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RELIABILITY ANALYSIS OF FIBER-REINFORCED COHESIVE SOIL'S UCS BEHAVIOR

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Abstract:

In this study, the use of steel fibers in addition to chemical stabilization for stabilizing expansive soil is analyzed and evaluated. The goal of this research is to determine how effectively these fibers and lime are able to reduce the expansive nature of the soil by enhancing its Unconfined Compressive Strength (UCS) behavior. The UCS of an expansive soil was studied under different conditions, including with and without steel fibers including lime, and after 0, 7, 28, 60, 120, and 160 days of curing. The experimental data is used to train a neural network to make predictions. Fiber-reinforced soil's UCS was predicted using an Artificial Neural Network. Predicting and modelling UCS is challenging because it is a highly nonlinear function of its components. When complex relationships between inputs and outputs need to be modelled or discovered, ANNs are often used as a tool for nonlinear statistical data modelling. UCS values were used as the dependent variable, with the dosages and fiber lengths of the steel fibers, soil weight, water and lime content, and curing days all serving as input (predictor) variables. For assessing the reliability of the utilized model's predictions, a performance metric known as Mean Square Error (MSE) is used. The input and output data sets used to train and evaluate ANN models can vary. The statistical error criteria of correlation coefficient (R) and Mean Square Error (MSE) are utilized to evaluate the network's efficacy. In the current investigation, ANNs are trained using the Feed Forward Back Propagation (FFBP) algorithm. Good correlations greater than 97% were obtained during the training, testing, and validation of data using the back propagation training method. The unconfined compressive strength is predicted by the ANN model with a low R and MSE. The experimental and ANN-based prediction of unconfined compressive strength have a perfect correlation, with very small mean square errors. After the model has been trained using experimental data, it is tested using a new set of input data or input values to make predictions about the target output value (UCS). Very low prediction errors were achieved by training on historical data and then using that information to make predictions about new data sets. As a result, this model reduces the need for manual labor, money, and time while accurately predicting the UCS value of any given set of inputs.

Keywords: Artificial Neural Network (ANN), Mean Square Error (MSE), Predict output values (Unconfined Compressive Strength).

I. INTRODUCTION

The use of soil in the construction of paved areas and buildings is of critical importance. It will save money in the long run if the initial stabilization of the soil is performed before or while construction is taking place. These soils are made considerably more resistant to compression by the addition of lime, but their resistance to tension is not nearly as great.When used as reinforcement, steel fibers have the potential to help increase the tensile strength of soil. An investigation into the Unconfined Compressive Strength (UCS) behavior of fiber-reinforced soil samples is carried out. In order to make an accurate prediction of the UCS of fiber reinforced soil, an Artificial Neural Network (ANN) was utilized. Since the UCS is a highly nonlinear function of its constituents, modelling and

predicting it is a challenging endeavor due to the complexity of this relationship. ANNs are considered to be nonlinear statistical data modelling tools because they are used to model or discover complex relationships between inputs and outputs. As input (predictor) variables, the dosages and lengths of the steel fibers, as well as the weight of the soil, the amount of water and lime content, and the number of curing days are used. The Unconfined Compressive Strength values served as the output variable. The performance measure of Mean Square Error, also known as MSE, was utilized for the purpose of evaluating the accuracy of predictions made by the model that was utilized.
Training and testing are performed on ANN models for a wide variety of input and output data sets. The effectiveness of networks is evaluated using the statistical error criteria of correlation coefficient (R), Mean Square Error (MSE), and standard deviation (SD). In this particular research endeavor, artificial neural networks (ANNs) were trained using the Feed Forward Back Propagation (FFBP) algorithm. Good correlations with scores higher than 97% were achieved through training, testing, and validation of data carried out during the back propagation training process. It has been found that the ANN model is capable of making accurate predictions of the unconfined compressive strength in the form of R and MSE. There is a perfect correlation between the experimental results and the prediction of the unconfined compressive strength based on ANN, with very low mean square errors in both cases. Following the training on the experimental data, a different set of input data or a different set of input values are provided in order to predict the output values (UCS) value. The UCS values are predicted as output based on the training of previous data, and very low error rates were obtained as a result of this process. The inputs vary in terms of the combination of data sets that are used. As a result, the amount of manual labor, money, and time required to complete the task is reduced, and the model is flexible enough to accommodate any combination of input values.

2. METHODOLOGY

2.1 TESTS CONDUCTED

- The soil sample for the investigation came from Anantapur, which is located in Andhra Pradesh. After the soil has been gathered, it was left to air-dry for some time, and then it was pulverised into fragments that were 4.75 millimetres in size.
- Dry and wet sieve analysis tests were conducted in order to get a better idea of the grain size distribution.
- It was determined what the specific gravity of the soil was, as well as its Atterberg limits. physical properties of the soil were analysed which are reported in Table 1.
- After that, the results of standard proctor tests were used to determine the optimal moisture content and maximum dry density of soil samples that had not been treated and soil samples that had been treated with lime. Both sets of samples were tested using the same conditions.
- In order to determine how different lengths of steel fibres (20mm and 30mm), amounts of steel fibres (0.2,0.4, and 0.6% dosage by weight of soil), and curing periods (0,7,28, 60,120, and 160 days) affected the UCS when lime was present at a concentration of 9% by weight of soil, research was conducted. According to the findings, the length of the steel fibres was the factor that had the most significant impact on the UCS. Soil samples were cured by using plastic wraps with the help of an adhesive tape.
- After that, the results of the experiments were incorporated into an artificial neural network (ANN) model for the purpose of making predictions.
- Weight of the soil, the amount of water and lime content, the number of curing days, and the dosages and lengths of the steel fibres were used as input (predictor) variables in our study. UCS values obtained in the laboratory tests are taken as the output value or target value to predict the UCS fit values.
- In this particular piece of research, artificial

neural networks, also known as ANNs, were educated with the help of an algorithm called Feed Forward Back Propagation (FFBP). Training, testing, and validation of data were carried out during the process of back propagation training, and as a result, good correlations with scores greater than 97% were achieved as a result.

- There is a perfect correlation between the experimental results and the prediction of the unconfined compressive strength based on ANN, with very low mean square errors in both cases. This is due to the fact that ANN is able to model the experimental data very accurately.
- After that, a different combination of input data is provided in order to discover the predicted UCS values directly without performing the UCS experiment.
- It is hypothesised that the effect will vary depending on the dosage as well as the length of the steel fibres (40mm, 50mm, or 15mm). Therefore, UCS values are predicted for fibre reinforced soil with length of 40 mm, 15 mm, and 50 mm using the employed predictive model.
- The findings demonstrated a strong correlation which can be observed in Figure 5. while exhibiting low error rates; consequently, this model is suitable for use in predicting the outcomes for a diverse range of combinations of data.

(a) (b) (c)

Figure 1: (a) Standard proctor test; (b) Preparation of soil sample for UCS test.(c)Soil specimen after failure.

2.2. UNCONFINED COMPRESSIVE STRENGTH OF SOIL

Unconfined Compressive Strength (UCS) stands for the maximum axial compressive stress that a cohesive soil specimen can bear under zero confining stress. Unconfined compression test is one of the fastest and cheapest methods of measuring shear strength of clayey soil.

Unconfined Compressive Strength (UCS) is the load per unit area at which an unconfined cylindrical specimen of soil will fail in the axial compression test. If the axial compression force per unit area has not reached a maximum value even at 20 percent axial strain, the UCS shall be taken as the value obtained at 20 percent axial strain.

APPARATUS REQUIRED

Compression Device

The loading device shall have sufficient capacity and strain controlled. It may be any of the following type:

a) Platform weighing scale equipped with a screw-jack activated yoke.

b) Hydraulic loading device.

c) Screw jack with a proving ring; and

d) Any other loading device.

Figure 2: Unconfined Compressive Strength testing machine.

Proving Ring

For soils with UCS less than 100 KPa, load shall be measurable to 1 KPa. For soils with UCS greater than or equal to 100 KPa, load shall be measurable to nearest 5 KPa.

Deformation Dial Gauge, having a least count of 0.01mm and travel to permit not less than 20 percent axial strain.

Vernier Callipers, having least count of 0.1mm.

Timing device, to indicate the elapsed testing time to the nearest second may be used for establishing the rate of strain.

Oven, thermostatically controlled with interior of non-corroding material and capable of measuring 1100 ± 50 C.

Weighing Balances, with least count of 0.01g if the specimen weight is less than 100g or least count of 0.1g if the specimen weight is equal to more than 100g.

Miscellaneous Equipment: Specimen trimming and carving tools, remolding apparatus, water content cans etc.

2.3. PREPARATION OF TEST SPECIMEN

Specimen Size: The specimen shall have a minimum diameter of 38mm and the largest particle in the specimen shall be smaller than 1/8 of the specimen diameter. After completion of test on the undisturbed sample, if it is found that the larger particles than permitted are present, it shall be noted in the report of test data under remarks. The height to diameter ratio shall be within 2 to 2.5.

Undisturbed Specimens:

Undisturbed specimens shall be prepared from large undisturbed samples or samples secured in accordance with IS 2132: 1986.

When samples are pushed from the drive sampling tube the ejecting device shall be capable of ejecting the soil core from the sampling tube in the same direction of travel in which the sample entered in the tube and with negligible disturbance of the sample. Conditions at the time of removal of the sample may dictate the direction of removal, but the principal concern should be to keep the degree of disturbance negligible.

Remolded Specimen:

The specimen may be prepared either from a failed undisturbed specimen or from a disturbed soil sample. In the case of failed undisturbed specimen, the material shall be wrapped in a thin rubber membrane and thoroughly worked with the fingers to assure complete remolding. Care shall be taken to avoid entrapped air, to obtain a uniform density, to remould to the same void ratio as that of the undisturbed specimen and to preserve the natural water content of the soil.

Compacted Specimen:

When compacting disturbed material, it shall be done using a mould of circular cross-section

Compacted specimen may be prepared at any predetermined water content and density. After the specimen is formed, the ends shall be trimmed perpendicular to the long axis and removed from the mould. Representative sample cuttings shall be obtained, or the entire specimen shall be used for the determination of water content after the test. Then to perform UCS test:

 The initial length, diameter and weight of the specimen shall be measured, and the specimen placed on the bottom plate of the loading device. The upper plate shall be adjusted to make contact with the specimen.

 The deformation dial gauge shall be adjusted to a suitable reading, preferably in multiples of 100. Force shall be applied so as to produce axial strain at a rate of 0.5 to 2 % per minute causing failure with 5 to 10. The force reading shall be taken at suitable intervals of the deformation dial reading.

The specimen shall be compressed until failure surfaces have definitely developed, or until an axial strain of 20% is reached.

Stress-strain values shall be calculated as follows:

a) The axial strain(e) shall be determined from the following relationship:

$$e = \Delta L / L0 \quad (1)$$

Where:

ΔL = the change in the specimen length as read from the strain dial indicator, Lo= the initial length of the specimen.

b) The average cross-sectional area (A), at a particular strain shall be determined from the following relationship:

$$A = A0 / (1-e) \quad (2)$$

Where:

A0 the initial average cross-sectional area of the specimen.

c) Compressive stress (σ0), shall be determined from the relationship:

σ0 = P/A (3)

Where:

P= the compressive force, and A= average cross-sectional area.

The maximum stress gives the value of the unconfined compressive strength (qu). In case no maximum occurs within 20% axial strain, the unconfined compressive strength shall be taken as the stress at 20% axial strain.

In the case of soils which behave as if the angle of shearing resistance Ø=0 (as in the case of saturated clays under undrained conditions) the undrained shear strength or cohesion of the soil may be taken to be equal to half the unconfined compressive strength obtained in Para above.

3.RESULTS & DISCUSSION

Table 1: Physical properties of soil

Physical properties	Values
1. Specific Gravity	2.6
2. Liquid limit (%)	58.4
3. Plastic limit (%)	31
4. Plasticity index (%)	27.4
5. Soil type	CH
6. Optimum Moisture Content (untreated soil sample)	16.2 %
7. Maximum Dry Density (untreated soil sample)	1.79 g/cc
8. Optimum Moisture Content (lime treated soil sample)	18.7 %
9. Maximum Dry Density (lime treated soil sample)	1.83 g/cc

Table 2: Percentage of soil fraction

Type	Percentage
Gravel	0.4
Sand	5
Silt	75.8
Clay	18.8

Table 2 shows the percentage of soil fraction.The grain-size distribution of the soil was found by carrying out both wet sieve and dry sieve analyses per IS 2720 (BIS 1980) and the type of the soil was found as CH.

Table 3: UCS for lime (9%) and fibre treated soil samples

Length of fibers	Percentage of steel fibers	UCS (kn\m^2) values for different curing periods					
		0 (Day)	7 (Days)	28 (Days)	60 (Days)	120 (Days)	160 (Days)
	0	52.7	63.4	88.94	230.52	180.2	72.3
20 mm	0.2	53.1	64	90.2	233.2	182.34	90.3
	0.4	61.2	70	100	240.5	194.2	85.6
	0.6	52.02	63	87	230.4	102.3	76.4
30 mm	0.2	51.03	61	87.1	160.5	100.01	72.1
	0.4	50	59	75.6	123.2	95.3	62.3
	0.6	48.2	52.4	63.2	112.4	90.2	60.1

Table 3 represents unconfined compressive strength values for both conventional as well as fiber and lime inclusive soil samples for the above curing days.

Effect of 20mm fibers on UCS:

From the UCS tests, it is clear that the strength of the soil improves nominally as the percentage of steel fiber increases up to 0.4%, whereas there is a reduction in UCS at 0.6% of steel fibers of 20mm length and with the increase in curing period UCS also increases up to 60 days and drastically decreased after 60 days. Optimum Values are obtained at 0.4% of steel fibers and for 60 days curing for 20mm steel fibers as shown in Table 3 and also the variation of UCS can be observed in the graphical representation which is shown in fig.3.

Effect of 30mm fibers on UCS:

The strength of the soil decreases as the percentage of steel fiber increases in the case of 30mm steel fibers. From the Table 3 it is clear that, UCS decreases drastically with the increase in curing days which can also be observed from graphical representation which is shown in fig.4.

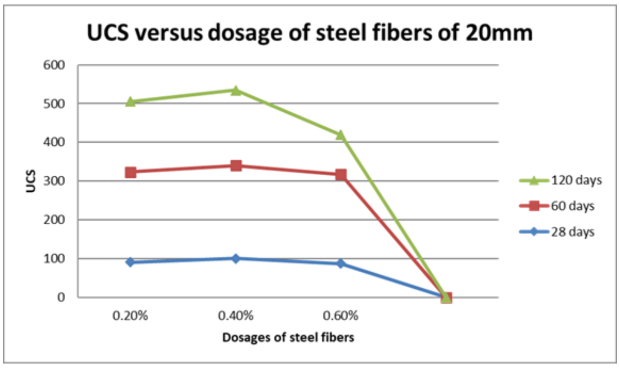

Figure 3: UCS versus dosage of fibers (20mm).

Figure. 3 shows the variation of UCS at different percentages of steel fibers of 20mm for different curing days.

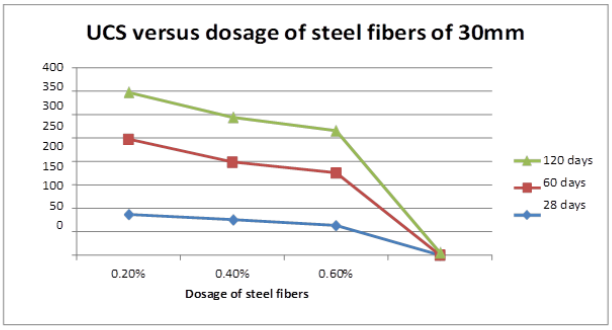

Figure 4: UCS versus dosage of fibers (30mm).

Figure. 4 shows the variation of UCS at different percentages of steel fibers of 30mm for different curing days.

Table 4: Trained experimental input data and predicted output values with errors in ANN

s.no	soil weight	water content	lime content	curing days	fiber length	fiber dosage	UCS kn/m2	UCS kn/m2 Predicted	Errors ploted
1	100	18.7	9	0	0	0	52.7	52.6943	0.00556248
2	100	18.7	9	0	20	0.2	53.1	53.20123	-0.1012
3	100	18.7	9	0	20	0.4	61.2	61.052	0.148
4	100	18.7	9	0	20	0.6	52.02	52.153	-0.133
5	100	18.7	9	0	30	0.2	51.03	51.02856	0.0014
6	100	18.7	9	0	30	0.4	50	49.86542	0.1346
7	100	18.7	9	0	30	0.6	48.2	48.2931	-0.0931
8	100	18.7	9	7	0	0	63.4	63.35621	0.04379
9	100	18.7	9	7	20	0.2	64	64.0235	-0.0235
10	100	18.7	9	7	20	0.4	70	69.7654	0.2346
11	100	18.7	9	7	20	0.6	63	62.8893	0.1107
12	100	18.7	9	7	30	0.2	61	60.9945	0.0055
13	100	18.7	9	7	30	0.4	59	59.4321	-0.4321
14	100	18.7	9	7	30	0.6	52.4	52.3995	0.0005
15	100	18.7	9	28	0	0	88.94	88.93999745	2.54639E-06
16	100	18.7	9	28	20	0.2	90.2	90.16509575	0.034904253
17	100	18.7	9	28	20	0.4	100	99.99999991	9.46438E-08
18	100	18.7	9	28	20	0.6	87	86.99999978	2.17419E-07
19	100	18.7	9	28	30	0.2	87.1	87.10794744	-0.007947437
20	100	18.7	9	28	30	0.4	75.6	75.59999987	1.33466E-07
21	100	18.7	9	28	30	0.6	63.2	63.20000005	-4.71385E-08
22	100	18.7	9	60	0	0	230.52	230.4762945	0.043705479
23	100	18.7	9	60	20	0.2	233.2	233.9533007	-0.75330068
24	100	18.7	9	60	20	0.4	240.5	240.4943004	0.005699564
25	100	18.7	9	60	20	0.6	230.4	230.5000619	-0.100061926
26	100	18.7	9	60	30	0.2	160.5	160.4818655	0.018134547
27	100	18.7	9	60	30	0.4	123.2	123.2333303	-0.033330283
28	100	18.7	9	60	30	0.6	112.4	112.4320169	-0.032016869
29	100	18.7	9	120	0	0	180.2	180.2863788	-0.086378836
30	100	18.7	9	120	20	0.2	182.34	182.5833629	-0.243362925
31	100	18.7	9	120	20	0.4	194.2	194.2875991	-0.08759914
32	100	18.7	9	120	20	0.6	102.3	101.9118676	0.388132441
33	100	18.7	9	120	30	0.2	100.01	99.63565827	0.374341728
34	100	18.7	9	120	30	0.4	95.3	95.35321575	-0.053215754
35	100	18.7	9	120	30	0.6	90.2	90.2442302	-0.044230195
36	100	18.7	9	160	0	0	72.3	72.29997782	2.21792E-05
37	100	18.7	9	160	20	0.2	90.3	90.30005988	-5.98777E-05
38	100	18.7	9	160	20	0.4	85.6	85.60001733	-1.73254E-05
39	100	18.7	9	160	20	0.6	76.4	76.42210427	-0.022104271
40	100	18.7	9	160	30	0.2	72.1	72.14915643	-0.049156426
41	100	18.7	9	160	30	0.4	62.3	62.30000846	-8.45833E-06
42	100	18.7	9	160	30	0.6	60.1	60.10000207	-2.07081E-06

The UCS predicted values shown in the above table were obtained by training the experimental data in ANN. Above table shows all the input data considered to train the network and also the errors obtained to ensure efficiency of the training.

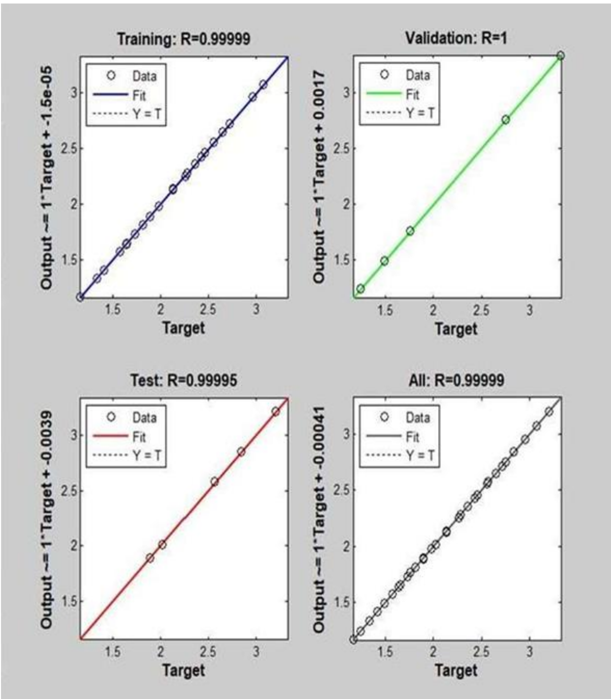

Figure 5: Regression plot.

Figure 5 shows Regression plots for training, testing and validation of ANN in MATLAB. Network is trained multiple times till the R is almost equal to one. R is the coefficient of correlation which shows how well our predicted outputs are matching with real outputs. From fig.5 we can say that our trained network is good.

Table 5: UCS predicted values for different input combinations from past data.

s.no	soil weight	water content	lime content	curing days	fiber length	fiber dosage	UCS kn/m2 Predicted
1	100	18.7	9	28	40	0.2	79.82
2	100	18.7	9	28	40	0.4	72.4
3	100	18.7	9	28	40	0.6	63.05
4	100	18.7	9	28	50	0.2	61.05
5	100	18.7	9	28	50	0.4	59.0432
6	100	18.7	9	28	50	0.6	59.0222
7	100	18.7	9	60	40	0.2	113.0432
8	100	18.7	9	60	40	0.4	112.4681
9	100	18.7	9	60	40	0.6	111.0321
10	100	18.7	9	60	50	0.2	110.2915
11	100	18.7	9	60	50	0.4	107.5432
12	100	18.7	9	60	50	0.6	100.172914
13	100	18.7	9	120	40	0.2	90.3924146
14	100	18.7	9	120	40	0.4	89.643865
15	100	18.7	9	120	40	0.6	83.58693336
16	100	18.7	9	120	50	0.2	82.64833
17	100	18.7	9	120	50	0.4	79.2711932
18	100	18.7	9	120	50	0.6	75.49452
19	100	18.7	9	160	40	0.2	60.053852
20	100	18.7	9	160	40	0.4	59.9051099
21	100	18.7	9	160	40	0.6	57.7936
22	100	18.7	9	160	50	0.2	55.12199
23	100	18.7	9	160	50	0.4	50.4947867
24	100	18.7	9	160	50	0.6	47.7556787
25	100	18.7	9	28	15	0.2	85.4231
26	100	18.7	9	28	15	0.4	87.2493
27	100	18.7	9	28	15	0.6	80.2229
28	100	18.7	9	60	15	0.2	100.2364
29	100	18.7	9	60	15	0.4	102.3546
30	100	18.7	9	60	15	0.6	98.54621
31	100	18.7	9	120	15	0.2	95.15321
32	100	18.7	9	120	15	0.4	95.56842
33	100	18.7	9	120	15	0.6	88.94321
34	100	18.7	9	160	15	0.2	76.241
35	100	18.7	9	160	15	0.4	70.32149
36	100	18.7	9	160	15	0.6	68.76439

Table 5 contains UCS predicted values for different input combinations as shown above. The UCS values were obtained according to the training of past experimental data. Feed Forward Backdrop Algorithm is used. according to the table as fiber length and dosage of fiber increases, UCS decreases.

4.CONCLUSION

The combined addition of lime and fiber has a significant effect on the rate of gain of UCS. These values notably increased with curing periods up to 60 days for 20mm steel fiber. Steel fiber soil sample produced higher UCS value compared to conventional soil sample before stabilization and UCS values decreases with the increase in the length of steel fibers.The optimum UCS values were obtained at 20mm fiber length and for 0.4% dosage of steel fibers of 20mm by the weight of the soil and UCS values decreased for 30mm steel fibers with the increase in percentage of steel fiber and with the increase in curing days in the present study. In order to train, validate, and test the data using a three-layered feed forward back propagation network in MATLAB, the Neural Network was used. This will allow us to be able to predict UCS values for a variety of new input combinations by employing previously collected experimental data as a training set. The UCS behavior is found to be directly dependent, not only on the dosage, but also on the length of the fibre. An investigation is being conducted to determine whether or not lime and steel fibres are effective in stabilizing expansive soil.

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