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Automatic optimal design algorithm for the foundation of tower cranes

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ABSTRACT

As buildings become taller and larger, the lifting plan safety review has become more important in construction project management. However, the cost and safety aspects of the lifting plan are contradictory to each other. Therefore, an optimization algorithm needs to be devised as a solution to this problem. In many cases at construction sites, the selection and stability review of the tower cranes are assigned to the equipment suppliers or the field managers, which causes problems for the safety and cost of a project. To prove this aspect of the current situation, this study examines an automatic optimization algorithm for designing the foundation of tower cranes. This algorithm can be implemented by a computerized system and easily and promptly utilized by field managers without the need for substantial knowledge.

1. Introduction

Tower cranes are widely used for the construction of high-rise and congested urban buildings all over the world. It is very important to select an appropriate crane based on the lifting load and to guarantee its structural safety in order to keep the cost and duration of a project as well as its productivity at adequate levels. The Korea Occupational Safety & Health Agency reported in July 2007 that crane-related safety accidents represent approximately 32% of all accidents that occurred at construction sites in Korea [14]. In contrast, only 8% of the accidents at construction sites in the US between 1991 and 2002 were crane-related [7]. This means that additional efforts need to be made to reduce the number of crane-related fatalities in Korea.

The stability of a tower crane basically depends on the choice of the model, which is based on its lifting load, and the construction site conditions, more specifically the length of the jib, its self-standing height, the lateral supports, the foundations, etc. Collision prevention and the resistance levels for gust and earthquake loadings are also important factors. Various research such as those on the selection of an appropriate crane for a construction site [3,22], the stability of the lateral supports for cranes [2,5,12], and crane collision prevention [20,24] have been performed in the past. The stabilities of tower crane foundations have been examined in some studies [8,10,13], but the regulations require only a simple structural safety check. This limitation seems to exist due to the fact that the design and construction of the foundation are conducted based on the standard drawings provided, in most cases, by the equipment vendors. However, this may not be an optimal solution since it does not consider other structural safety factors that are specific to construction site conditions, thus leading to the design of a crane foundation that is neither stable nor economically feasible.

Although the stability of a tower crane is a very important factor, it should be balanced with economical feasibility. For instance, if the site-specific conditions are not considered, a loss of economic feasibility may result. Consequently, it is required to find an optimal design for tower crane foundations by considering these two factors simultaneously. Since it is not easy to manually create an optimal design for tower crane foundations, this system should be automated.

In this paper, we aim to develop an automatic algorithm to optimize the design of tower crane foundations while achieving structural stability during its installation and operation and cost efficiency of the final product. Among the many parameters involved in the design procedure of tower crane foundations, this work evaluates stability by focusing on overturn, shear, and bearing capacities. As shown in Fig. 1, this research only considers normal isolated foundations and fixed trolley-type tower cranes, the most commonly used types at construction sites in Korea. In addition, it is assumed that other supports such as lateral supports or pile foundations are not used because the construction site ground has sufficient bearing capacity to allow for the use of a shallow foundation.

The following list shows the sequence used in this study to obtain the automatic optimal design algorithm.

- Survey the literature concerning an automatic optimal design algorithm for tower crane foundations.
- Examine theories on generic tower crane foundation designs and define the optimization concept.
- Develop an optimal tower crane foundation design concept and optimization equations.
- Analyze the factors affecting the stability of a tower crane foundation and propose an optimal design process involving an automation algorithm.

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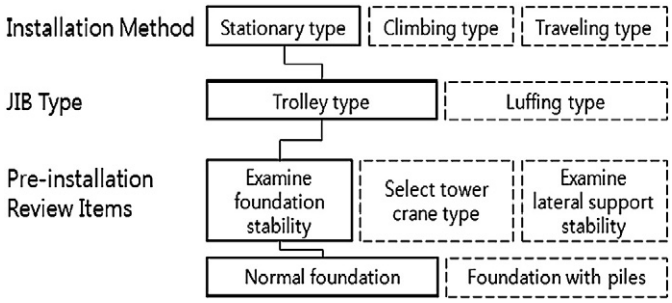

Fig. 1. Scope of the research.

– Review the stability of the tower crane foundation and automate an estimation of the minimum crane foundation construction costs in relation to such stability.

2. Theoretical considerations

2.1. Literature survey

Much research has been conducted with regard to the lifting plan of a tower crane, the selection of a model and its location on the construction site, crane operation efficiency, and crane safety analysis. Hornaday et al. [6] studied the computer-aided lift planning of mobile cranes in 1993, and Ajmal Deen Ali et al. [20] proposed an approach to generate a collision-free path during multiple heavy lifts. In 2003, Sivakumar et al. [23] presented cooperative crane lifts using a heuristic search, and Varghese et al. developed a heavy lift planning system for crane lifts [25].

To research the safety and efficiency issues of a lifting device during its operation, in 1997, Bernold et al. [16] introduced a mobile crane monitoring system using intelligent technology. Everett and Slocum [11] proposed a video communication system to improve the productivity and safety of a tower crane, and, in 1999, Leung and Tam [17] performed a study to develop a lifting time estimation model for tower cranes. These studies on the planning and operation of lifting devices aimed to improve their effectiveness and to reduce safety accidents.

Furusaka and Gray [22] developed a model for the selection of the optimum crane for each specific construction site. Rodriguez-Ramos and Francis [26] proposed a mathematical prescriptive model to establish the optimal location for a crane within a construction site. Gray and Little [3] presented a systematic approach for selecting an appropriate mobile crane consistent with design work during the early design process. Tam et al. [4] suggested a site layout algorithm model by optimizing supply locations around a tower crane, and Lin and Haas introduced a computer-aided planning process model for

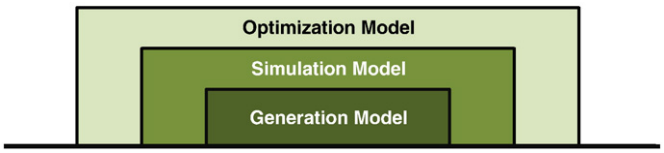

Fig. 3. Optimization concept.

the optimization of multiple heavy lifts [15]. Shapira and Glascock [1], Zhang et al. [21], and Ali-Hussein et al. performed other related research for the optimal selection and location of cranes [19]. The aforementioned studies on the selection and location of tower cranes have a different purpose than those researching design algorithms of tower crane foundations.

There have been several approaches to reviewing the safety issues of a tower crane. Ho et al. [9] performed a study to optimize tower crane selection and stability examination as per construction site conditions. Ho [8] also surveyed the tower crane operation status in Korea and introduced a development program for tower crane stability examination. In a subsequent study, Ho et al. [10] proposed a simulation program for improving the efficiency of the tower crane stability examination preceded by its type selection. Lee and Ro [18] categorized some examples of tower crane collapses that have occurred in Korea and proposed reinforcing methods to prevent accidents based on the result of a structural analysis for each categorized case. Han et al. [13] presented a method to examine the stabilities of foundations using the OptiCRANE program, a computerized program that selects a tower crane and designs its foundation. All of this research deals with the analyses of disaster cases, the general design and stability examination of the foundations, or the reinforcement of their supporting structures. Instead, we intend to focus on the development of an automatic optimum design algorithm to ensure the stability and economic feasibility of a crane foundation.

2.2. Generic design process

Fig. 2 summarizes a generic tower crane foundation design process [13]. The tower crane stability is examined in reference to data acquired by a pre-installation review, and the site or foundation conditions are modified to reflect the stability examination feedback determined prior to construction. However, such a process is designed to only handle generic items and is limited in that it only produces a foundation design at an adequate level. In other words, the concept of optimal design is missing.

2.3. Foundation of a tower crane

The foundation of a tower crane includes the fixing anchor and the concrete that holds it. As for the foundation of the fixed tower crane

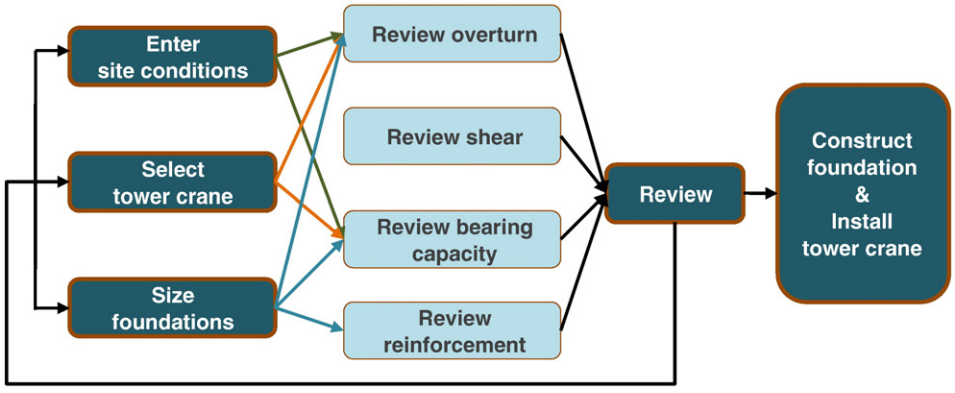

Fig. 2. Generic design process.