*3rd International Conference on Advances in Civil and Environmental Engineering (ICACEE-2024)*

*University of Engineering & Technology Taxila, Pakistan*

*Conference dates: 21st and 22nd February 2024; ISBN: 978-969-23675-2-3*

# Applications of Artificial Neural Networks for the prediction of subgrade CBR values

**Muhammad Amaad Muzaffar[1,*], Mian Muhammad Jawad[1], Muhammad Dawood Mushtaq[1], Naveed Ahmad[1], Shaheera sharib[2]**

[1]Civil Engineering Department, University of Engineering and Technology, Taxila, Pakistan

[2]Communication & Works Department, Punjab, Pakistan

*Corresponding author: amaadrana665@gmail.com

## ABSTRACT

This study delves into the development of Artificial Neural Networks for predicting subgrade strength properties based on experimental data. Based on the validity and quality of soil tests, using ANN to predict CBR value may offer a suitable replacement for lengthy and expensive laboratory testing based on validated data for materials supplied from all over Pakistan. Key soil parameters like liquid limit (LL), plasticity index (PI), coarse content, fines content, optimum moisture content (OMC), and maximum dry density (MDD) serve as model inputs. The trained ANN models predict California bearing ratio (CBR), a crucial parameter for flexible pavement design. An optimized ANN model was built and evaluated in MATLAB using performance indicators like correlation coefficient, mean square error, and mean absolute error. The predicted CBR values are then compared to actual values, with the coefficient of determination ($R^2$) of 0.92 serving as the final validation metric. The close agreement between predicted and actual CBR values demonstrates the model's effectiveness. Furthermore, the study highlights the flexibility of ANNs by suggesting that altering input and output parameters can enable prediction of various other soil engineering properties.

**KEYWORDS:** Artificial Neural Network, Subgrade, California Bearing Ratio, Prediction Model

## 1 INTRODUCTION

Strong highways are a cornerstone of a nation's progress, reflecting both social and economic development. The subgrade, the road's foundation, plays a crucial role in its lifespan and performance. Variations in subgrade strength, influenced by factors like compaction, soil type, and moisture, can lead to uneven settlements and road damage. Accurately predicting subgrade behaviour is therefore essential for engineers [1-3].

The California Bearing Ratio (CBR) is the most common test characterising subgrade and unbounded pavement materials, being the ratio (expressed as a percentage) of the stress needed to penetrate a soil mass with a 50 mm diameter plunger at a rate of 1.25 mm/min to the stress needed for corresponding penetration of a standard material (normally defined as crushed stone [4]. Generally, the ratio is calculated at penetrations of 2.5 and 5 mm; while normally the ratio at 2.5 is considered, when that at 5 mm is reliably greater, the ratio at 5 mm is considered. The corrected load values (at 2.5, and 5mm penetration) are then extracted from the load penetration curve, and the CBR is determined using the following formula [4]

$$CBR = \frac{Applied\ Stress}{Standard\ Stress} \times 100\% \tag{1}$$

Artificial Neural Networks (ANNs), inspired by the human brain, have emerged as powerful tools in recent decades [5]. They offer an alternative to complex traditional methods for predicting and solving challenging engineering problems, including soil behaviour. ANNs excel at predicting soil engineering properties through a complex network of interconnected processing units called neurons. These neurons are organized in layers: input, hidden, and output. While input and output layers vary based on the number of parameters, hidden layers and their neurons are typically determined through trial-and-error [6].

Subgrade behaviour data is obtained from extensive laboratory testing of soil samples, forming datasets that capture soil variations under different design conditions. However, collecting, testing, and analysing these samples can be costly and time-consuming [7].

This research aims to establish a framework for developing an effective ANN model that leverages both the strengths and limitations of available data to predict specific aspects of subgrade soil behaviour. We utilize a multilayered feed-forward backpropagation (MFFBP) neural network implemented in MATLAB. This tool, with its adaptable input and output parameters, offers flexibility for researchers to tackle various complex engineering problems beyond subgrade prediction [8].

## 2 EXPERIMENTATION

### 2.1 Soil Database

In the current investigation approximately 100 test samples collected from Soil Mechanics Laboratory of UET Taxila were used. The important statistical parameters for the included soil parameters are given in table 1.

*Table 1 Statistical parameters of the datasets of soil*

| Parameters | Min. | Max. | Average |
|---|---|---|---|
| **M.D.D** (lb/cft) | 115 | 147.5 | 132.29 |
| **O.M.C** (%) | 5 | 18 | 9.08 |
| **L.L** (%) | 0 | 36.37 | 15.62 |
| **P.I** (%) | 0 | 16.12 | 4.38 |
| **Swell** (%) | 0 | 5.59 | 0.78 |
| **Coarse Sand** (%) | 16.85 | 100 | 72.49 |

| | | | |
|---|---|---|---|
| **Medium Sand** (%) | 1.85 | 100 | 65.5 |
| **Fine Sand** (%) | 0.56 | 100 | 57.27 |
| **Fines** (%) | 0.28 | 99.5 | 45.61 |
| **CBR** (%) | 2.2 | 76 | 27.45 |

## 3 DEVELOPMENT OF ANN MODEL

Human and animals' brain is composed of biological neurons interconnected together with axons and dendrites to perform specific functions related to response of the sensation to various environmental conditions. In the same analogy, ANNs simulate the key functions including estimation and approximation. These functions largely relay on sets of input and output parameters, which do not directly or clearly affect each other. However, with the excellent ability of ANNs in learning, generalizing, categorizing, and finally predicting values in response to their ability to adopt a new nature and remember the data or information provided to them. This action of adoption and remembering the information is done by training the specific ANN model.

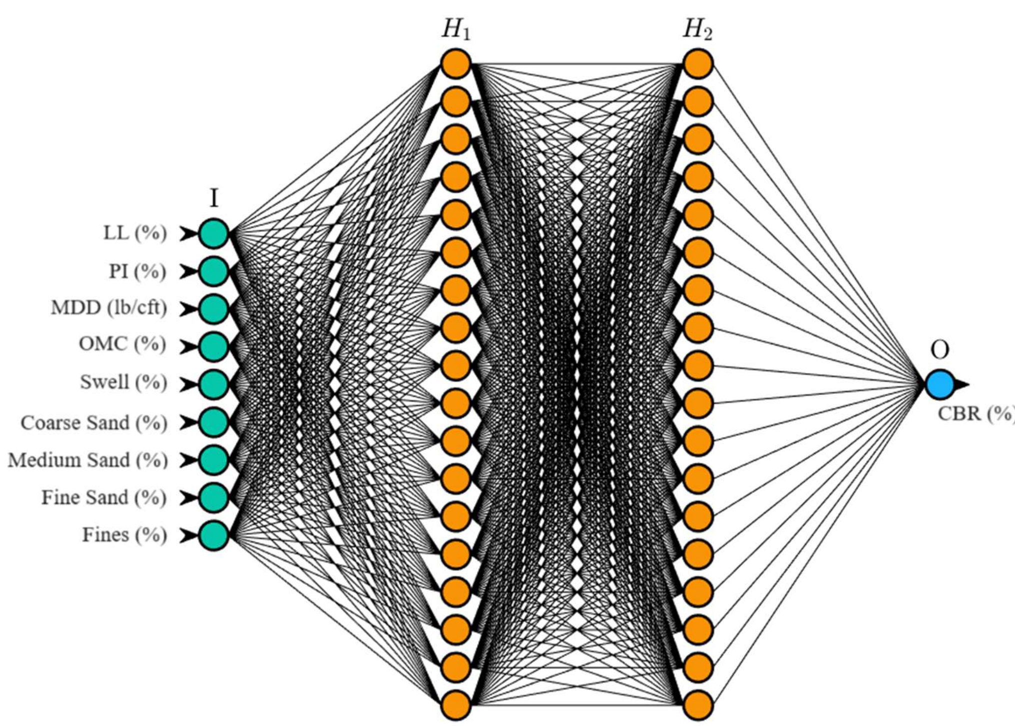


*Figure 1 ANN Structure*

In the current investigation, feedforward back propagation neural networks (FBPNN) are developed because of their absolute efficiency of computing the error by comparing the predicted output with the target values.

## 4 RESULTS AND OBSERVATIONS

The ANN model is developed based on 120 datasets of soaked CBR value determined experimentally in the laboratory containing nine (9) input parameters including coarse content, fine content, liquid limit (LL), plasticity index (PI), maximum dry density (MDD), optimum moisture content (OMC), swell percentage, and one output parameter which is CBR. MATLAB is used to develop the ANN model and division of database into TVT subsets. Figure 2 given below indicates the performance of TVT phases throughout the working of ANN model. Total 20 epochs have been reached for the complete training and learning of ANN model.

Figure 3 presented below includes four plots to illustrate the regression results of training, validation, and testing of ANN in MATLAB. One can easily observe and understand the performance of the training, validation, and testing (TVT) process using the fitting of the data around fitting line and correlation factor (R) values for each phase.

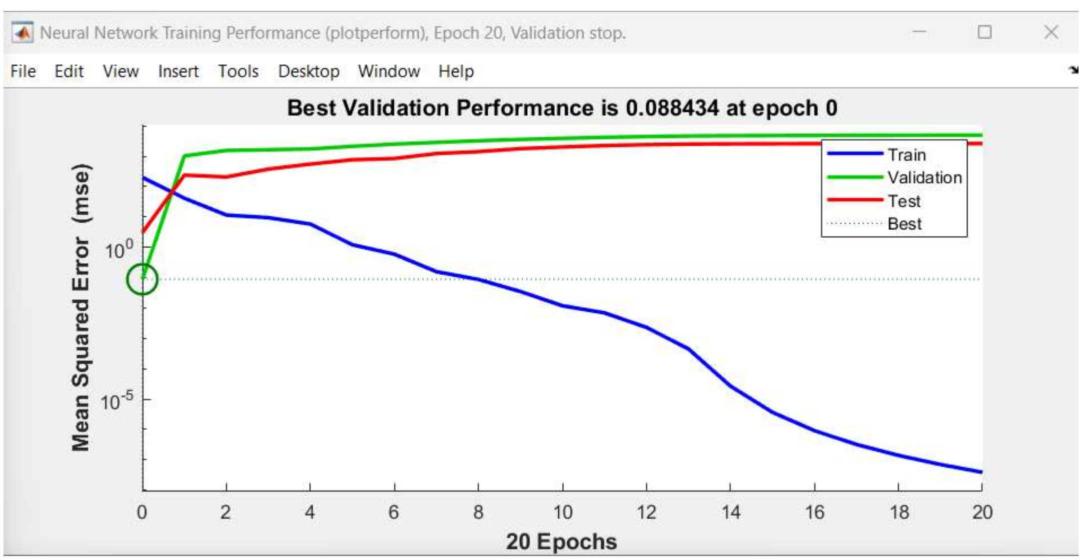


*Figure 2 Performance Plot of developed ANN Model*

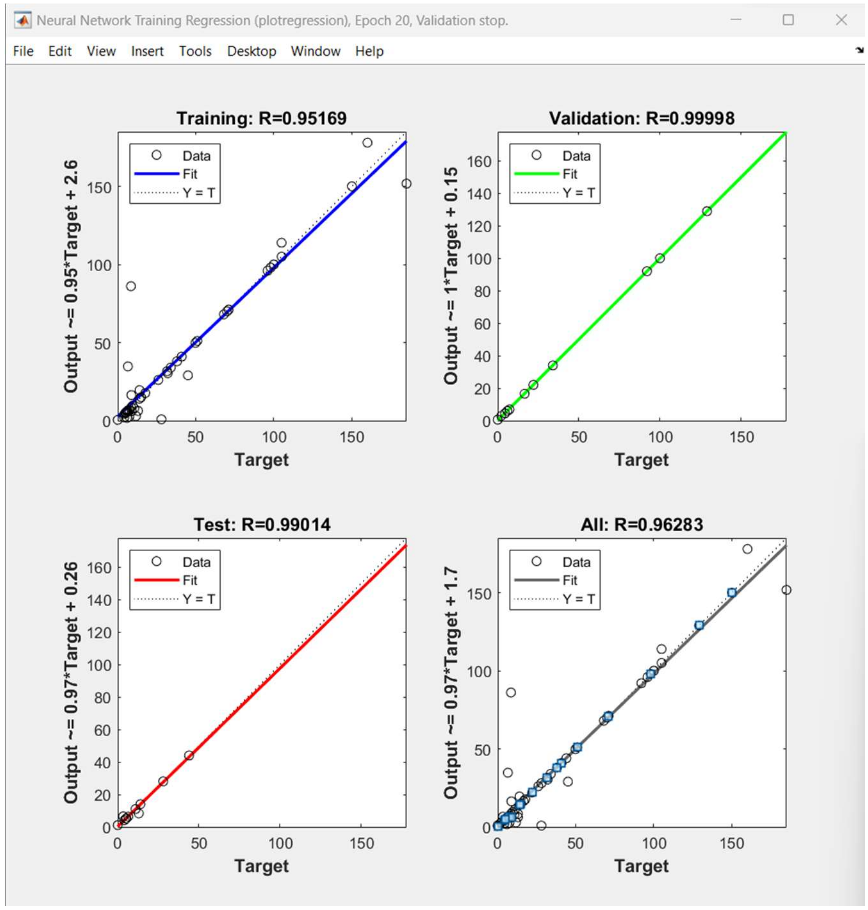


*Figure 3 Regression of developed ANN Model*

The output predicted by the developed ANN model for the CBR values is compared with target or experimental values of CBR calculated in the laboratory in this section. The optimization of ANN model is done using an additional indicators such as coefficient of determination ($R^2$) as shown in figure 4. The scattered plot with line of linearity or linear fitting line for the model between the target CBR at ordinate (y – axis ) and predicted CBR at abscissa (x-axis).

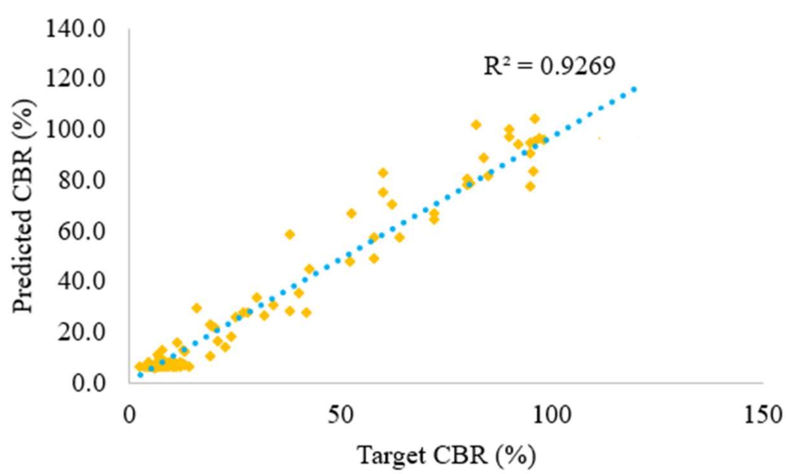


*Figure 4 Comparison of experimental CBR and ANN predicted CBR.*

The coefficient of determination ($R^2$) and coefficient of correlation values for the proposed ANN model are 0.92 and 0.96 respectively indicating the performance of our ANN model. The more the $R^2$ and R values are close to 1 indicates more accuracy of the prediction model as shown in figure 5 given below.

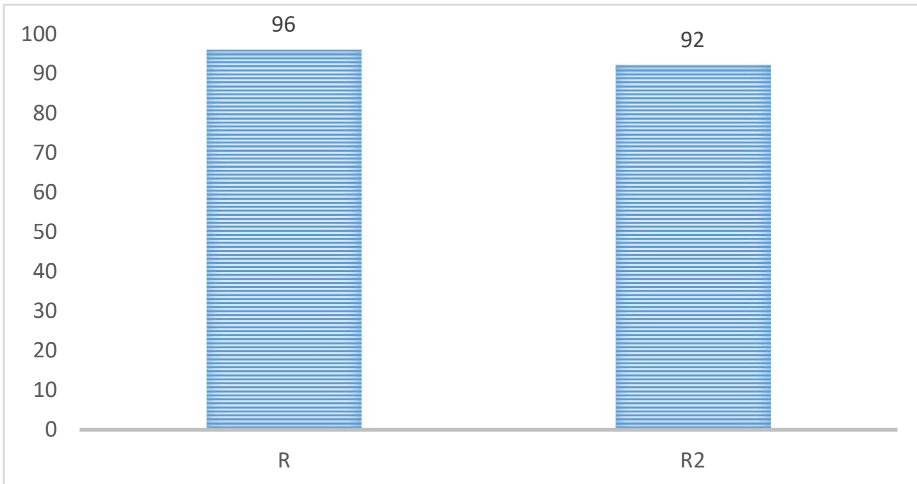


*Figure 5 The coefficient of determination ($R^2$) and Correlation factor (R) for the developed ANN model*

The other performance indicators adopted for evaluating the performance of the ANN model are mean square error and mean absolute error values. The more the values of MSE and MAE are close to zero, the more reliable performance of the developed ANN model. The values of MSE and MAE for the developed ANN model are shown in figure 6 given below.

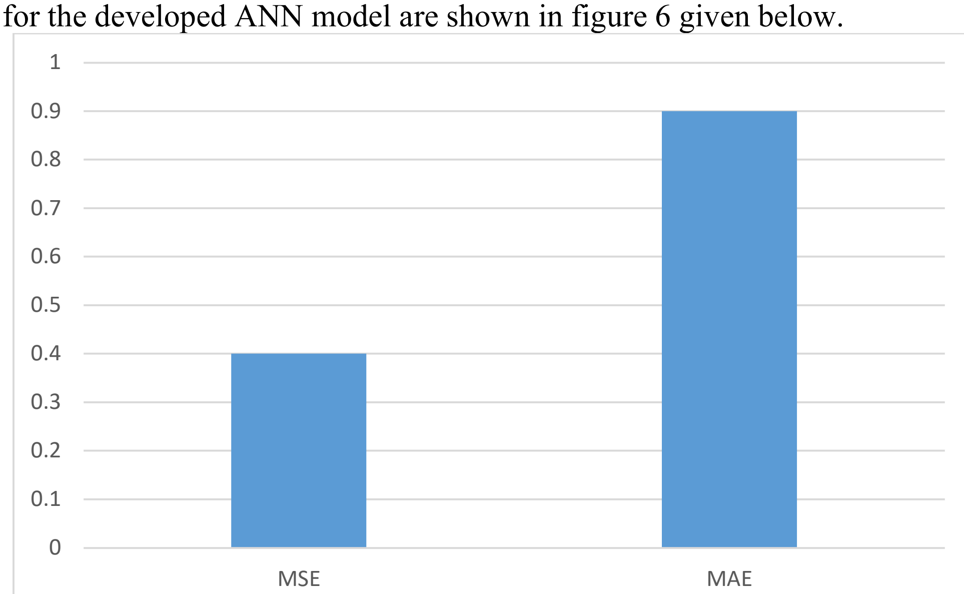


*Figure 6 MSE and MAE for the developed ANN model*

## 5 CONCLUSIONS

This study successfully developed an Artificial Neural Network (ANN) model capable of predicting subgrade California Bearing Ratio (CBR) values with high accuracy. The model utilized 120 datasets containing nine input parameters (soil properties) and one output parameter (CBR).

- The optimized ANN model demonstrated excellent performance with a coefficient of correlation (R) of 0.96, indicating strong accuracy of the prediction.
- The coefficient of determination (R2) of the proposed ANN model is 0.92, indicating its high performance. Figures illustrate the close alignment between target and predicted CBR values.
- Mean square error (MSE) and mean absolute error (MAE) are used as performance indicators. Smaller values of MSE and MAE indicate higher reliability in the developed ANN model's performance. In this study, MSE values was 0.4 and MAE was observed as 0.9.

## REFERENCES

1. Kim, S.-H., J. Yang, and J.-H. Jeong, *Prediction of subgrade resilient modulus using artificial neural network.* KSCE Journal of Civil Engineering, 2014. **18**: p. 1372-1379.
2. Park, H., G. Kweon, and S.R. Lee, *Prediction of resilient modulus of granular subgrade soils and subbase materials using artificial neural network.* Road Materials and Pavement Design, 2009. **10**(3): p. 647-665.
3. Zaman, M., et al., *Neural network modeling of resilient modulus using routine subgrade soil properties.* International Journal of Geomechanics, 2010. **10**(1): p. 1-12.
4. Zou, W.-l., et al., *Predicting resilient modulus of compacted subgrade soils under influences of freeze–thaw cycles and moisture using gene expression programming and artificial neural network approaches.* Transportation Geotechnics, 2021. **28**: p. 100520.
5. Hanandeh, S., A. Ardah, and M. Abu-Farsakh, *Using artificial neural network and genetics algorithm to estimate the resilient modulus for stabilized subgrade and propose new empirical formula.* Transportation Geotechnics, 2020. **24**: p. 100358.
6. Wang, X., et al., *Automated monitoring and evaluation of highway subgrade compaction quality using artificial neural networks.* Automation in Construction, 2023. **145**: p. 104663.
7. Nagaraju, T., et al. *Prediction of California bearing ratio of subgrade soils using artificial neural network principles*. in *Communication and Intelligent Systems: Proceedings of ICCIS 2020*. 2021. Springer.
8. Nazzal, M.D. and O. Tatari, *Evaluating the use of neural networks and genetic algorithms for prediction of subgrade resilient modulus.* International Journal of Pavement Engineering, 2013. **14**(4): p. 364-373.