Improvement in CBR Value for Flexible Pavement Design Using Solid Waste: A Statistical Analysis with Confusion Matrix Evaluation

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ABSTRACT

In the present research work, an attempt is made to enhance the California Bearing Ratio (CBR) values of subgrade soils by using industrial waste materials such as fly ash (FA) and rice husk ash (RHA) with Artificial Neural Network (ANN)–based prediction to strengthen the reliability of pavement design decisions. Soil samples collected from varied locations were stabilized with 5%, 10%, and 15% FA and RHA, and evaluated through compaction and California Bearing Ratio (CBR) tests in both soaked and unsoaked conditions. To complement laboratory analysis, a classification-based ANN model was developed using the MATLAB Neural Network Toolbox, incorporating stabilizer type, dosage, MDD, OMC, and CBR as input parameters. The ANN predicted CBR category, cost reduction, and pavement thickness, while prediction accuracy was assessed using confusion matrices and associated performance metrics. Results showed significant improvement in CBR values with increasing stabilizer content, particularly with FA. The ANN model achieved high prediction accuracy, validating the consistency of experimental outcomes. The study demonstrates that combining experimental and ANN-based approaches provides a robust decision-support framework for soil stabilization and flexible pavement design.

Keywords—Flexible pavement design, soil stabilization, California Bearing Ratio, confusion matrix, statistical analysis, waste materials.

1. INTRODUCTION

Flexible pavement design relies on the value of California Bearing Ratio (CBR) of the soil subgrade as per the recommendations of the Indian Roads Congress (IRC) standards [1]. The CBR value is important in pavement design. In industrial areas like Durgapur, India—where subgrade soils have low CBR values close to 3%—designing the pavement layers with this CBR value may raise construction expenses, as there will be a requirement in construction of thick pavement. As a result, there is a need to apply soil stabilization methods that improve soil strength and aim for the sustainability.

Previous studies confirm the significance with established correlations between parameters of soil strength and CBR values [2], [3]. Dynamic Cone Penetrometer (DCP) research, for example, shows linear relationships with subgrade characteristics, providing other rapid field evaluation tools [4], [5]. Further, increasing the unavailability of natural stabilizers such as cement, lime has encouraged the interest in using industry by-products. FA's pozzolanic ability creates cementation compounds that improve the durability, whereas RHA's silica content improves soil strength. Both FA and RHA offers stabilization methods that are cost-effective and environmental friendly [6-8].

The use neural network model through the MATLAB's NN toolbox and confusion matrices thereafter enhances the validity of prediction [9-10]. Conventionally used in machine learning (ML), the tools measure predictive and analytical performance. This allows for the use of predictive models and data analysis in soil stabilization to eliminate design uncertainties and simplify sustainable infrastructure construction..

This study investigates the application of various industrial by-products and wastes, like fly ash (FA) and rice husk ash (RHA), as stabilizers of soil. FA is a by-product

obtained from thermal power plants, and RHA is an agricultural waste [11]. These materials, rich in silica, are richly available in India. Their addition in soils not only enhances strength properties but also mitigates the environmental issues related to disposal of waste. So, the stabilization of soil using FA and RHA provides economic and environmental problems in construction engineering.

Additionally in this study, a combined experimental-computational approach is adopted to evaluate the efficiency of FA and RHA in stabilizing local soils. Laboratory tests, including compaction and CBR analysis, form the experiential basis for performance assessment, while an ANN model using the MATLAB Neural Network Toolbox is used to predict CBR category, cost reduction, and pavement thickness. Confusion matrices, applied for classification, were used to classify pavement performance into low, medium, and high categories. An accurateness of 87.5% for prediction, and an improvement of 38.7% in CBR value is found. These results highlight the importance of statistical validation alongside the conventional testing framework. This study proves that FA and RHA improve soil properties while reaching the goals of waste disposal for sustainability. The combination of sustainable material use and predictive data analysis method, this study encourages cost-effective, and performance-based road construction methods for the industrial areas like Durgapur.

2. METHODOLOGY AND STATISTICAL FRAMEWORK

Laboratory tests were conducted on soil samples obtained from various locations in Durgapur and a point outside the city where different traffic conditions were found (Fig. 1). Stabilization of soil was achieved using fly ash (FA), rice husk ash (RHA), and cement, which were obtained from local hostels, a nearby village, and a building site, respectively. The procedure started with sieve analysis to find the grain size distribution of the soil, employing a dry method for coarse particles. To prepare the specimens, the soil was blended with respective percentages of the stabilizers, and water was added to obtain the Optimum Moisture Content (OMC) for Maximum Dry Density (MDD). The specimens were then compacted in a mold in three layers of 55 blows each, and afterwards the 2.5 kg and 5 kg loads were placed. These specimens were then tested to find California Bearing Ratio (CBR); some of the specimens were tested directly (unsoaked), while others were soaked in water for 96 hours for soaked CBR. The CBR value is basically the ratio between the pressure for 2.5 mm (or 5 mm) penetration into the sample under test condition to the pressure for the same amount of penetration for the standard crushed rock sample. This testing program is intended to compare the performance of various waste materials as the stabilizers on soil properties, used directly for road construction as well as design. Following the IRC guidelines, the performance of the tested soil was categorized into four groups based on its CBR value- Poor ($\leqslant$ 2%), Fair (>2% to $\leqslant$ 4%), Good (>4% to $\leqslant$ 7%), and Excellent (> 7%).

Using the MATLAB Neural Network (NN) Toolbox, an ANN-based prediction model was created to supplement and validate the experimental results. Three outputs- Final CBR, pavement thickness, and cost reduction- were predicted by the model using five important input parameters: stabilizer type, stabilizer %, MDD, OMC, and experimental CBR value (Fig. 2). A 70:15:15 split was used to train, validate, and test a feed-forward classification network. The toolkit automatically updated weights, assessed the model's learning efficiency, and adjusted the network architecture.

Confusion matrices created for every output class were used to evaluate the model's performance. These matrices made it possible to calculate accuracy, precision, recall, and F1-score by offering insight into real classifications as opposed to misclassifications. This thorough statistical analysis guaranteed that the ANN model could be used as a decision-support tool in conjunction with test results and accurately described the nonlinear behavior of stabilized soils.

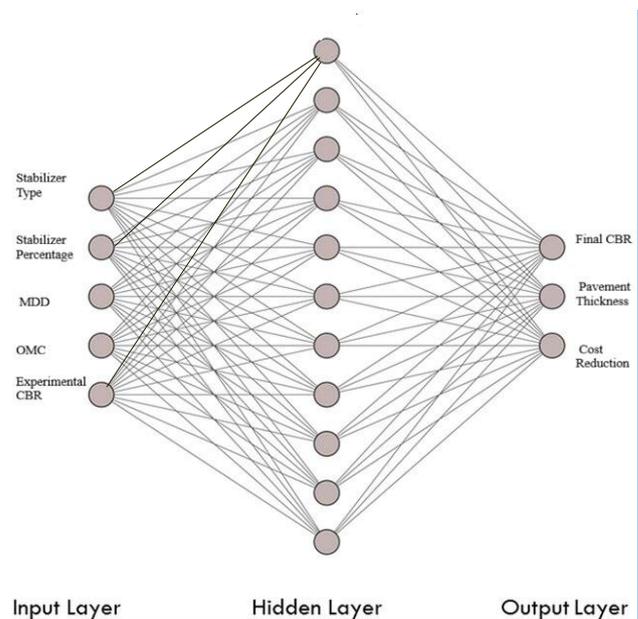FIG. 1 DIFFERENT SOIL SAMPLE

FIG. 2 ANN MODEL ARCHITECTURE

3. RESULTS

From the experimentally obtained data, we have found that fly ash (FA) and rice husk ash (RHA) when added with

soil, there is an improvement in. the CBR values (Table 1), and the optimum performance was attained when 15% FA was added, raising the CBR value from 3.1 to 4.3 and the performance category of the soil from "Fair" to "Good."

TABLE 1 CBR VALUES FOR DIFFERENT SOIL TREATMENTS

Soil Treatment	CBR Value	MDD (kN/m³)	OMC (%)	Performance Category
Natural Soil	3.1	17.2	19.0	Fair
Soil + 5% FA	3.6	17.5	18.5	Fair
Soil + 10% FA	4.2	17.8	18.2	Good
Soil + 15% FA	4.3	18.0	18.0	Good
Soil + 5% RHA	3.5	17.4	18.8	Fair
Soil + 10% RHA	3.9	17.6	18.5	Fair
Soil + 15% RHA	4.0	17.7	18.3	Fair

Although RHA improved the CBR value, the values obtained with addition of FA was slightly better. The maximum CBR value was obtained when 15% of RHA was added and the CBR value found was 4.0, which was still in the "Fair" class. The testing showed that the additions of FA have a better mean CBR improvement (22.3%) than the addition of RHA (16.8%). For enhancing the prediction and establish a framework for CBR value estimation, an Artificial Neural Network (ANN) model was developed using MATLAB's Neural Network Toolbox.

TABLE 2 MODEL ARCHITECTURE AND PARAMETERS

Parameter	Specification
Network Type	Feed-forward Backpropagation
Input Layer	6 neurons (FA%, RHA%, Initial CBR, OMC, MDD, Traffic Load)
Hidden Layer 1	15 neurons (Hyperbolic Tangent activation)
Hidden Layer 2	8 neurons (Hyperbolic Tangent activation)
Output Layer	3 neurons (Final CBR, Pavement Thickness, Cost Reduction)
Training Algorithm	Levenberg-Marquardt
Data Division	70% Training, 15% Validation, 15% Testing
Learning Rate	0.01
Maximum Epochs	1000

TABLE 3 PERFORMANCE OF ANN MODEL

Output Parameter	MSE	RMSE	MAE	R²
CBR Prediction	0.0156	0.125	0.098	0.967
Pavement Thickness	245.7	15.67	12.45	0.943
Cost Reduction	1.23	1.11	0.876	0.891

The model architecture and the statistical matrices are given in Table 2 and 3. The high R-squared values show model's excellent performance across all output parameters. The confusion matrix analysis demonstrated the ability to forecast correctly under different classifications (Table 4). The CBR category Forecast was 75% accurate, with a perfect 1.00 recall for "Good" soil performance prediction. The Treatment Precision was also very much accurate at 0.875, with a F1-Score of 0.909, demonstrating that the model is reliable in selecting effective treatments. The Pavement Design Requirements was also highly accurate at 0.875, confirming that the model could accurately classify the required pavement thickness.

TABLE 4 PERFORMANCE METRICS FOR DIFFERENT PERFORMANCE CATEGORIES

Performance Metrics	Performance Categories		
	Final CBR	Pavement Thickness	Cost Reduction
Accuracy (%)	75	87.5	87.5
Precision	0.8	0.875	0.892
Recall	1.0	0.9	0.875
F1	0.909	0.9	0.95

A regional comparison showed that although the Durgapur soil had a lower base CBR (3.1%), the incorporation of FA resulted in improvement of CBR of 38.7% against the 18.4% improvement for the external soil, a difference proven to be statistically significant (Table 5).

TABLE 5 REGIONAL COMPARISON OF CBR

Location	Base CBR (%)	Optimal FA Addition (%)	Final CBR (%)	Improvement (%)
Durgapur	3.1	15	4.3	38.7
External	3.8	10	4.5	18.4

Finally, the cost-benefit analysis brought out the effects of the results in practice (Table 6). The soil stabilization using 15% FA resulted in cost saving and reduction in thickness of pavement construction by 12.3%, while the addition of 15% RHA providing an 8.7% cost saving. This confirms that soil stabilization using these materials, especially fly ash, is a cost-saving approach for soil CBR improvement for flexible pavement construction.

TABLE 6 COST ANALYSIS FOR PAVEMENT THICKNESS

Treatment	CBR	Pavement Thickness (mm)	Cost Reduction (%)
Natural Soil	3.1	580	-
Soil + 15% FA	4.3	520	12.3
Soil + 15% RHA	4.0	540	8.7

4. DISCUSSION AND FUTURE SCOPE

Statistical analysis of the results proved the method and its utility. The confusion matrix showed high accuracy (87.5%) for effectiveness of soil treatment and in predicting pavement design requirements, showing the reliability of the method for quality control and decision making in practice. Although a moderate accuracy of 75% was achieved for CBR prediction, it shows that soil behaviour is complex and more research is required. The analysis also helped in establishing the optimum content of the stabilizers: 15% for FA and 10-15% for RHA.

Overall, both FA and RHA were found to be good stabilizers, with FA giving a better improvement of 38.7% in CBR compared to the RHA's 16.8%. The increased soil strength has a major economic and environmental advantage. It was discovered that the use of such stabilizers can minimize pavement thickness while doing the designing for construction by 8.7% to 12.3%, saving a lot of money and promotion of environment-friendly practices through the utilization of waste materials produced by the industries. The statistical model adopted in the study puts a solid foundation for further research, such as integrating machine learning for predictive modelling, long-term field verification, and

investigation of multiple combinations of waste materials to frame region-specific guidelines. Several areas for improvement and for the future scope of work are noted based on the performance of the present ANN model- More regional soil types have been added to the dataset, Modelling Time: Capacity to predict long-term performance, Integration of the Environment: Including the weather and seasonal factors.

The findings show that adding FA and RHA as soil stabilizers greatly improves subgrade soil's engineering qualities, especially the CBR values that are crucial for pavement construction. The improving trend is consistent with previous research demonstrating pozzolanic responses between FA/RHA components and soil minerals. Beyond laboratory testing, the ANN modeling offered an extra layer of validation. The network discovered the nonlinear relationships controlling soil behavior by utilizing stabilizer type, dosage, MDD, OMC, and CBR as input parameters. The selected input set successfully captures the major parameters determining soil performance, as evidenced by the strong alignment between experimental and ANN-predicted classes. The accuracy and dependability of the ANN are further validated by the confusion matrix study.

The model's ability to correctly classify both high-performing and low-performing stabilization treatments is indicated by high precision and recall values. This lowers uncertainty when making practical decisions, particularly when laboratory testing is difficult or time-consuming. This study's integrated experimental–computational methodology supports the applicability of ANN tools in geotechnical engineering. The ANN serves as a quick decision-support tool for soil stabilization projects by assessing both performance categories and pavement design classifications. Prediction consistency, automation, and reproducibility are guaranteed by using MATLAB's NN Toolbox.

5. ACKNOWLEDGMENT

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