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Advanced planning model of formwork layout for productivity improvement in high-rise building construction

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ABSTRACT

The recent trend toward irregular shapes in high-rise building construction makes planning formwork layouts a more complex and laborious task that has been mainly conducted by a heuristic method based on the intuitive judgment of formwork engineers. This study suggests a new planning approach integrated with practical software for formwork layout that is optimized for deploying formwork panels around structural obstacles while minimizing manual efforts. The proposed approach uses a harmony search algorithm (HSA); it has demonstrated improvement in work efficiency of formwork and has reduced formwork costs by minimizing both the use of nonstandard panels and the total number of panels. A case verification showed that the proposed planning method provided a 56% decrease in nonstandard panel-covered area with 14.1% lower cost than the previous heuristic approach by a formwork expert. Moreover, the results indicated that HSA was more efficient than the genetic algorithm (GA) in layout planning of formwork panels. The advanced planning method will support formwork engineers and will also contribute to increasing formwork productivity.

1. Introduction

The planning of formwork layouts is a significant factor in determining the productivity of formwork [1]. Layout planning involves identifying the types, numbers, and arrangement of the formwork materials [2]. In this process, the proportion of standard (modular) panels and the total number of formwork panels significantly affect the productivity as well as the costs for formwork operation. This is because standard formwork panels use a regular space between supports and require less time than nonstandard ones during production, installation, and dismantlement. Additionally, standard formwork panels can generally be applied to another project without remolding. On the other hand, the number of formwork panels is related to their coupling time; therefore, a smaller number would secure a more productive layout alternative. Because many layout alternatives are possible even on a small floor, a systematic approach is needed in the design stage to consider the layout alternatives in a scientific manner.

Layout planning with standard formwork panels is becoming more crucial, complex, and difficult in high-rise building construction, which generally has a more spacious floor area and a trend toward irregular shapes. In particular, layout planning around structural obstacles, such as columns, is important for productivity because of the diversity of layout options and the difficulties in applying standard formwork panels in an orderly way. Although much software has been developed and employed in systematizing the planning task, the existing software can only partly cope with a floor that does not have obstacles. Extensive rearrangement and modifications are required when deploying standard formwork panels, as their shapes and sizes do not match well with the spaces around obstacles. For this reason, if the layout of the floor plan and columns is complicated, the software cannot be applied or it requires excessive time to find an optimal solution; consequently, much layout planning is performed manually with heuristic approaches based on personal experience and intuition [3,4].

This study presents an advanced method for formwork layout planning optimized for deploying formwork panels around structural obstacles with minimizing manual efforts. The suggested model finds optimal formwork layout solutions even with complex floor layouts or many columns. The harmony search algorithm (HSA), which has been widely applied in solving nonlinear optimization problems [17,25,26], is applied to deduce a coherent and optimal layout solution automatically and quickly. The optimization model is based on a mathematical formula, and its design is based on the analysis of a literature review and advice from three experts. The model was basically made for the planning of aluminum formwork layouts because these products have the most complicated layout alternatives, and they are also very widely used in high-rise building construction projects [5]. The

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suggested model was developed as an add-on for the AutoCAD architecture, which is the most widely used system when drawing formwork planning, to verify the applicability and efficiency of the model. A case study is presented of a high-rise building construction floor plan in which aluminum formwork was used. A comparative analysis between results from the suggested model and from an expert engineer (heuristic approach) was conducted to verify the efficiency of the suggested model quantitatively. Moreover, a comparative analysis between the previous genetic algorithm (GA)-based model and the HSA model demonstrated the superiority of the latter in layout planning of formwork panels.

2. Literature review

2.1. Existing formwork planning methods

Formwork layout planning for efficient formwork operation focuses on minimizing the number of nonstandard panels and the total number of panels. Standard panels have regular coupling holes and shape, and are nonoriented and easy to install and dismantle with their constant and regular types of procedure for linking to beams and support units. Furthermore, the proportion of standard panels should be as high as possible, so that the work space under the installed panels would secure a more spacious and neat condition improving work productivity. Additionally, a standard panel can be reused throughout its lifespan because it can be used at any construction site. In contrast, semi-standard and nonstandard panels are made for a specific project, so it is hard to apply them to another project without remolding. As the coupling time between panels, and between panels and supports, occupies most of the working hours of formwork operation, the number of formworks should be minimized to improve the productivity. When planning a formwork layout, coverage around the columns is the most significant issue that affects the productivity of the formwork. It requires a large amount of manual work, and consequently, much time and effort are needed to plan for the many columns in the floor plan.

With this background, the current procedure for layout planning of aluminum formwork is a six-step process as follows. (i) The layout planning area is set up without structural members such as columns and walls. (ii) The standard forms, in particular panels of size 600 × 1200, are placed along the long span direction of the floor plane. (iii) Semistandard panels are arranged around structural members, considering the remaining area. A trial-and-error method is used until the uncovered area is minimized. (iv) Nonstandard panels are arranged in the remaining area. (v) Beam units and supports should be drawn around panels to finish the layout planning. (vi) The responsible manager selects the best alternatives considering the number of forms and the proportion of standard forms.

Several programs (PERI CAD, ELPOS, Tipos, DokaCad, etc.) for aiding the planning process have been developed by professional formwork manufacturing companies [6,7]. However, these programs can only provide automation until step (ii). They can only be applied to rectangular areas with no columns; floor layouts are complex, and a high-rise building has many columns, rendering the programs difficult to apply. As the formwork panels need to be arranged to avoid columns, the engineers must consider the available space between columns and walls after step (ii). Furthermore, the layout planning method will be used in quite different ways by different engineers, and the low reliability of the software could make the task labor-force dependent. In particular, previous heuristic planning methods cannot deduce coherent alternatives, and many errors can occur around obstacles because of the infinite number of planning alternatives. Therefore, a layout planning model for formwork panels is required to find an optimal solution, increasing the proportion of standard panels and decreasing the overall number of panels and the proportion of nonstandard panels, in particular around obstacles. This is needed regardless of an engineer's intuition or experience, to minimize the additional planning tasks after arranging the standard formwork panels.

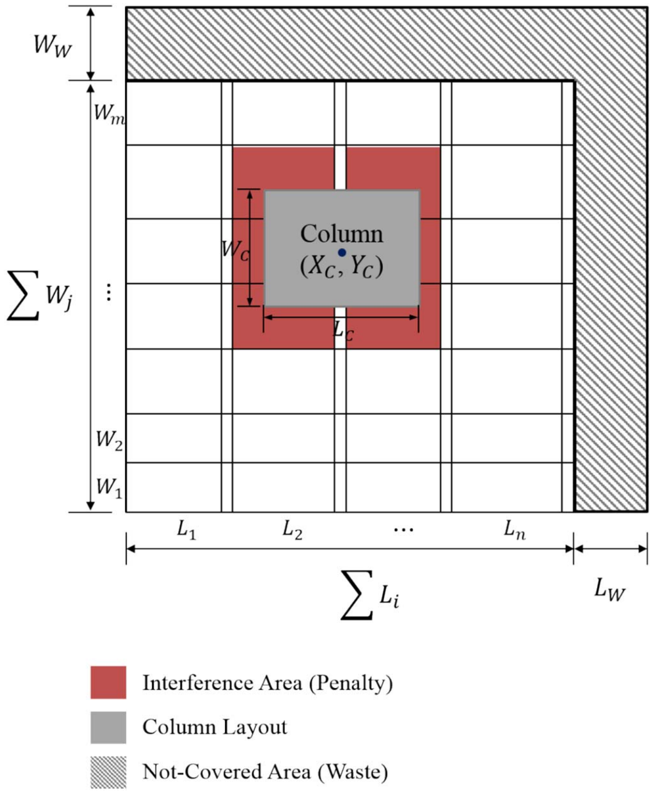

Fig. 1. Formwork layout diagram for the mathematical approach.

2.2. Previous research on formwork planning

Several studies have been performed in Korea regarding formwork layout planning. Lee [1] suggested a building information modeling (BIM)-based automatic formwork layout model. A three-dimensional (3D)-based formwork layout platform was made based on this study, but the layout planning work still required manual steps because of the variety of layout options. Cha [3] and Kim [2] first proposed an optimization model for formwork layout based on a mathematical theory. The studies focused on the layout planning of table formwork. Their formwork planning procedure is totally different from the panelized formwork method; in addition, the model does not consider the arrangement of special formwork panels around obstacles. Additionally, many assumptions and simplifications are required to solve the formwork layout problem, which is one of the nondeterministic polynomial-hard types of problem with the mathematical model. Furthermore, the approach was inappropriate for panelized slab forms such as aluminum formwork because of the infinite number of layout solutions.

Lee et al. [11] suggested a layout planning model based on the GA to solve the layout optimization problem. The model showed that the GA-based approach provides better solutions in a shorter time than the current heuristic approach. However, the previous Lee's model also has several limitations, as follows. (1) The previous GA model generated an optimal solution at once without considering a comparison among solutions even when there are many different layout combinations that have the same fitness function, and it also did not have a module to consider the structural safety condition or design factor. Consequently, the engineer had to reiterate and modify until a solution was found that satisfied structural safety requirements within the predetermined design concept boundary of structural members. Furthermore, the GA model only considered minimization of the nonstandard panel covered areas without considering the total number of panels; consequently, the numbers increased while the area covered by nonstandard panels