by a Grant (18AUDP-B106327-04, 18AUDP-B121595-03) from Architecture & Urban Development Research Program funded by Ministry of Land, Infrastructure and Transport of Korean Government and was supported by the National Research Foundation of Korea grant funded by the Korea government (2016R1A2B3015348).

**Competing Interests**

The authors declare that they have no competing interests.

**Availability of Data and Materials**

Please contact author for data requests.

**Funding**

This research was funded by a Grant (18AUDP-B106327-04, 18AUDP-B121595-03) from Architecture & Urban Development Research Program funded by Ministry of Land, Infrastructure and Transport of Korean Government and was funded by the National Research Foundation of Korea grant funded by the Korea government (2016R1A2B3015348).

## Publisher's Note

Received: 8 August 2018 Accepted: 3 October 2018
Published online: 03 January 2019

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