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Design and Reliability analysis of energy pile using soft computing technique and a comparative study between the developed soft computing models

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Geothermal or energy piles, are environmentally friendly piles that extract heat energy from shallow depths of the earth surface to heat or cool the structures constructed over them, such as multi-storey residential buildings, industrial complexes, and shopping malls [1]. Through the energy piles, the heat is injected into the ground or extracted from the ground by the fluid circulating mechanism inside the heat exchanger pipes (HEP). The fluid is passed through the (HEP), which are attached to the reinforcement cage of the pile foundation element [2]. The use of energy piles to meet the thermal needs of the built structures has proven to be both environmentally and economically viable, as well as having significant social benefits [3]. A lot of uncertainties are associated with geotechnical engineering applications, which are unavoidable as they deal with natural materials. The reliability analysis of geotechnical structures has gained much attention in the last few decades [4]. Therefore, this paper aim is to study the reliability analysis of the ultimate group capacity (Q_{ug}) of energy piles along with the comparative study of the models developed using soft computing techniques. In the current study, cone penetration test (CPT) was carried out at Manali, Chennai (India), which falls in earthquake zone 3. Furthermore, (Q_{ug}) of piles was determined using CPT data by considering various parameters (such as pile length (L), pile diameter (D), cone resistance (q_{c0}), average cone penetration resistance (q_{c1}), an average of minimum cone penetration resistance (q_{c2}), Young's modulus (E), temperature change (ΔT), and coefficient of thermal expansion (α_c)) and then the reliability analysis was performed. IS 2911 (Part 1): 2010 was followed to find out the Q_{ug}. The total load (mechanical load and thermal load) coming on a single pile was computed by assuming mechanical load as 100 kN and thermal load as stated in [5]. The average annual temperature variation of the ground surface was considered as 21℃ and the average yearly ground temperature as 13℃ to determine the thermal load applied to piles through the heat-circulating fluid (HCF). A cast-in-situ concrete energy pile of M35 grade was considered in this work. Based on the total applied load and Q_{ug} of the pile, the various parameters of the bored cast-in-situ concrete energy piles (9.0 m × 0.7 m) were determined. Two U shape copper pipes having a diameter of 40 mm, and a thickness of 3mm, were embedded and placed 250 mm apart in the energy pile to carry fluid, i.e., water [5], as shown in Figure 1. A laminar flow having a heat-carrying flow inlet velocity of 0.183 m/s and a flow rate of 0.326 m^3/h was considered for this work[6]. The thermal conductivity and heat capacity of the steel and concrete materials used in this work are {44.4 (W/m K) and 475 (J/kg K) } and {1.8 (W/m K) and 880 (J/kg K)}, and Young's modulus of steel and concrete are 200×10^3 (MPa) and 32×10^3 (MPa), respectively [7]. The reliability index (β) was calculated using equation 1 for reliability analysis.

$$\beta = \frac{C-D}{\sigma_C^2-\sigma_D^2} \qquad (1)$$

where σ_C and σ_D are the standard deviation of capacity (C) and demand (D). After designing and selecting various parameters of the energy pile, 100 sets of data were generated randomly for $q_{c0}, q_{c1}, q_{c2}, and$ E and accordingly Q_{ug} was determined. The data

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set is divided into two parts, i.e., training and testing data. The 70 sets of data are used to train the model, and the remaining sets of data are used for testing purposes. In this work, two soft computing models, Random Forest (RF) and Extreme Gradient Boosting (XGBM), were used to predict the output, i.e., the Q_{ug} of the energy pile [8]. To compare expected and observed values, various performance assessment parameters were used. The performance assessment of the developed model for the training and testing datasets is shown in Table 1.

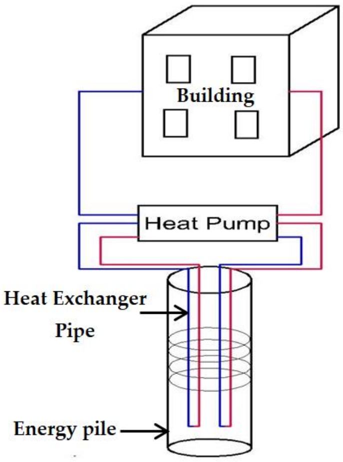

Figure 1: Schematic representation of the energy pile system.

Table 1: The details of different performance assessment parameters for the developed model in predicting the ultimate group capacity of a training and testing data set.

Parameter	RF		XGBM	
	Training	Testing	Training	Testing
R	0.985	0.943	0.997	0.999
WMAPE	0.124	0.263	0.033	0.009
NS	0.977	0.921	0.998	0.999
RMSE	0.067	0.115	0.194	0.005
VAF	90.85	70.50	99.24	99.93
R^2	0.977	0.920	0.998	0.999
ADJ R^2	0.976	0.904	0.997	0.999
PI	1.81	1.49	1.97	1.99
RSR	0.150	0.281	0.043	0.012

For reliability analysis, the first-order reliability method (FORM) is used. It was observed that the reliability index (β) for the actual case is 3.166, and the XGBM and RF models are 3.860 and 7.612, respectively. The XGBM model has a lower minimum deviation compared to RF. Correspondingly, the XGBM model is more reliable than the RF model for predicting the group capacity of the energy pile. The design and reliability analysis of energy piles are the main objectives of this work. These two models were developed using ML techniques. Developed models are used to predict the ultimate group capacity and reliability index (β) of energy piles. After prediction, various performance assessment parameters are used to compare and check the performance of models to select the best one. The present work concludes that the XGBM model is the best model for reliability analysis of ultimate group capacity and for designing the energy pile.

Contributor Statement:

Conceptualization: Ashutosh Kumar, Pijush Samui, Ramakrishna Bag; Project Administration: Ramakrishna Bag, Pijush Samui; Writing: Ashutosh Kumar, Ramakrishna Bag.

References:

[1] Mohamad, Z., Fardoun, F., & Meftah, F. (2021). A review on energy piles design, evaluation, and optimization. Journal of Cleaner Production, 292, 125802. https://doi.org/10.1016/j.jclepro.2021.125802
[2] Gao, J., Zhang, X., Liu, J., Li, K., & Yang, J. (2008). Numerical and experimental assessment of thermal performance of vertical energy piles: An application. Applied Energy, 85(10), 901–91https://doi.org/10.1016/j.apenergy.2008.02.010
[3] Hassani Nezhad Gashti, E., Malaska, M., & Kujala, K. (2014). Evaluation of thermo-mechanical behaviour of composite energy piles during heating/cooling operations. Engineering Structures, 75, 363–373. https://doi.org/10.1016/j.engstruct.2014.06.018
[4] Pradeep, T., GuhaRay, A., Bardhan, A., Samui, P., Kumar, S., & Armaghani, D. J. (2022). Reliability and Prediction of Embedment Depth of Sheet pile Walls Using Hybrid ANN with Optimization Techniques. Arabian Journal for Science and Engineering, 47(10), 12853–12871. https://doi.org/10.1007/s13369-022-06607-w
[5] Sani, A. K., Singh, R. M., Amis, T., & Cavarretta, I. (2019). A review on the performance of geothermal energy pile foundation, its design process and applications. Renewable and Sustainable Energy Reviews, 106(February), 54–78. https://doi.org/10.1016/j.rser.2019.02.008
[6] Song, H., Pei, H., Zhou, C., Zou, D., & Cui, C. (2022). Calculation of the representative temperature change for the thermomechanical design of energy piles. Geomechanics for Energy and the Environment, 29, 100264. https://doi.org/10.1016/j.gete.2021.100264
[7] Florides, G., & Kalogirou, S. (2005). Annual ground temperature measurements at various depths. 8th REHVA World Congress, Clima, January, 1–6. http://ktisis.cut.ac.cy/handle/10488/844
[8] Zhang, W., Wu, C., Li, Y., Wang, L., & Samui, P. (2021). Assessment of pile drivability using random forest regression and multivariate adaptive regression splines. Georisk, 15(1), 27–40. https://doi.org/10.1080/17499518.2019.1674340