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EXTENDED ABSTRACT

Prediction of Properties of Sand Mixture with HDPE by MLR, EPR and Stepwise Models

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1. Introduction

The main goal of this research is to present a suitable mathematical model using the MLR (Multiple Linear Regression), EPR (Evolutionary Polynomial Regression), and Stepwise statistical methods. This model aims to predict the relationship between the properties of sand mixed with High Density Polyethylene (HDPE) (as a waste additive material to soil), including the elastic modulus, the coefficient of compressibility, and lateral earth pressure coefficient at rest. The purpose of presenting this model is to reduce laboratory work, and consequently, reduce costs and time. Additionally, the present study focuses on designing and developing a set of models, fitting experimental results, and comparing the best models provided by EPR, MLR, and Stepwise, to find the best modeling approach.

2. Materials and Experimental Methodology

In this study, the results of large-scale oedometer tests on the mixture of Anzali sand, which is a poorly graded sand (SP) under a unified soil classification system, and HDPE have been utilized. The HDPE used in this study has been shredded into small pieces by specialized cutting devices. These plastic wastes are obtained from shredding high-density polyethylene plastics, including detergent bottles, shampoo containers, thick milk bottles, and similar products.

Initially, considering the relative density and dry mass of sand and the percentage of shredded HDPE, the weight of each material was calculated separately. Then, the sand and HDPE were mixed together and thoroughly stirred until complete uniformity and homogeneity were achieved. For the experiments, the sand-HDPE mixtures were poured into a large-scale oedometer cell with a diameter of 50 centimeters and a height of 50 centimeters in 5 layers. Fig. 1 shows the schematic of the large-scale oedometer device. To achieve the desired relative density of the mixture, a hand tamper was used. A total of 30 large-scale oedometer tests were conducted under three normal pressures. Firstly, the test equipment and data logger system were set up, and then the loading stages were initiated. Loads were applied sequentially at values of 100, 200, and 300kPa. The test method in the large-scale oedometer involved applying incremental loads to the sample under dry conditions. The results of the large-scale oedometer tests conducted on the sand-HDPE mixture have been used as input data for the models. The initial variables selected for predicting the models in this study include relative density (D_r=40,70%), HDPE percentage (η=0, 2, 4, 6, 8%), and normal stress (σ=100, 200, 300kPa).

The values of the soil lateral earth pressure coefficient at rest, the coefficient of compressibility, and elasticity modulus obtained from the large-scale oedometer tests were used as output parameters for

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developing regression models using MLR, EPR, and Stepwise methods. To compare and evaluate the performance of the examined models, the parameters of root mean square error (RMSE) and coefficient of determination (R^2) were utilized.

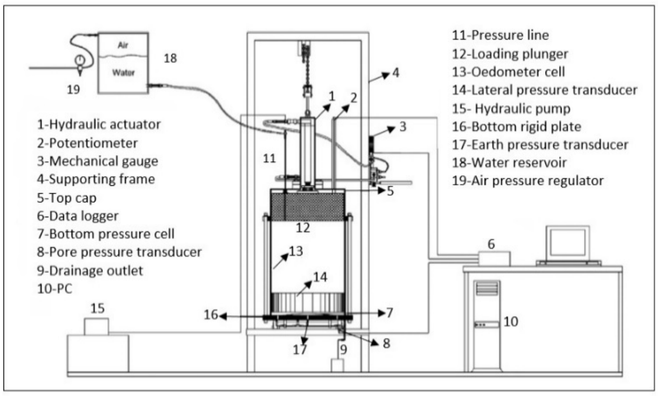

Fig. 1. Schematic representation of the large oedometer system

3. The comparison of the results of MLR, EPR, and Stepwise methods

3.1. MLR method

MLR is an extension of the linear regression method and can be used to demonstrate the relationship between a dependent variable and some independent variables. The input data was analyzed using multiple linear regression, and the output was determined. The general form of the equation obtained using this method is as follows:

$$y = \xi_0 x_1^{\xi_1} . x_2^{\xi_2} . x_3^{\xi_3} \tag{1}$$

Table 1 presents the coefficients of the MLR model for the output parameters of the large-scale oedometer test, along with their corresponding coefficient of determination. The coefficient of determination for each of the 3 parameters of the large-scale oedometer test is greater than 0.99, indicating the high accuracy of the relationship provided by the MLR model.

Table 1. The coefficients of the MLR model

	R^2(%)	ξ_0	ξ_1	ξ_2	ξ_3
k_0	0.9992	1.1734	-0.084	-0.023	0.0681
m_v	0.9984	0.5638	0.193	0.1624	0.3579
E	0.9984	1.4110	-0.1321	-0.1234	-0.3747

3.2. EPR method

EPR uses a genetic algorithm to find the form of multi-sentence expressions and optimize least squares to find the values of constants in expressions. In the execution of modeling using the EPR method, various functions such as linear (No Function), logarithmic (Log), exponential (Exponential), hyperbolic sine (Sh), and hyperbolic tangent (Th) can be employed to present relationships. Modeling was performed for each of these five functions, and ultimately, based on the coefficient of determination, the best relationship for each parameter was selected from the EPR models, which has output results closer to the experimental results. Formulas 2 to 4 present the equations obtained from EPR.

$$K_0 = -5.2 \times 10^{-4} D_r + 1.04 \times 10^6 \sigma_v^{0.5} . sh(D_r)^{0.5} - 1.66e^{-5} \sigma_v {D_r}^{0.5} - 0.071 \sigma_v^2 {D_r}^2 . sh(D_r)^{0.5} - 1.3 \times 10^{-4} \eta \sigma_v + 0.499 \tag{2}$$

$$m_v = -2.4 \times 10^{-9} D_r - 2.989 \times 10^{-10} \sigma_v^2 + 6.53 \times 10^{-8} \eta D_r + 1.482 \times 10^{-9} \eta \sigma_v - 4.3 \times 10^{-11} \eta {\sigma_v}^2 + 5.47 \times 10^{-5} \quad (3)$$

$$E = 91.09 {\sigma_v}^{0.5} {D_r}^{0.5} - 127.73 \sigma_v^1 + 0.415 {\sigma_v}^2 + 3.56 \times 10^{-5} {\sigma_v}^2 \eta^2 sh(\eta) - 0.3955 \eta^2 {\sigma_v}^{0.5} {D_r}^{0.5} + 16129.5 \quad (4)$$

3.3. Stepwise method

Equations 5 to 7 represent the formulas obtained from the Stepwise model for the output parameters of the large-scale oedometer test, based on the input parameters.

$$E = 2032.652 + 72.441 \sigma_v - 933.18 \times \eta + 124.972 \times D_r \quad (5)$$

$$k_0 = 0.549 + 0.000173 \sigma_v - 0.0094625 \times \eta - 0.00112071 \times D_r \quad (6)$$

$$m_v = 6.873 \times 10^{-5} - 1.293 \times 10^{-7} \sigma_v + 2.121 \times 10^{-6} \times \eta - 1.558 \times 10^{-7} \times D_r \quad (7)$$

Table 2 respectively compares the R^2 and RMSE of the three models (EPR, MLR, and Stepwise) for the output parameters of the oedometer test. As mentioned, the closer R^2 is to 1, the better the model's performance is evaluated. Unlike the Stepwise method, both EPR and MLR methods have R^2 values exceeding 99% for E, k_0, and m_v. Considering that RMSE calculates the sum of errors for each point relative to the constructed model, the lower the value, the better the result. According to Table 2, the lowest RMSE value in modeling output for parameter E corresponds to the MLR method, followed by EPR, and then the Stepwise method.

Table 2. the R^2 and RMSE of EPR, MLR, and Stepwise

	MLR		EPR		Stepwise	
	R^2	RMSE	R^2	RMSE	R^2	RMSE
E	99.996	135.87	99.54	466.33	82.2	5454.52
k_0	99.999	0.0011859	99.15	0.004653	94.7	0.001186
m_v	99.9	4.08E-07	99.44	9.15E-07	95.4	4.08E-07

4. Conclusions

In this study, regarding the reuse of HDPE waste in civil engineering projects to improve the properties of sand, leading to waste volume reduction and environmental pollution mitigation, a comparative investigation was conducted on the performance of statistical methods MLR, EPR, and Stepwise for predicting the results of geotechnical tests on sand-HDPE mixtures. The results indicate that the use of MLR and EPR methods, respectively, is feasible and desirable in predicting the geotechnical properties E, K_0, and m_v of sand-HDPE mixtures. However, the Stepwise method is not a suitable and accurate approach for use in predicting the behavioral model of sand-HDPE mixtures.