PREDICTION OF CRITICAL HYDRAULIC GRADIENT USING ARTIFICIAL NEURAL NETWORK

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ABSTRACT: One of the main causes of failure of earthen embankments is by the process of soil erosion or piping. This type of failure is dangerous because there is no external evidence that the phenomenon is taking place. Small bubbles may appear on the surface of water few hours before the failure of the structure. The head of water above the soil which tends to disturb this equilibrium of soil causing piping is termed as critical head. Critical head divided by length of the sample gives the 'Critical Hydraulic gradient'. In this study, artificial neural network (ANN) algorithm is proposed for predicting the critical hydraulic gradient of soils. Critical hydraulic gradient is correlated to the easily measurable parameters like 'Field density', 'Water content', 'Percentage of Gravel', 'Percentage of Sand', 'Percentage of silt and clay' and 'Specific Gravity'. Soil samples were collected from different locations in Trivandrum, Kerala. Properties of each of the soil sample including the critical hydraulic gradient of the soil were determined in the laboratory. Artificial Neural Network modeled using MATLAB software can be employed as an alternative tool to laboratory methods for estimating critical hydraulic gradient of the soil.

KEYWORDS: artificial neural network, critical hydraulic gradient, piping, MATLAB.

1 INTRODUCTION

Piping, the internal erosion of soil caused by seepage is one of the undermining factors affecting the stability and long-term performance of earthen embankments. The initiation of the phenomenon is based on the hydraulic load acting on the soil which must exceeds the resistance of the soil. This is related to the critical hydraulic gradient at which effective stress of the soil becomes negligible. Soil may be carried off from under the structures which can result in its settlement. The term critical hydraulic gradient is important as it helps in identifying, by what level, water can rise above an earthen embankment or earthen structure. The condition can be corrected by lowering the head of water by underground drainage. For the structure to be stable its hydraulic gradient should be less than the critical hydraulic gradient. Number of researches are going on related to inclusion of fibers in soil to improve the seepage and piping resistance. A.K. Vasudevan and G. L. Sivakumar Babu [6] conducted a number of experiments to determine the seepage velocity and piping resistance of different types of soil mixed randomly with coir fibers. Fiber additions were found to reduce the seepage velocity and increase the piping resistance. J Raja and G L Siva Kumar Babu [3] studied the effect of seepage and piping resistance of fly ash mixed with plastic waste. Experiments revealed that the inclusion of fibers increased the piping resistance. J.V Reeba and Y.E Sheela [4] studied the effects of coir fibers and coir geotextiles on the piping behavior of pond ash. The UCC strength increased as the fiber content was increased. The seepage velocity was reduced and the piping resistance was found to be increased on addition of fiber. Roniya Roy and Sreekumar N R [5] studied the effect of organic soil and arecanut fiber on the piping behavior of sand. Mixing of organic soil with sand reduces the potential for piping erosion. Additions of fibers impart strength isotropy and reduce the formation of weak zones.

Artificial neural networks (ANN) are a family of statistical learning algorithms inspired by biological neural networks. The objective of a neural network is to compute output values from input values by some internal calculations. ANN in civil engineering problems is popular due to its reliable predictive capability in complex problems [1], [2]. They are not very different from statistical methods, it has the ability to develop a correlation based on the input and output data only. Simple structural analysis problem can be solved using the most popular form of neural networking system – feed forward network. Many studies have successfully used ANN for modeling soil properties and behavior. V. Rashidian and M. Hassanlourad have developed an ANN model to predict the mechanical behavior of different carbonate soils. Five input neurons were used to predict two output neurons with ten neurons in the hidden layer. Nisai Wanakule and Alaa Aly [7] have presented ANN as alternative models that are capable of providing accurate water level forecasts. In the current study, ANN has been implemented using MATLAB and its neural network toolbox.

The specific objective of the study is to develop an ANN model to relate the critical hydraulic gradient of the soil to its properties. Critical hydraulic gradient is related to the properties of the soil like field density, water content, percentage of Gravel, percentage of Sand, percentage of Silt&Clay and Specific Gravity. The developed model can be used as an alternate method to predict the value of critical hydraulic gradient of lateritic soils. 80:20 distribution models is used for training and testing the network**.** Additional tests are done to analyze the variation of critical hydraulic gradient with density and water content of the soil.

2 MATERIALS AND METHODOLOGY

2.1 Soil Properties

Fifty different soil samples (lateritic soil) were collected from different locations in Trivandrum. The field density and water content at each site were determined. The other parameters of the soil percentage of gravel, percentage of sand, percentage of silt and clay, Specific Gravity are also determined in the laboratory. Soil consists of a mixture of particles of different size, shape and mineralogy. The size of the particles has a significant effect on the soil behavior hence the grain size and grain size distribution are used to classify soils. The size distribution of gravel and sand particles are typically measured using sieve analysis. Soil retained on 4.75 mm is classified as Gravel, those passing through 4.75 mm but retained in 75 micron sieve is classified as Sand and those smaller than 75 micron is classified as Silt and Clay

Critical hydraulic gradient of the soil was determined in the laboratory by the experimental setup described in section 2.2

2.2 Experimental Setup

The apparatus used in the test are 1) Water reservoir 40 cm in diameter and 100 cm in height with an attached graduated scale to measure the level of water 2) The mould for the soil specimen having a diameter of 10 cm and height of 11.5cm. A porous stone is placed at the bottom of the mould.

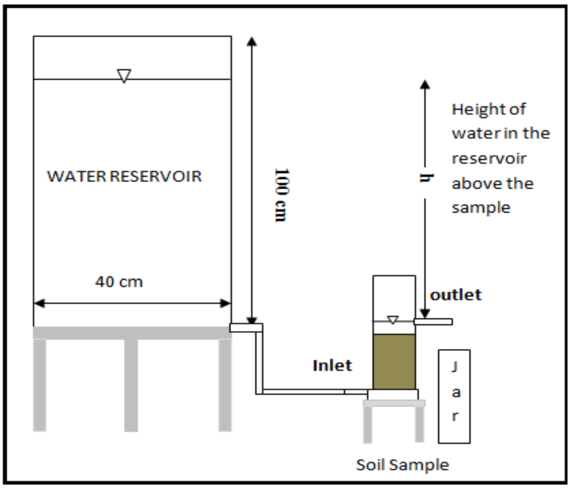

Fig 1- Experimental Setup (Not drawn to scale)

Each of the soil is filled in the mould to the density and the water content available in the field. The required weight of the soil was filled in the cylindrical mould in approximately three layers with uniform compaction at each layer. The upper half of the mould (with an outlet pipe) is fixed in place.

Fig 2- Cylindrical mould compacted with soil

The mould is then connected to the water reservoir. Water is permitted to flow through the sample in the upward direction. The soil will get saturated and the discharge will be collected through the outlet. The graduated scale on the reservoir helps to measure the head of water. Water is maintained at a particular level in the reservoir to permit steady flow through the outlet.

The experiment is continued by increasing the head of water until formation of bubbles or local boiling are observed through the top of the mould. The local boiling so observed is the piping failure in the soil. The head at which piping occurs is termed as the critical head (hc). Critical hydraulic gradient is obtained by dividing the critical head by the length of the sample.

$$i_c = hc/L$$

Fig 3- Mould connected to the water reservoir

Fig 4- Sample getting saturated

The soil test result obtained from the experiment is used to model the ANN. Field density, water content, % of Gravel, % of Sand, % of Silt and Clay, Specific Gravity are used to predict the critical hydraulic gradient of the soil. The test data is divided into two parts using 80:20 mode of distribution. Eighty percentage of the data is used for training the neurons to develop the model and the remaining data is used for testing. After training, the trained model is used to test the remaining twenty percentage data. The predicted value of critical hydraulic gradient from ANN is compared with the actual value obtained from the experimental result. A graph is plotted between the predicted and actual values, to check the percentage variation.

3 RESULTS AND DISCUSSIONS

Figure 5 shows the variation of Critical Hydraulic gradient with percentage of Gravel. For all the samples collected, the percentage of Silt and Clay was very less (Maximum 4%, Average 1.16%), so the particle size composition would be either Gravel or Sand.

For samples where the gravel percentage was more (left portion of graph), the critical hydraulic gradient was found to be high. Average value of critical hydraulic gradient on the left side of the graph is 8.2. As the gravel percentage reduced, the critical hydraulic gradient also seemed to decline till about 50% Gravel. As the percentage of Sand increased (towards the right portion of the graph), there was no direct increase or decrease. On an average, there is decrease in hydraulic gradient as the sand particle size increases. Average value of critical hydraulic gradient was 4.9.

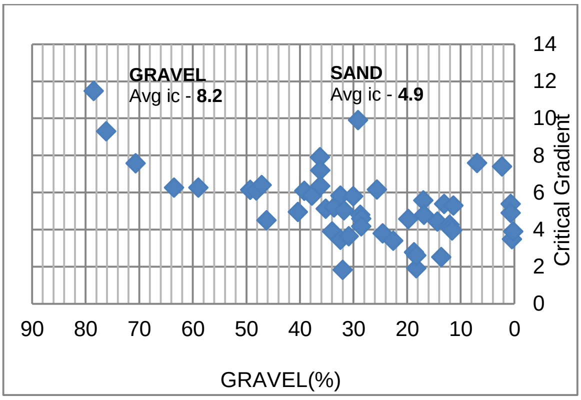

Fig 5 – % Gravel Vs Critical Hydraulic Gradient

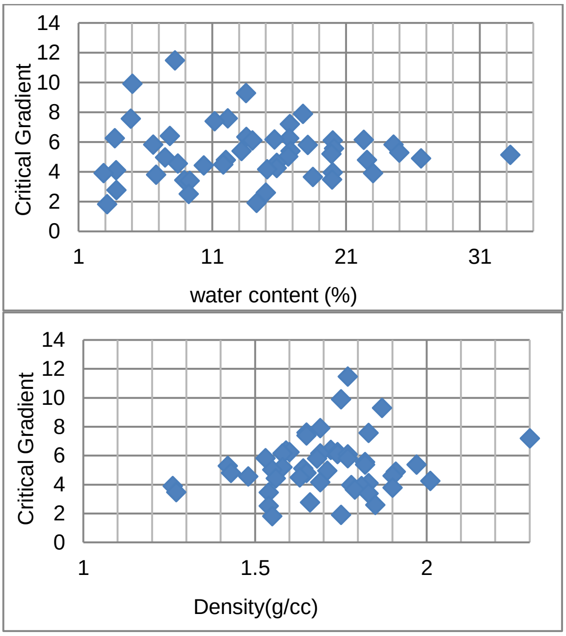

Fig 6 -Variation of Critical Hydraulic Gradient with Density and Water content

Figure 6 shows the variation of critical hydraulic gradient with Density and Water content. From the graph, it is very clear that critical hydraulic gradient is not the maximum for the sample with maximum density. Also, critical hydraulic gradient is not the maximum for the sample with maximum water content.

For the same soil sample, if the density with which soil is compacted is higher, the height of water which rises above the soil sample to cause the piping phenomenon was found to be higher. Thus the critical hydraulic gradient was higher. Figure 7 shows the variation of critical hydraulic gradient with density.

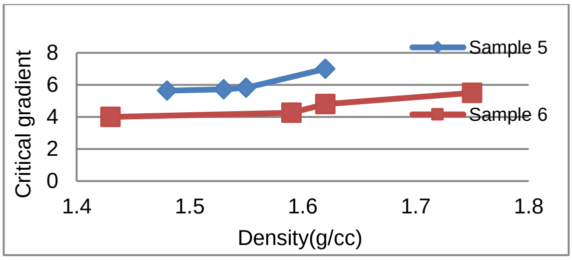

Fig. 7 – Density Vs Critical Hydraulic gradient

Critical hydraulic gradient was first found to increase with increase in water content and then decrease beyond the optimum moisture content of the soil. Figure 8 shows the variation of critical hydraulic gradient with water content.

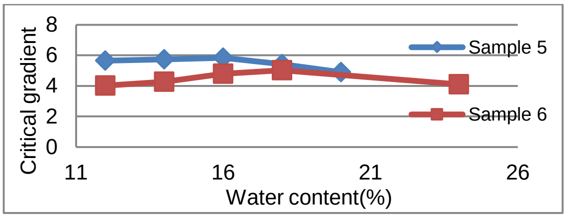

Fig 8 – Water content Vs Critical Hydraulic gradient

ANN using MATLAB with feed forward network was used to create a model with six input parameters (Field density, Watercontent, Percentage of Gravel, Percentage of Sand, Percentage of Silt & Clay, and Specific Gravity) and Critical hydraulic gradient as the output parameter. The number of neurons chosen was ten for 2 hidden layers. Thus the model chosen was 6-2-1. The newly created model with eighty percentage trained data was used for testing the remaining twenty percentage data. Figure 10 shows the variation between predicted values from the ANN model and the actual values obtained from the experiment. The average error between the actual and predicted values was close to 0.396 and the R^2 value of the model was close to 0.96.

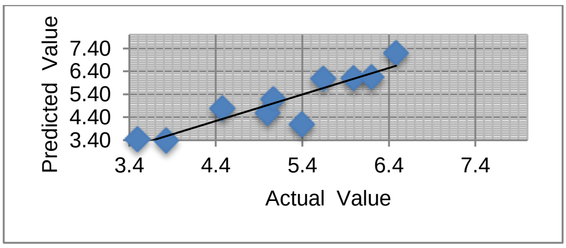

Fig 10 – Predicted vs Actual Data

4 CONCLUSION

Particle size is an important parameter which determines the critical hydraulic gradient. Soil having particle size as Gravel is found to have a greater value of critical hydraulic gradient compared to sandy soil particles. Critical hydraulic gradient is not maximum for the sample with maximum density or maximum water content. Combination of density and water content greatly influence the critical value of hydraulic gradient. Keeping the water content constant and increasing the density, critical hydraulic gradient was found to increase. With an increase in water content, critical hydraulic gradient increased till the optimum moisture content of the soil and then decreased. An ANN model 6-2-1 was developed using MATLAB to predict the critical hydraulic gradient with eighty percentage of the collected data. The best fitting model had input parameters as Field Density, Water content in the field, percentage of Gravel, percentage of Sand, percentage of Silt and Clay and the Specific gravity. The ANN model developed with the eighty percentage data was validated using the remaining twenty percentage data. The R^2 value of the model was 0.96 and the average error between the observed and the predicted value was 0.396.

REFERENCES

[1] Flood, I., Kartam, N. (1994) 'Neural Networks in Civil Engineering. I: Principles and Understanding.' *J. Comput. Civ. Eng.*, ASCE, 8(2), pp131-148.

[2] Flood, I., Kartam, N. (1994) 'Neural Networks in Civil Engineering. II: Systems and Application.' *J. Comput. Civ. Eng.*, ASCE, 8(2), pp149-162.

[3] Raja, J., Siva Kumar Babu, G. L. (2011). 'Piping and seepage resistance of fly ash mixed with plastic waste.' *Proceedings of Indian Geotechnical Conference.*, 15 Dec – 17 Dec. 2011, Kochi.

[4] Reeba, J. V., Sheela, Y. E. (2015). 'Seepage and Piping analysis of Pond ash reinforced with Coir fibers and Coir geotextiles.' *50th Indian Geotechnical Conference.*, 17 Dec – 19 Dec.2015, Pune

[5] Roy, Roniya. , Sreekumar N.R (2016). 'Effect of Organic Soil and arecanut fiber on the piping behavior of sand.' *International Journal of Advanced Research Trends in Engineering and Technology., IJARTET*, Volume 3, Special Issue 23.

[6] Sivakumar Babu, G., Vasudevan, A. (2008). 'Seepage Velocity and Piping Resistance of Coir Fiber Mixed Soils.' *J. Irrig. Drain Eng.*, ASCE, 134(4), pp485-492

[7] Wanakule, N., Aly, A. (2005). 'Artificial Neural Networks for Forecasting Groundwater Levels.' *Computing in Civil Engineering.* ASCE, pp1-10.