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Prediction of pile bearing capacity using a hybrid genetic algorithm-based ANN

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ABSTRACT

The application of artificial neural network (ANN) in predicting pile bearing capacity is underlined in several studies. However, ANN deficiencies in finding global minima as well as its slow rate of convergence are the major drawbacks of implementing this technique. The current study aimed at developing an ANN-based predictive model enhanced with genetic algorithm (GA) optimization technique to predict the bearing capacity of piles. To provide necessary dataset required for establishing the model, 50 dynamic load tests were conducted on precast concrete piles in Pekanbaru, Indonesia. The pile geometrical properties, pile set, hammer weight and drop height were set to be the network inputs and the pile ultimate bearing capacity was set to be the output of the GA-based ANN model. The best predictive model was selected after conducting a sensitivity analysis for determining the optimum GA parameters coupled with a trial-and-error method for finding the optimum network architecture *i.e.* number of hidden nodes. Results indicate that the pile bearing capacities predicted by GA-based ANN are in close agreement with measured bearing capacities. Coefficient of determination as well as mean square error equal to 0.990 and 0.002 for testing datasets respectively, suggest that implementation of GA-based ANN models as a highly-reliable, efficient and practical tool in predicting the pile bearing capacity is of advantage.

1. Introduction

Pile foundations are structural elements to transfer superstructure loads deep into the ground. In the last few decades, several methods for estimating pile bearing capacity including experimental, numerical and analytical have been proposed [1–4]. Nevertheless, the level of accuracy and consistency of the estimated bearing capacity is of prime importance. For instance, the estimated pile bearing capacity using famous Meyerhof formula could be different from the bearing capacity estimated through semi-empirical methods [5]. However, it is expected and it may be attributed to several assumptions incorporated in the problem for simplification purposes. Therefore, still, the most direct and reliable approach to determine the pile bearing capacity is statically loading the pile up to its failure. Being expensive and time-consuming is the major limitation of conducting static load test (SLT). One of the most innovative methods to predict the bearing capacity of piles is High-Strain dynamic testing of piles (HSDT). The test is based on one-dimensional wave propagation theory and is provided by a Pile Driving Analyzer (PDA). HSDT is standardized by American Standard Test Methods [6]. Numerous literature show that the bearing capacity predicted by PDA is in close agreement with that of SLT [7]. Apart from that, compared to SLT, PDA (HSDT) tests are quick and economical. However, there is a need for conducting several PDA tests in each project. Considering the cost of each PDA test, reducing the number of required PDA tests could

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be of interest as it can reduce the total cost of a project. This can be done through developing artificial intelligence-based predictive models of pile bearing capacity. In the last decade, the application of artificial intelligence and predictive models as a practical, feasible and quick tool in solving engineering problems is underlined in several studies [8–12]. In essence, artificial intelligence (AI) is a combination of math, algorithm and creativity and it incorporates several techniques such as artificial neural network (ANN), genetic algorithm (GA), and particle swarm optimization.

Many scholars suggested the use of ANN-based predictive model of bearing capacity for foundations [8,13,14]. As an example, Goh et al. [15,16] designed an ANN-based model to predict the bearing capacity of driven piles in cohesionless soils. His well-respected studies suggest that pile set, length, width and cross sectional area of the driven piles as well as hammer properties, weight and drop height are the most influential input parameters to the pile bearing capacity. Pal and Deswal [17] reported the applicability of ANN in predicting the ultimate bearing capacity of concrete spun pipe piles. Their model dataset consisted of stress-wave data and pile geometrical properties. According to their conclusion, compared to a support vector machine, ANN performs better in predicting the pile bearing capacity. The high coefficient of determination i.e., $R^2 = 0.98$ suggests the high reliability of their proposed predictive model. In another study, Benali and Nechnech [18] addressed the feasibility of ANN in predicting the bearing capacity of piles in sandy soils. For training the ANN, they compiled the mechanical properties of purely cohesive soil as well as the geometrical characteristics of 80 recorded cases of axially loaded piles. The coefficient of determination, R^2, equal to 0.84 reveals the reliability of their ANN-based predictive model. For brevity purposes, other recent related works are summarized in Table 1. This table highlights the reliability of the recently developed ANN-based predictive models of footing bearing capacity as well as their major inputs, footing type and the number of datasets.

Nevertheless, ANNs suffer from some disadvantages such as getting trapped in local minima and slow rate of learning. Utilization of optimization algorithm such as GA can significantly enhance the ANN performance [25–27]. The focus of this study is on the efficiency of hybrid GA-based ANN model in predicting the bearing capacity of piles. The work presented here is different from the previous predictive models of pile bearing capacity (see Table 1) in two main aspects: implementing ANN enhanced with genetic algorithm and relatively simple input data. That is the feeding data *i.e.* pile geometrical properties, hammer weight and drop height of the proposed predictive model in this paper are relatively easy to obtain while in some other proposed ANN-based predictive models of bearing capacity, to train the models, there is a need for conducting relatively extensive experimental tests such as standard penetration test [24], cone penetration test [23] among others. It is worth mentioning that relatively simple input data results in developing a more practical, feasible and economical predictive model of pile bearing capacity.

2. Methods

2.1. High strain dynamic pile test

HSDT, also called PDA test, is one of the most common and popular ways of predicting pile bearing capacity. The method is based on the theoretical assumption that any mechanical impact on piles, as slender elements with uniform cross sections surrounded by materials with much lower stiffness, causes wave propagation along the pile. For brevity purposes, solution to partial differential equations of wave propagation is not given here. However, it is reported elsewhere [28]. Smith [29] was the first one who related wave propagation concept to axial bearing capacity of pile. However, Smith's model which divided the pile, hammer, and driving accessories into discrete elements, suffers from poor estimation of the actual energy delivered by the hammer. Later on, a group of researchers in Case Western Reserve University reported the use of force and acceleration records in a simplified model to predict pile bearing capacity [30]. However, the main deficiency of their developed method, known as CASE method, was that the static soil resistance was sensitive to the CASE damping factor. Nevertheless, full power of the wave equation analysis is first realized when combined with dynamic monitoring of the pile during driving [31–33]. In the combined analysis, it is not necessary to model the hammer and driving system as in Smith's model; instead PDA records are used. In other words, the bearing capacity (soil resistance) is estimated by measuring the force and

Table 1
Proposed ANN-based predictive model of bearing capacity.

Reference	Database	Major inputs	Footing type	Reliability (R^2)
Soleimanbeigi and Hataf [19]	351	G, ϕ, γ	Spread	0.94
Padmini et al. [20]	97	γ, G, ϕ	Spread	098
Ornek et al. [21]	28	G, S	Spread	0.95
Kiefa [22]	59	G, ϕ, σ'	Pile	0.91
Pal and Deswal [17]	105	G, SW	Pile	0.98
Shahin and Jaksa [23]	94	CPT, G	Pile	0.94
Jianbin et al. [24]	9	N, ϕ, G, γ, C	Pile	–
Benali and Nechnech [18]	80	G, C, σ'	Pile	0.84

N: standard penetration test N value; G: footing geometrical properties; q: footing net applied pressure; ϕ: friction angle of soil; γ: unit weight of soil; σ' effective stress of the soil; S: settlement of the footing; R^2: coefficient of determination; SW: stress-wave data; CPT: cone penetration test; C: cohesion of soil.