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Predicting the climbing rate of slip formwork systems using linear biogeography-based programming

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ABSTRACT

Nowadays, it is undeniable necessity to select a fast and appropriate method for construction of high rise concrete structures. Slip formwork technology, as an automatic formwork system, has many advantages for high rise buildings and can reduce the construction time and costs. However, the climbing rate of slip formwork systems is a challenging task and depends on different factors. In this paper, the potential factors in calculating the climbing rate were identified. Then, a comprehensive database including 81 slip formwork projects in Iran was gathered. Afterwards, a symbolic regression method called linear biogeography-based programming was introduced and applied for extracting a formula that obtains a good climbing rate of slip formwork systems. For evaluating the performance of the proposed method, artificial neural network and linear genetic programming were utilized as well. The results show that the proposed formulation has good agreement with actual values of climbing rate of slip forming systems with low error and complexity and find it to be quite confident. Moreover, weather conditions criteria is known as the most effective parameter in climbing the rate of slip formwork systems based on the performed sensitivity analysis.

1. Introduction

Formwork system is one of the most important components of any construction project and consumes a significant part of concrete structure construction costs, i.e. around 10–20 percent of the total project cost [1–3]. The formwork cost can be significantly increased in some special projects such as tall buildings. Moreover, the completion time of a construction project depends on the progress of the activities that follow it, e.g., mechanical and electrical installation, internal finishing and external cladding [4].

Generally speaking, the formwork systems in construction projects can be classified into horizontal and vertical ones used to support the horizontal concrete elements (slabs or roofs) and the vertical concrete elements (walls or columns), respectively [5]. Selecting an appropriate type of formworks depends on some factors such as building requirements and construction challenges.

Slip-form technology is an automatic formwork system which has many benefits in construction industries and can shorten the construction time and reduce costs [6]. It is a continuous process of moving formwork to allow for the simultaneous extrusion and concrete finishing. This formwork system can be used as vertical formwork for different structures such as bridges, towers, buildings, dams and silos as well as horizontal structures such as roadways. Compared to conventional formwork system, slip formwork system can decreased the formwork cost for tall structures greater than 20 stories and larger than 600 m^2 formed area per floor. Moreover, for silos higher than 15 m, the slip-form method is the most economical and time saving technique as reported in Ref. [7].

There are limited researches about predicting the properties of formwork systems using artificial intelligence methods and most of them have focused on the formwork selection process. Shin et al. [8] proposed a formwork selection model based on boosted decision trees to assist the participator's decision making. Dikmen and Sonmez [9] suggested a method based on an artificial neural network (ANN) for estimating the required man-hours for the formwork activity of reinforced concrete frame buildings. Javanjal and patil [10] introduced a fuzzy model for predicting the best suited formwork depending upon the factors affecting the particular building project in selection of formwork systems. Elazouni et al. [11] employed an ANN-based approach to anticipate the acceptability of new formwork systems. Elbeltagi et al. [12] presented a

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Nomenclature

AD	Additive dosage
ANN	Artificial neural network
AOWH	Amount of operational works at height
BBO	Biogeography-based optimization
CM	Concreting method
CT1	Concrete thickness
CT2	Concrete temperature
ET	Expression tree
GA	Genetic algorithm
GP	Genetic programming
GS	Geometry of structure
HSI	Habitat suitability index
LA	Leadership ability
LBBP	Linear biogeography-based programming
LGP	Linear genetic programming
LM	Levenberg-Marquardt
MAE	Mean absolute error
MAPE	Mean absolute percentage error
MBBP	Multi-sub-habitat BBP
MGP	Multi-gene genetic programming
NH	Number of habitats
R	Pearson correlation coefficient
RMSE	Root mean squared error
SAI	Sensitivity analysis index
SBBP	Simple multi-sub-habitat BBP
SIV	Suitability index variable
SO	Supporting organization
SR	Symbolic regression
WC	Weather conditions
WE	Workforce experience

fuzzy logic-based model that supports decision makers for appropriate selecting of vertical formwork systems. Also, Kamarthi et al. [4] developed an ANN approach to provide a selecting proccess of vertical formwork systems for a given building site. Elbeltagi et al. [5] proposed a fuzzy model for selecting the slab formwork system to help decision makers in small/medium Egyptian construction companies. Tam et al. [1] suggested a probabilistic neural network for choosing vertical formwork systems.

Various types of symbolic regression (SR) methods have been developed to explore the mathematical relationship between the output and inputs of a system. Genetic programming (GP), developed by Koza [13] in 1992, is one of the first SR methods inspired by genetic algorithm and utilizes crossover and mutation operators to generate new formulas. After that, some researchers paid attention to apply individuals in programming [14] and aggregation of sub-individuals [15] while other ones defined different forms of genetic operators [16–20]. Cabrita et al. [21], motivated by the bacterial evolution mechanism, introduced bacterial programming as the extension of bacterial evolutionary algorithm and proposed a modified mutation operator called bacterial mutation, based on the natural phenomenon of microbial evolution [22]. Clone selection programming, inspired by artificial immune system, is another method of automatic programming in which a specific operator is implemented by an antibody's affinity and a set of probabilistic parameters [23]. Dynamic ant programming is a paradigm of evolutionary computation based on ant colony optimization which uses dynamically changing the pheromone table [24]. Inspired by artificial bee colony optimization, Karaboga et al. [25] presented a new method of automatic programming called artificial bee colony programming and utilized different artificial bee operators to find the best formula of the problem. Biogeography-based programming (BBP), proposed by Golafshani [26], is another novel SR method which uses migration and mutation operators to produce new formulas.

Climbing rate of slip formwork is one of the important and challenging issues among contractors and can be varied between 50–250 millimeter per hour depending mainly on many factors such as properties of the concrete structure, job specifications, weather conditions, workforce and management. In this study, the information of 81 construction projects in Iran was gathered for determining the climbing rate of vertical slip-form technology. In order to predict the climbing rate, a powerful automatic regression model, namely linear biogeography-based programming (LBBP) model was used. LBBP is an extension of the BBP programming method which can create an explicit mathematical relation as a polynomial regression model and was successfully applied in some real engineering problems [27–29].

This paper is organized as follows: Section 2 explains the slip formwork system and factors affecting on the climbing rate of slip formwork systems. Section 3 presents ANN and two SR models i.e. LBBP and LGP methods. In Section 4, the ANN, LBBP and LGP models are developed, whereas Section 5 presents the results and discussion, followed by the main conclusion in Section 6.

2. Slip formwork system

The slip formwork system is a sliding-form construction method introduced in the early 1900 to construct tall and slender structures [30]. This construction method served as the best forming solution for building silos and grain elevators, etc., throughout the world but it was used for the residential and commercial high-rise concrete structures in late 1960 [31]. It has already proved that this method can significantly improve the constructability, safety, and quality control. It is used to erect the pylon by sliding up the whole forms using an automated jacking device embedded in concrete and pouring continuously concrete. The slip-form construction process is that, once concrete has attained a specified strength after placement, the forms are moved up, while continuously assembling the steel and placing the concrete [6]. Various parts of slip formwork system are shown in Fig. 1.

2.1. Factors affecting the climbing rate of slip formwork system

In this study, a total number of 81 slip formwork projects in Iran from 1998 to 2016 were considered. The height of these projects varies from 16 to 308 m. These slip formwork systems have been used for different purposes and in different projects such as dams, power plants, towers, cement factories, steel plants, airports, bridge piers, flour factories and elevator pits. To determine the most important factors affecting the climbing rate of slip-form systems, semi-structured interviews were conducted with the project managers of above mentioned projects as well. As shown in Fig. 2, the factors affecting the climbing rate of slip formwork system can be classified into four major groups. These groups are factors related to the concrete structure, job specifications, weather, workforce and management. Some major groups are divided into primary factors as described in the following.

2.1.1. Geometry of structure (GS)

This factor has a significant effect on the rising rate of slip-form. If the geometry of a structure is more complicated, the climbing rate decreases. There are different types of slip formwork systems with one, two and three dimensional movement of slip-form. Figs. 3 and 4 illustrate different forms of concrete structures and Table 1 gives their properties. Moreover, there can be special slip formwork system as shown in sub-figure 'f' of Fig. 4. In this case,