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Article

Applications of Two Neuro-Based Metaheuristic Techniques in Evaluating Ground Vibration Resulting from Tunnel Blasting

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Abstract: Peak particle velocity (PPV) caused by blasting is an unfavorable environmental issue that can damage neighboring structures or equipment. Hence, a reliable prediction and minimization of PPV are essential for a blasting site. To estimate PPV caused by tunnel blasting, this paper proposes two neuro-based metaheuristic models: neuro-imperialism and neuro-swarm. The prediction was made based on extensive observation and data collecting from a tunnelling project that was concerned about the presence of a temple near the blasting operations and tunnel site. A detailed modeling procedure was conducted to estimate PPV values using both empirical methods and intelligence techniques. As a fair comparison, a base model considered a benchmark in intelligent modeling, artificial neural network (ANN), was also built to predict the same output. The developed models were evaluated using several calculated statistical indices, such as variance account for (VAF) and a-20 index. The empirical equation findings revealed that there is still room for improvement by implementing other techniques. This paper demonstrated this improvement by proposing the neuro-swarm, neuro-imperialism, and ANN models. The neuro-swarm model outperforms the others in terms of accuracy. VAF values of 90.318% and 90.606% and a-20 index values of 0.374 and 0.355 for training and testing sets, respectively, were obtained for the neuro-swarm model to predict PPV induced by blasting. The proposed neuro-based metaheuristic models in this investigation can be utilized to predict PPV values with an acceptable level of accuracy within the site conditions and input ranges used in this study.

Keywords: tunnel blasting; Peak particle velocity; metaheuristic algorithms; neuro-swarm; neuro-imperialism

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1. Introduction

Blasting operations are frequently used in mines, quarries, and tunnels to excavate rock mass, due to their economy and efficiency. An important control object during blasting is the magnitude of ground vibration, as this is related to the safety of the surrounding buildings and equipment [1]. During blasting operations, the blast-induced ground vibration can propagate in three directions: transverse, longitudinal, and vertical direction [2]. When the vibration starts to propagate, each particle has its velocity. The peak particle velocity (PPV) is defined as the highest velocity of the particles, which is the base factor to assess the magnitude of ground vibration produced by blasting events [3–6]. Dozens of investigations were carried out to determine the PPV magnitude [7], and they included three types:

empirical/experimental methods, statistical-based methods, and artificial intelligence (AI) techniques.

In the case of empirical/experimental methods, many researchers [8,9] suggested a uniform style, which works based on only two parameters, namely, the distance of the measuring transducer from the blasting face and the explosive weight (charge amount). This uniform style was introduced by Duvall and Petkof [10], and it is known as the USBM equation form. The scaled distance (*SD*) is the main term of the USBM equation, which can relate the two mentioned parameters to predict PPV values. However, average performance accuracy was reported by the researchers for different proposed empirical equations, whereas a high prediction capacity is required for such techniques to minimize the risk associated with ground vibration produced by blasting. In addition, typically, these empirical/experimental equations were proposed for the conditions of the specific site, which has a unique geological structure and setting [11]. It seems that these empirical/experimental formulas cannot predict PPV with a satisfactory level of accuracy in the other blasting locations, and there is a need to try other available techniques to get more reliable results with higher accuracy.

Statistical regression methods have also been used to predict blast-induced PPV. For example, Hasanipanah et al. [12] developed a multiple linear regression (MLR) model/equation to forecast blast-induced PPV in the Miduk copper mine, in Iran. In their research, 69 data samples were allocated to the training (development) data sets for constructing the MLR model, while 17 data sets were apportioned to the testing (assessment) data sets to evaluate the MLR model. The results showed that the constructed MLR model had favorable accuracy (coefficient of determination, R^2 = 0.883) by comparing the measured PPV values with the predicted PPV values. Similarly, Ram Chandar et al. [13] proposed another MLR model to forecast PPV values in three mines. Their applied input variables included the maximum charge per delay, distance, burden, spacing, amplitude, and frequency. The results indicated that MLR was a reliable tool that can produce good accuracy and can be applied at any mine site. However, PPV is a sensitive indicator that can significantly characterize the influence of the ground vibration resulting from blasting on the safety of a building or equipment.

Some researchers [14] mentioned that the accuracy level of statistical models and MLR techniques in predicting PPV was inadequate compared to AI techniques, which can yield more reliable results. For example, Khandelwal and Singh [15] compared the PPV prediction results of both artificial neural networks (ANN) and MLR and found that the corresponding coefficients of correlation for predicting PPV are 0.994 by ANN and 0.4971 by MLR. It showed that the ANN model had a greater accuracy, whereas the proposed MLR equation had a higher error. Similar results were seen by Xue and Yang [16], Parida and Mishra [17], and Lawal and Idris [18].

In recent years, many models and studies have been developed using AI techniques for solving civil and mining problems [19–37] and specifically for predicting PPV produced by blasting. These models mainly include ANN, gene expression programming (GEP), neuro-fuzzy, decision tree, support vector machine (SVM), fuzzy logic, genetic algorithm (GA), and genetic programming [38–40]. The studies highlighted the feasibility and applicability of AI models in solving PPV produced by mine or quarry blasting. However, the AI studies for predicting PPV induced by tunnel blasting are limited to a few investigations only, as presented in Table 1. For instance, Monjezi et al. [41] attempted to use ANN to predict PPV values produced by tunnel blasting in a project carried out in Iran. They reported that the ANN technique was a powerful and easy-to-use method for solving such problems. Lawal et al. [42] conducted research to predict tunnel blast-induced PPV in the Daejeon tunnel, in South Korea. They proposed different techniques, i.e., ANN, moth-flame optimization (MFO)-ANN, and GEP, and used the controllable (e.g., hole depth) and uncontrollable (e.g., rock mass rating) factors. The results showed that the MFO-ANN model performed better in predicting PPV compared with ANN and GEP. In another work, Jelušič et al. [43] used a neuro-fuzzy model to predict PPV values in two tunnels located in Slovenia. In their study, the charge and the distance from the blast face to the monitoring positions