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# Management Processes for Tower Crane Selection and Support Design

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# Abstract

Appropriate tower crane selection according to lifting load and structural stability of the selected crane is important in aspect of productivity as well as the costs and duration of a project. Although technological knowledge is necessary, these processes have been decided using the experience of field engineers and at the suggestion of equipment suppliers in most of the cases. However, the errors of decisions in the processes can cause huge cost overruns and fatal human accidents when an artificial or natural disaster occurs. In this study, the objective is to propose the management process for tower crane selection and supporting detail design for stable operation. The results of this study can be used to develop a computing system for tower crane management.

**Keywords:** tower crane, stability examination, lifting plan, lateral support, rope guying, wall bracing.

# **1** Introduction

As construction projects become more focused on building large scale, super-high buildings, an initial lifting plan is becoming increasingly significant. In particular, selection of an appropriate tower crane that is suitable for the given lifting load and securing stability not only affects productivity, but also in terms of the project cost, duration and so forth. For instance, when the height of crane installation increases or the materials delivered are heavy, it may result in incalculable loss generating disastrous incidents, if there is no appropriate review on stability including the foundation of a crane and reinforcement of lateral support.

There have been several studies on crane selection processes and stability of the crane up to now. Ho et al proposed an optimal tower crane selection system (Opt-TC) that allows selection of the most suitable crane under various field conditions

and easy, quick reviews of its stability [1]. However, the system only considers the foundation support design process when reviewing stability, not taking into account on examining lateral support reinforcement and material selection. Also, Ho et al improved the existing Opt-TC to devise only a detailed stability examination process on bearing capacity and pile foundation [2].

Gray and Little suggested a systematic approach in selecting tower cranes [3]. It is a comprehensive approach that enables not only selection of a jib type crane and a wide range of base type cranes under suitable field conditions, but identification of its location. Yet, there was no method to review stability of the selected crane and to utilize information of various types of cranes.

Lee et al developed a lateral support optimized design algorithm that satisfies the lateral support stability of a tower crane with only the minimum cost. Yet, this study also limits the scope only to a wall bracing method, which is one of the lateral support methods [4]. Lee et al examined only the stability of rope guying, one of the lateral support methods [5]. As described above, a few studies have been carried out on tower crane selection and stability examination, yet they did not reflect various field conditions such as a soft ground. Currently, there are not enough studies conducted on tower crane selection and stability examination processes that both considered designing a foundation and reinforcing lateral support when it exceeds the free-standing.

Thus, this study is intended to supplement limitations of the previous studies, in order to select a tower crane and to examine stability of the selected crane at the same time, suggesting the 'management process for tower crane selection and support design'. The process suggested in the study shall be helpful in systematically selecting an optimal tower crane based on the data on performance of various tower crane types at the lifting operation planning stage. It is expected that operators may be able to establish an efficient lifting operation plan for practical use by adopting the stability examination process on the crane foundation support design and lateral support reinforcement developed.

# 2 Methodology

Generally, a lifting operation plan consists of the following stages: 1) establishment of a process plan; 2) selecting tower crane equipment and its quantity; 3) installing the tower crane equipment; and 4) operation and dismantlement. Among these stages, this study focuses on tower crane selection and the process to review stability of the selected crane. In addition, the targets of stability examination process are the foundation (bearing capacity & pile foundation) support design of the tower crane and the lateral support reinforcement (wall bracing & rope guying).

To achieve the objective of this study, first, the lifting operation plans of construction projects is identified and the trend in relation to crane selection is analyzed. Second, after analyzing limitations of the previous studies, the improved optimal tower crane selection and stability examination process are suggested. Finally, the suggested process details are described.

### **3 Previous Studies**

Currently, there have been studies on optimal crane selection and stability examination carried out adopting various methods. Furusaka and Gray used an objective function that minimizes the costs of rent, installation and dismantlement so as to select an optimal crane, which is a model that enables to combine multiple cranes [6]. However, this model is difficult to be applied to high-rise buildings that are 20 stories or higher since they are only beneficial in terms of construction duration and cost only when the same crane is constantly used. Gray and Little presented a systematic approach to selecting a mobile crane and a tower crane that are appropriate for the design in the initial design stage [3]. Especially, they suggested a comprehensive method to select a jib type and a wide range of base type cranes suitable for the field conditions, as well as its location. However, there was no method to review stability of the selected crane and to utilize information of various types of cranes.

Lee et al developed a lateral support optimized design algorithm of tower cranes [4]. The optimized design algorithm is divided into wall bracing design, bracket design, stability examination and cost review, and it is aimed to select a combination of materials that satisfies the structural stability of tower crane's lateral support with the minimum available cost. However, the study only concentrated on the wall bracing which is one of the lateral support reinforcing methods, and did not consider a Rope Guying method. Kim et al introduced a structural approach to the support methods based on the tower crane installation types [7]. The study suggested a base type when under a stationary type and a lateral support reinforcing method under a lateral anchoring type, yet there is only general information on the matter, making it difficult to be applied for practical use and it requires a concrete stability examination process.

As described above, the previous studies did not reflect various field conditions, and currently, there are not enough studies conducted on tower crane selection and stability examination processes that both considered designing a foundation plate and reinforcing lateral support. Thus, this study supplements limitations of the previous studies conducted in order to propose a process that includes both the tower crane selection and the lateral support method of the selection tower crane.

### **4** Tower Crane Selection Process Analysis

In general, there is a fixed type and a mobile type tower crane, which is subdivided into a fixed type, a climbing mobile type and a travelling type [8]. First, a fixed type is to install a tower crane by fixing an angle with a concrete block on the ground,

which is mostly used at apartment sites or low buildings. However, if sufficient bearing capacity cannot be secured after analyzing the geological features of sites, a pile foundation must be selected for the stability of a tower crane. Second, an climbing mobile type is largely applied to steel frame structure or concrete building construction sites where there is no place to install a tower crane, and it is supported to the structure of a building itself and then lifted upwards. Third, a travelling type tower crane uses a rail to move around, so a mat foundation is used for the soft ground. This study is carried out focusing on the tower crane selection process and the stability examination of foundation plate design and lateral support reinforcement.

#### 4.1 Foundation Support Design

The load imposed to the concrete foundation of a tower crane is measured to analyze the stability of tower crane foundation. A tower crane is a steel structure with an excessive slenderness ratio when compared to its cross-section. Thus, lateral load greatly influences the tower crane. Moreover, counter weight, counter jib winch, jib boom, hook assembly trolley, lifted load, head section slewing mount, mast load & slewing torque, overturning moment and horizontal/vertical force must be considered when reviewing the foundation stability. It is desirable to design a foundation based on the spread foundation, but if it is short of bearing capacity or the foundation cannot be enlarged to a certain size, it must be designed as a pile foundation.

#### 4.2 Lateral Support Design

If a tower crane is to be installed higher than the free standing specified by the manufacturer, such tower crane shall be supported and fixed depending on the field conditions using either a Wall bracing method or a Rope guying method. The wall bracing method refers to firmly supporting and fixing the mast of a tower crane to a building wall. It is largely applied to the super tall building construction sites in a downtown area, where materials like a support frame is used to fix it to the building wall, and it can be easily done since the span between the building is not so big.

However, the operating radius is small, lowering the operating efficiency so additional equipment may be required for installation. The rope guying method is applied when there is no suitable supporting structure near the tower crane installation location or when a tower crane should be installed deeply in the underground floor. When a large scale apartment complex is to be built, a single crane can cover several buildings, improving its operating efficiency. However, it is difficult to adopt the rope guying method, and since there is no concrete standard for accurate measurement and structural review of materials that it may generate stability related issues.

# 5 Management Process for Tower Crane Selection and Support Design

### 5.1 Tower Crane Selection Process

This study proposes the "Management process for tower crane selection and support design" as shown in Figure 1. After selecting the tower crane type according to the field conditions, its stability can be examined based on the designed foundation and the lateral support method. Procedure of the process is as follows:

- 1) Selecting a jib type and an installation method: selecting a Trolley type or a Luffing type depending on the jib type; selecting a fixed type, a climbing movable type, or a travelling type depending on the installation method.
- 2) Inserting operating conditions: insert the maximum jib length, maximum jib turning radius, the distance between the tower crane center and the article center, and lifted load.
- 3) Candidate cranes: draw out a candidate crane that meets the lifting operation conditions based on the tower crane database configured.
- 4) Marketable allowance: a person in charge will select a tower crane considering the load chart analysis, possibility of procurement, costs, easiness of installation /operation/ dismantlement and so forth.
- 5) Additional date input: select the size of a base tower section and a typical towers section of the selected tower crane. Since the section type that can be selected varies according to the type, a person in charge shall select a section size considering the field conditions. Also, the free standing information is a critical element in determining whether lateral support shall be adopted during stability examination. Then, an installation height of the selected tower crane shall be examined considering the field conditions. If the installation height is equivalent to or less than the free standing, no lateral support is required, but if it exceeds the free standing, lateral support shall be examined or change the candidate crane into another type with a higher free standing.
- 6) Stability examination of the selected tower crane is implemented. If the foundation plate design and the installation height exceed the free standing, a final tower crane is selected through stability examination of the lateral support reinforcement. This study proposes two different processes such as a stability examination process and a foundation/lateral support design process.



Figure 1: Management process for tower crane selection and support design.

#### 5.2 Foundation Support Design Process

If a tower crane that meets the field conditions is selected, a final tower crane shall be determined via stability examination. The specification of a foundation is decided according to the stability examination of a bearing capacity and a pile foundation. In particular, when choosing a pile foundation, the geological features of a site shall be first analyzed, and if it is short of bearing capacity or if a foundation cannot be enlarged to a certain size (maximum bearing capacity > allowable bearing capacity), the pile foundation is adopted for designing. The foundation support design process is carried out under the following procedure.

- Insert field conditions: insert a concrete strength as master data for stability examination of bearing capacity suitable for the field conditions. Also, an allowable bearing capacity is a bearing capacity of the ground loaded, so load per unit area is to be inserted.
- Foundation design: insert the size and thickness of a foundation to determine its specification.

- 3) Bearing capacity review: When data insertion is completed, bearing capacity review shall be conducted. Above all, when the maximum bearing capacity exceeds the allowable bearing capacity, the foundation will sink, causing the tower crane to overturn, so it is important to review such risk, change the pile foundation design or the foundation specification and insert the changed matters. The maximum bearing capacity is the sum of total vertical force and bearing capacity imposed to the eccentric distance.
- 4) Stability examination: Stability examination consists of overturning review, bar arrangement interval review and shear review. First, it is checked whether a tower crane overturns owing to the eccentric load. Specifically, Resisting Moment (RM) refers to bearing with the self weight of a foundation and the vertical force, and Overturning Moment (OM) refers to no overturn of a foundation owing to the moment and the horizontal force. If the RM/OM values are equivalent to or more than the safety factor or the eccentric load value is equivalent to or less than L/3, it represents stability. If not, it refers to instability. Second, an appropriate interval for bar arrangement is examined after calculating axial reinforcement. Third, during the shear review, the shearing strength at dangerous sections (one-way and two-way) shall be less than the designed shearing strength loaded to concrete.

It is desirable to design a bearing capacity foundation in terms of the project duration and cost, but if the bearing capacity on site is insufficient or the foundation cannot be enlarged to a certain size, it shall be designed as a pile foundation. The following is a process to review the pile foundation stability.

- Insert field conditions: for the pile foundation, insert the pile size (m), thickness (m) and edge distance (m) as shown in Figure 4.
- 2) Pile design: insert the pile specification including the pile diameter, strength and quantity.
- 3) Stability examination: stability examination consists of overturning review, bar arrangement interval review and shear review. First, all three reviews are conducted as shown in the bearing capacity foundation stability examination. In particular, for review on the bar arrangement interval, not only one-way/two-way shear review is performed, but also drilling of pile itself shall be examined. Second, the allowable bearing capacity of a pile foundation compared to the maximum bearing capacity shall be examined.

#### 5.3 Lateral Support Design Process

There are two types of lateral support methods such as a wall bracing and a rope guying method to secure structural stability to be adopted considering the field conditions and projects. The wall bracing method is to firmly support and fix the tower crane mast to the building wall or slab taking into account of the field conditions and the tower crane installed location.

In case of the wall bracing method, first insert information of the selected tower crane (tower crane type, section size and jib length) that is determined in the previous stage so as to consider the lateral support methods of tower cranes. Second, set the installation height and intervals. It is a stage to set the interval of bracing installation after inserting the first bracing installation height. Also, examine the designed lateral force under non-operation, which is the lateral force imposed to the interval support structure at the height of the first wall bracing installed. Third, set a bracket of the interval support structure to be installed based on the wall bracing surface design, and a positional coordinate of the support point. Fourth, select the material type to be used as the wall bracing support structure. Initially, structural shape steels including H, L-2 and L-shape steel are to be examined for selection and finalize the selection that can secure structural stability. Fifth, stability examination is executed to identify the compressive force and tension of each material, in order to ensure the bearing strength of a structure. The maximum reaction by supporting point is examined to secure stability, as well.

In case of the rope guying method, first insert information of the selected tower crane just like the wall bracing method. Second, determine the height of Rope guying to be installed and examine the lateral force imposed to the crane. When a wire rope is selected, the lateral force is determined, so the lateral forces under operation and non-operation shall be all taken into account. Third is a stage on the surface design of the Rope guying method. It is a stage to determine whether to utilize 3-line, 4-line, 6-line or 8-line wire ropes. Fourth, when the tension of each rope is decided, select wire ropes, shackles and turn buckles applied with the safety factor and ensure the safety of materials and review stability of the fixed supports, all of which are to be carried out in the stability examination process.

### 6 Conclusions

Currently, a few studies have been carried out on tower crane selection and stability examination, yet they did not reflect various field conditions such as a soft ground. In addition, there are not enough studies conducted on tower crane selection and stability examination processes that both considered designing a foundation plate and reinforcing lateral support when it exceeds the free-standing. This study proposes the management process for tower crane selection and support design, which reflects the importance of lifting operation plans as construction projects are more concentrated on large-scale, high-rise buildings as well as the stability reviews of foundation and lateral support.

The proposed management process determines the operating conditions including the crane jib type, installation method, turning radius, operating radius and lift load, which are all identified in the initial lifting operation plan. Then, candidate cranes are selected from the crane database. A person in charge shall review the specifications of those candidates to select a tower crane that is the most appropriate to the field conditions. The selected tower crane shall go through stability examinations of foundation and lateral support design and material selection based on the information on section size, free standing and installation height, which will end the management process suggested in this study. In particular, lateral support methods are divided into the wall bracing and the rope guying method, developing a detailed process respectively.

The process suggested in the study shall be helpful in systematically selecting an optimal tower crane based on the data on performance of various tower crane types at the lifting operation planning stage. It is expected that operators may be able to establish an efficient lifting operation plan for practical use by adopting the stability examination process on the crane foundation and lateral support design developed. Furthermore, if the tower crane database is built and examination of economical aspects such as rental price and procurement terms are supplemented in the future, it is likely to be developed into a more practical and efficient crane selection system in terms of structural stability on site and economical aspects.

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