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ARTIFICIAL NEURAL NETWORK PERMEABILITY MODELING OF SOIL BLENDED WITH FLY ASH

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ABSTRACT: The determination of the permeability properties of soil is important in designing civil engineering projects where the flow of water through soil is a concern. ASTM D2434 Standard Test Method for Permeability of Granular Soils (Constant Head & Falling Head) is being followed to determine the vertical permeability, while for horizontal permeability, there are none. In this study, tests such as Atterberg limit, relative density tests, and particle size analyses are done to determine the index properties of soil blended with fly ash. Subsequently, microscopic characterizations tests, elemental composition tests and permeability tests are done to determine the chemical and physical properties of the soil mixes. A new permeability set-up was used in determining the horizontal permeability soil mixes. Data were extracted during the experiment and a relationship between the properties of soil and the permeability was established. An artificial neural network model was used to predict the coefficient of permeability when the percentage of fly ash is available.

Keywords: Permeability, artificial neural network, modeling, fly ash, waste utilization

1. INTRODUCTION

It is very important for engineers to understand the soil underneath because it will affect the way the structures are designed. Without its knowledge, lives would be at stake and it can reveal a lot of information by just analyzing the soil profile of a certain area.

Geotechnical properties of the soil (grain size distribution, Atterberg limits, specific gravity, maximum and minimum index densities, soil classification, permeability, shear strength and compressibility) should be considered by engineers when designing foundation, retaining walls, etc. but these properties change over time and are influenced by physical content, climate and weather.

Permeability generally relates to the propensity of a soil to allow fluid to move through its void spaces [1] and is vital to every project where the flow of water through soil is a concern.

Coal-fired power plants discharge large amounts of fly ash as waste but only half of them are used and the remaining half is trashed to land and sea, its disposal became an environmental concern, there are also local studies in the Philippines that shows the effect of wastes to the environment [2]-[4]. The utilization of fly ash may be a viable alternative for porous backfill material because fly ashes generally consist of silt-sized particles and consequently possess high permeability [5] but tests must be done to determine the permeability [6] of soil-fly ash mixture since there was a lack of information on the horizontal permeability of the said mixes.

2. METHODOLOGY

Fly ashes generally consist of silt-sized particles and consequently possess high permeability as mentioned by Prashanth (2001) [5].

Shown on Table 1 are the soil mixtures that were checked on the effect of fly ash on soil.

Table 1. Soil Mixtures

Soil Mixture	Fly Ash (%)	Soil (%)
100FA	100	0
75FA25S	75	25
50FA50S	50	50
25FA75S	25	75
100S	0	100

The density of the soil mixtures were determined using ASTM D854 [7], which is the standard for the specific gravity tests. In determining the Liquid Limit, Plastic Limit and the Plasticity Index of the soil mixtures, Atterberg limit tests based on ASTM D4318 was used [8]. Furthermore, the maximum (e_{max}) and minimum (e_{min}) index densities for soil mixtures was discerned using the ASTM D4253 [9] and ASTM D4254 [10], respectively. Then the particle size analyses using ASTM D422 was utilized to determine the percentage of different grain sizes in a soil [11].

Scanning electron microscopy (SEM) with energy dispersive X-ray spectroscopy (SEM/EDX) is the best known of the surface analytical techniques for different materials. The scanning electron microscopy (SEM) was used to evaluate the microscopic characterization of each soil mixture which produces high resolution images of surface topography, while Energy Dispersive X-ray Spectroscopy (EDX is used to determine the chemical composition of the soil and gives information on the elements present in the soil mixture.

The permeability of the different soil mixes were determined by the constant head test method and falling head test method. The direction of the flow weas also considered, thus, vertical and horizontal orientations of permeameter were used. A proposed set-up by Smith (2010) [12] for permeameter was used and modified to determine the horizontal permeability of the soil mixtures, shown on Fig. 1. The equation utilized for the permeability set-up is Eq. 1.

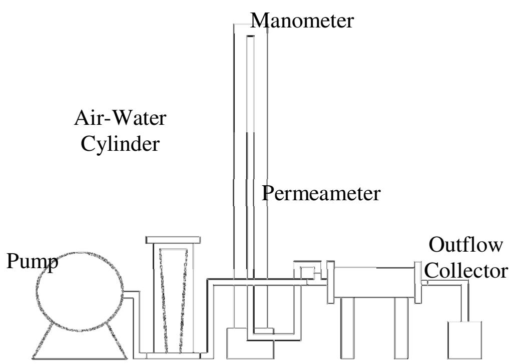

Fig. 1. Horizontal Permeability Set-up

$$\boldsymbol{k = \frac{Ql}{Aht}} \tag{1}$$

where:

k = coefficient of permeability, cm/s;
Q = quantity (volume) of water discharged during test, cm^3;
l = length between manometer outlets, cm;
A = cross-sectional area of specimen, cm^2;
h = head (difference in manometer levels) during test, cm;
t = time required for quantity Q to be discharged during test, s.

Many numerical modeling techniques have been introduced in the current technological era, and one of them is Artificial Neural Network (ANN). Artificial Neural Network can handle non-linear relationships between variables and incomplete data sets [13]. The proposed Artificial Neural Network Model will be validated by involving a 45-degree line as a guideline that provides insight into the measured variables and as a critical part of the analysis.

3. RESULTS AND DISCUSSIONS

3.1 Index Properties

Using ASTM D854 the specific gravity of each soil blend was determined. The specific gravity of the soil mixtures was reduced by the addition of fly ash [14] since the usual of the specific gravity of fly ash is much lower compared with the soil. Shown on Table 2, we can complement the study of Prabakar (2004) that the addition of fly ash (due to the light weight property of fly ash) reduces the specific gravity of a soil mixture.

Table 2. Summary of Specific Gravity

Soil Mixture	G_s
100FA	2.02
75FA25S	2.11
50FA50S	2.31
25FA75S	2.49
100S	2.58

Fly ash is considered as silt material, it is expected to have a plasticity index less than 1 based on stablished literatures [14], thus, by adding fly ash in the mixture has reduced the plasticity of a soil mixture. Results are shown in Table 3.

Table 3. Summary of Atterberg Limits

Soil Mixture	LL	PL	PI
100FA	66	65	1
75FA25S	64	57	7
50FA50S	61	49	12
25FA75S	59	45	14
100S	52	32	20

It can be noticed from Table 4, the Maximum Void Ratio (e_{max}) ranges from 1.78 to 1.99 because the fine contents of the fly ash contributed to the percentage of voids. 100S has the lowest value while 100FA has the highest, also from Table 4, 100S has the lowest fines content, while 100FA garners the highest. Their fines content and microfabric may have contributed to the minimum and maximum void ratio. These minimum and maximum void ratios together with the target relative density of 90% were used to determine the void ratio to be utilized for the permeability specimens.

To determine the maximum and minimum void ratios of the different soil-fly ash mixes ASTM D4253 and ASTM D4254 were used.

100FA has the greatest percentage of fines compared with other mixtures. Fly ash and soil are considered fines but the classification differ, fly ash is silt and soil is plastic. It can also be noticed that when fly ash is mixed with other soils increases the fines content. The summary of results from the particle size analyses are shown on Table 5.

Table 3. Summary of e_{min} and e_{max}

Soil Mixture	e_{min}	e_{max}
100FA	0.27	1.99
75FA25S	0.37	1.98
50FA50S	0.47	1.94
25FA75S	0.72	1.93
100S	0.84	1.78

Table 5. Summary of Particle Size Analysis Results

Soil Blend	% Passing #200	D_{10}	D_{30}	D_{60}
100F	61.83	0.029	0.03	0.04
75FA25S	50.78	0.019	0.032	0.06
50FA50S	29.79	0.032	0.0375	0.12
25FA75S	25.79	0.015	0.042	0.15
100S	21.84	0.01	0.4	1.2

3.2 SEM/EDX Results

In the Energy Dispersive X-ray Spectroscopy (EDX), chemical composition of soil is determined to give information on the element present in the soil, shown in Table 6. Oxygen (O) is very abundant, followed by Silicon (for Silty Sand) and Calcium (for Fly Ash). Silicon and Calcium are predominant in the soil elemental composition. Due to the presence of Oxygen and other dominant elements: Silica (from Silicon), Lime (from Calcium) and Alumina (from Aluminum) are the dominant minerals in the soil sample.

Table 6. Summary of Elemental Composition

Element	Composition (%) for Silty Sand	Composition (%) for Fly Ash
C, Carbon	17.39	5.41
O, Oxygen	46.65	40.64
Al, Aluminum	11.52	5.26
Si, Silicon	15.63	9.1
K, Potassium	1.05	0.78
Ca, Calcium	0.24	21.82
Fe, Iron	5.72	16.34
Cu, Copper	1.8	0.26
S, Sulfur	0	0.39

Most of the soil properties and characteristics like strength, compressibility and permeability are ascribed by its microfabric or microstructure. To evaluate the microfabric of soil, fly ash, the scanning electron microscopy (SEM) was used. Scanning electron microscopy (SEM) with energy dispersive X-ray spectroscopy (SEM/EDX) is the best known of the surface analytical techniques. High resolution images of surface topography of the different soil mixtures were produced using these tests. Pure soil and Fly Ash were initially tested to check their microscopic characteristics, mixed soils were also tested thereafter.

A combination of extremely strandy grains, large angular grains and abundant silt grains formed the micro fabric of 100S. It is well-graded microscopically and the silt grains have a rough surface. A smaller inter-particle voids were created by the smaller particles tend to fill the voids created by the larger particles shown in Figure 1. Looking closer to magnification of 1000x and 5000x, strand-like particles are present, his indicates that these elongated particles also fill the voids, giving small passageways for water to permeate.

While for 100F, it is a combination of larger silt grains and smaller silt grains to form the micro fabric normally 0.002-0.05 mm in size. Compared with silty sand (soil), particles have almost similar size, forming larger inter-particle void that allows water to pass through. On the 1000x and 5000x magnification, the surface of the particle is not smooth, this create passageway/voids for water to pass through.

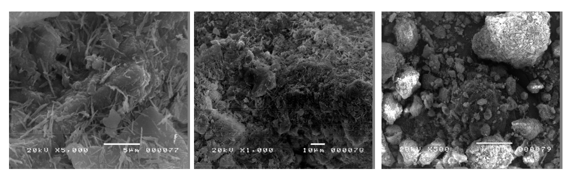

Fig. 1. Microfabric of 100S (5000x, 1000x and 500x Magnification)

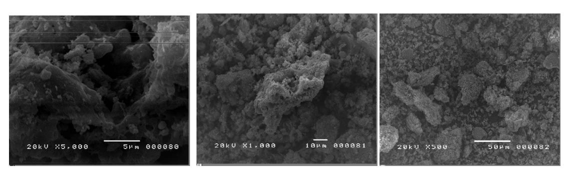

Fig. 2. Microfabric of 100FA (5000x, 1000x and 500x Magnification)

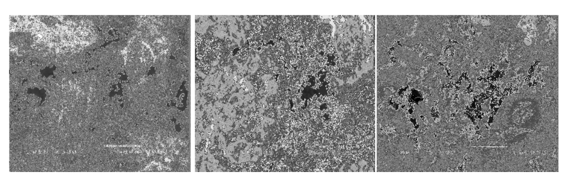

Fig. 3. Microfabric of 50FA50S (5000x, 1000x and 500x Magnification)

A combination of extremely strandy grains, large angular grains and abundant larger silt grains and smaller silt grains formed the micro fabric of 50FA50S. Looking closer to magnification of 1000x and 5000x, strand-like particles are present but noy prevalent compared with the pure soil, the soil particles may contribute to the reduction of permeability but the silt grains of fly ash will counteract to allow water to drain faster.

3.3 Permeability

The study of Smith (2010) [15] and was modified to determine the horizontal permeability of the soil mixtures. Shown in Table 7, are the range of permeability values gathered for the vertical oriented constant head permeability test, to determine the effect of fly ash when added to soil, a box and whisker plot is delineated, shown on Figure 4.

A proposed approach in determining the vertical permeability of the various soil mixtures was utilized, it was referred on. The results of the experiment agrees with the study of Prashanth (2001) that fly ashes generally consist of silt-sized particles and consequently possess high permeability since it is prevalent that the permeability is increased when the amount of fly ash is increased. Thus, the amount of fly ash increase the permeability of the soil mixes.

Table 7. Range of permeability values for vertical oriented permeability test

Soil Mixture	Minimum k, cm/s	Maximum k, cm/s
100FA	4.53E-05	5.52E-05
75FA25S	3.40E-05	3.80E-05
50FA50S	2.55E-05	3.16E-05
25FA75S	2.05E-05	2.51E-05
100S	1.47E-05	2.09E-05

In determining how long the contaminated water will penetrate the ground water, the horizontal permeability of soil mixtures shall be considered. Shown in Table 8, are the range of permeability values gathered for the horizontal oriented constant head permeability test. To determine the effect of fly ash in the horizontal permeability when added to soil, a box and whisker plot was drawn and shown on Figure 5. The data garnered in this study agree with the study of Das (2008) [16], that the horizontal permeability values are larger than the vertical permeability values, this is due to the pressure head induced during the permeability test. The specimen is laid in a horizontal position, which experiences no pressure drop within its body, unlike the vertical specimen, which experiences pressure drop, resulting to a slower flow of water.

Table 8. Range of permeability values for horizontal oriented permeability test

Soil Mixture	Minimum k, cm/s	Maximum k, cm/s
100FA	6.02E-05	7.28E-05
75FA25S	4.25E-05	5.02E-05
50FA50S	3.40E-05	4.04E-05
25FA75S	3.04E-05	3.70E-05
100S	2.21E-05	2.70E-05

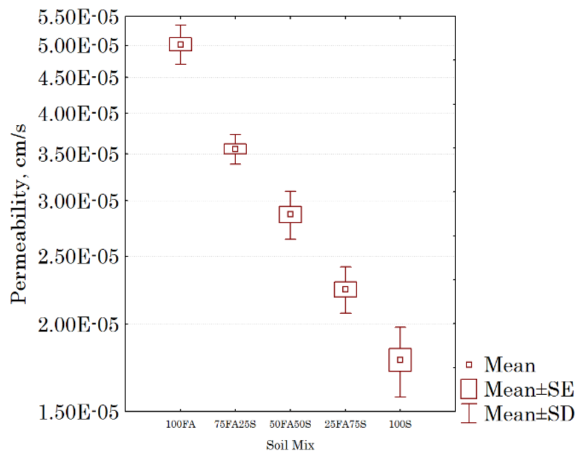

Fig. 4. Effect of fly ash on the vertical permeability when added to soil

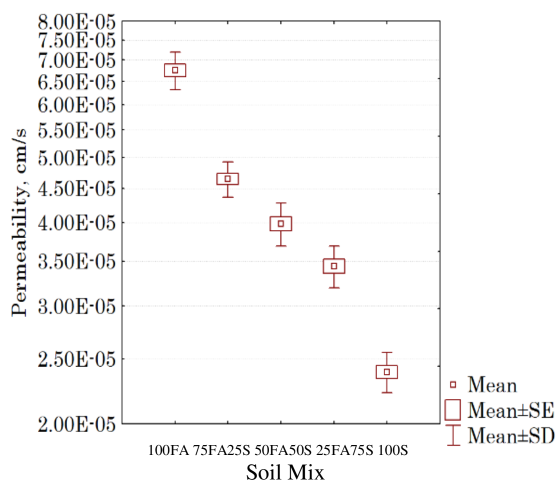

Fig. 5. Effect of fly ash on the horizontal permeability when added to soil

Fly ash is the recommended addition to the soil mixtures since waste materials are aimed to be utilized and the addition of fly ash, which has a combination of larger silt grains and smaller silt grains to form the micro fabric prevalent to the microscopic characterization test for 100F, to soils changes the inter-particle void ratio [14]

Subsequently, silt particles have almost similar size, forming larger inter-particle void, contributing to a much larger inter-particle voids, thus, the permeability of pure fly-ash ranges: (1) vertical oriented 4.51x10^{-05} cm/s to 5.35x10^{-05} cm/s and (2) horizontal oriented 1.93x10^{-05} cm/s to 7.29x10^{-05} cm/s.

75FA25S, 50FA50S, 25FA75S, 96S4FA are the mixtures that include fly ash and soil, their microfabric is a combination of extremely strandy grains, large angular grains and abundant larger rough-surfaced silt grains and smaller rough-surfaced silt grains. Evidently shown on Figure 4 and Figure 5, as the amount of fly ash is increased, the drainage also increased. Due to the contribution of fly ash to the inter-particle voids of the soil mixtures, the permeability of mixture of soil and fly-ash ranges: (1) vertical oriented 1.93x10^{-05} cm/s to 3.80x10^{-05} cm/s and (2) horizontal oriented 2.52x10^{-05} cm/s to 5.02x10^{-05} cm/s.

To validate the results of the vertical oriented and the horizontal oriented permeability tests, their ratio must be within the given range of Das (2008). The collected usual ratio of horizontal and vertical permeability of soils by Das (2008) is with the range of 1.2-3.3, thus, the data gathered are between 1.3-1.5, thus, ratios are within Das' desired range.

3.4 Artificial Neural Network

In the Artificial Neural Network Model, five (5) variables were considered:

1. The percentage of added fly ash in the soil
2. Specific gravity
3. Liquid Limit
4. Maximum Void Ratio
5. Minimum Void Ratio

The data garnered were divided into three (3) groups: 70% for training the neural network, 15% for validation and 15% for testing. In the hidden layer, tan-sigmoid transformation function was utilized, while in the output layer a linear transformation function was used. The feed-forward backpropagation technique was used to generate the best model for estimating the permeability of the soil mixtures. Also, fastest backpropagation algorithm and highly recommended Levenberg-Marquardt network training function was also employed. The authors utilized Matlab for the ANN Algorithm.

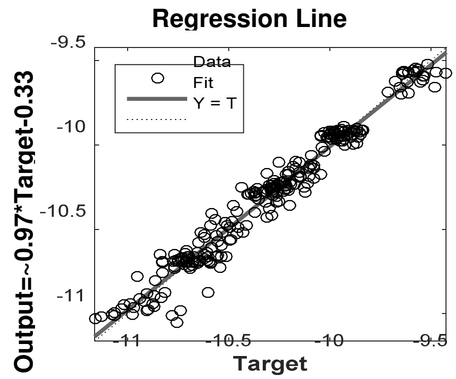

Fig 6. Regression Line for ANN Structure 5-9-2

By determining the number of neurons in the input and output layers, number of hidden layers and the number of neurons in each hidden layer, the best Artificial Neural Network model for the soil mixtures can be garnered. Thus, after numerous trial the ANN structure 5-9-2 (5 input, 9-nodes and 2 output) was determined to be the best model to estimate the permeability of the soil mixtures. The model was able to give an acceptable values of R: 0.98414, 0.97570, and 0.96843 for validation, training and testing, respectively. Figure 6, represents the regression line for ANN 5-9-2. Also, the 45deg line shows a validation and an agreement between the experimental (actual) and the predicted parameters. Subsequently, Figure 7 shows the performance curve of the ANN model, the mean squared error is 0.0061175 and occurred at epoch 25.

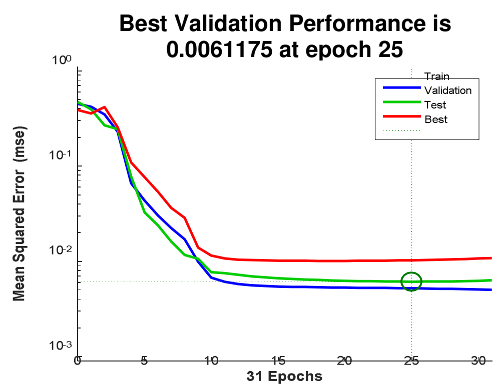

Fig. 7. Best validation performance of the model

There are many studies that provided a numerical approach in determining the permeability when the amount of fly ash is available [17],[18]. The permeability coefficient was further compared with a regression model. The said regression model gave an R^2 value of 0.9335 which is lower compared to calculated R^2

value of the ANN method for validation 0.9685, 0.9520, and 0.9379 for validation, training and testing, respectively.

4. CONCLUSION AND RECOMMENDATIONS

The addition of fly ash to soils changes the inter-particle void ratio [5], it increases the permeability, thus, the microscopic characteristics of the soil mixtures may contribute to the increase in permeability. Based on the tests, fly ash is a combination of larger silt grains and smaller silt grains to form the micro fabric. Silt particles have almost similar size, forming larger inter-particle void, contributing to a much larger inter-particle voids.

ANN Structure 5-9-2 is the best architecture since it has the highest correlation coefficient, R^2, and the said model has a good predicting ability compared with previous studies. To improve the results, extensive manipulation of parameters should also be considered. Sensitivity analyses may be conducted to further validate the model and the results.

Furthermore, it is recommended for the purpose of ground improvement engineering, testing the shear strength and the compressibility of the soil mixtures should be determined and relate them to the permeability.

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