Estimation of Shear Strength of Soil by using Machine Learning

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***Abstract*—Soil shear strength is a fundamental engineering measurement for designing and auditing geotechnical structures that comprises retaining walls, road foundations, and earthen dams. It is determined using tests performed in laboratories like the Direct Shear Test, Unconfined Compression Test (UCS), Vane Shear Test, as well as Triaxial Test. These types of tests tend to be costly as well as time-consuming, suggesting the adoption of more adaptable practices such as Machine Learning Models. However, existing Machine Learning (ML) al-gorithms often lack preciseness. To deal with such a limitation, improved machine learning (ML) models have been designed that offer greater accuracy and flexible to a larger range of soil conditions. This groundbreaking development suggests numerous benefits, including minimized test expenses and time, along with greater precision.**

Machine learning algorithms may be used to estimate soil shear strength primarily on easily accessible soil characteristics such as grain size distribution, liquid limit, and plas-tic limit. This may considerably lower the cost and length of soil testing yet providing exact estimates of soil shear strength. Soil shear strength is composed of two crucial soil charac-teristics such are Angle of internal friction and Unit cohesion.On the other hand, it is labori-ous and costly. As it turns out, predicting shear strength with advanced Machine Learning algorithms is a successful solution for immediate and low-cost experiments. Only a few re-search have been conducted to predict the characteristics of soft soil utilizing Machine Learning.

Keywords: Soil shear strength, Machine Learning, Direct Shear Test, Angle of internal friction, Grain size distribution

1. INTRODUCTION

T Soil shear strength is a key consideration in geotechnical engineering that is used to design foundations, determine slope stability, and construct retaining walls. Previously, figuring out shear strength required laboratory tests and the expertise of experts. However, with the development of Machine Learning, we all are able to develop greater precision and efficient estimates by making use of data-driven methodologies. By investigating the correlations between soil parameters and shear strength, Machine Learning provides a data-driven way to comprehend and compute soil shear strength. This may substantially enhance the preci-sion and rapidity of these estimations, lowering the need for tough and complex laboratory testing. The approach of computing soil shear strength by utilizing Machine Learning in-volves acquiring sufficient information, preprocessing and feature engineering, model selec-tion, training, and assessment.

This method offers a systematic technique that utilizes the information in the data to develop predictions as well as better comprehend the fundamental systems that determine shear strength. Machine learning algorithms could be developed on a soil characteristics da-taset and shear strength readings to learn the correlation between the two, allowing algo-rithms to predict the shear strength of fresh soil samples based on their characteristics. This method offers multiple perks over traditional methods for determining soil shear strength, which includes laboratory testing. In the beginning, it is significantly quicker and more effi-cient. Second, it may be utilized to calculate shear strength over a wider spectrum of soil types and conditions.

2. Literature Review

Elham Amiri Khaboushana,et.al. have published their research work on Estimation of un-saturated shear strength soil parameters using easily available soil properties in 2018. The information provided is meant to demonstrate the vital role of soil shear strength in as-sessing soil erosion sensitivity, tillage performance, load support capacity, plant develop-ment, and water transport in agricultural soils. It also emphasises the requirement for af-fordable and quick strategies of estimating soil characteristics and shear strength on a wide range of scales. Although laboratory procedures such as direct shear, ring shear, as well as triaxial shear tests are precise they prove to be challenging and time-consuming for broad application in agriculture. On the contrary hand, the cone penetration test (CPT), which is frequently utilized in geotechnical engineering, has potential uses in measuring soil shear strength and features in agricultural soils, specifically cohesion and internal friction angle.

Jun-Jie Wang,et.al have examined the Shear Strength of an Accumulation Soil from Direct Shear Test to emphasize the importance of shear strength in geotechnical engineering, par-ticularly for the development and evaluation of multiple geo-environmental and geotech-nical structures such as dams, retaining walls, and road foundations. Shear strength is de-termined by soil properties such as internal friction angle and unit cohesion, and it is affect-ed by plastic index, liquid limit, moisture content, and clay content. This section also dis-cusses multiple studies and approaches for calculating shear strength in soft soils. The evi-dence obtained suggests that accurately forecasting shear strength in soft soils is vital for the safe and efficient design of geotechnical constructions. The studies and methodologies listed are current scientific initiatives to construct mathematical models.

Minh-Tu Cao,et.al. have published their research work on An advanced meta-learner based on artificial electric field algorithm optimized stacking ensemble techniques for enhancing prediction precision of soil shear strength which proposes an advanced meta-learner capable of precisely determining the shear strength characteristic and providing a reliable estimate of the final shear strength of soil. The model is known as a metaheuristic optimized meta-ensemble learning model (MOMEM). Shear strength is the highest level of resistance or stress that a soil can withstand before deteriorating due to inappropriate surface loading. Knowing the shear strength of soil is critical for any stability study. As an outcome, it be-comes essential that we develop reputable soil shear strength estimations.

3. OBJECTIVE

The objective is to present a new approach for predicting soil shear strength using machine learning algorithms. Traditional methods for determining soil shear strength involve expensive and time-consuming laboratory tests. The abstract proposes that machine learning models can be used to estimate soil shear strength based on easily obtainable soil characteristics, leading to significant cost and time reductions. The development of more accurate machine learning models for a wider range of soil conditions is highlighted.

4. METHODOLOGY

There are multiple methods for collecting a dataset of soil parameters, such as soil type, grain size distribution, moisture content, and stress conditions, such as normal stress, shear stress, cohesion, and internal friction angle. Data can be obtained via laboratory studies, field tests, or from the past work done by several Engineers. After gathering the data, it is very important to classify it into three categories: training, validation, and test sets. This is required to precisely develop and examine the machine learning model. Cross-validation techniques could additionally be used to assess the performance of models.

Because shear strength is a continuous variable, we must choose an appropriate machine learning approach for regression. Linear regression, support vector machines, decision trees, and neural networks are all common alternatives. Once we've decided on a good method, we may train it on the training dataset using appropriate loss functions and optimization ap-proaches.

Next, we must analyze the model's performance on the validation set using appropriate metrics to see how well it predicts shear strength. Finally, we can evaluate the completed model's generalization performance by running it on an independent test dataset.

After studying the model's output, we are able to determine which components are the most significant to estimate shear strength. This research may be useful in delivering in-sights concerning soil behavior. Data collection, like soil characteristics, from literature studies.

1. Select machine learning tools.
2. Analyzing data.
3. Obtaining outcomes.
4. Conclusion.

6. RESULTS AND DISCUSSIONS

(a) Laboratory Test Results

Geotechnical testing was carried out in a laboratory, and the results were used to determine the soil's characteristics of the experiment. The trials were conducted on both the Black cotton soil and Red cotton soil.

Table-5.1 Results of Black Cotton Soil

Sample No	Optimum moisture content (%)	Specific gravity	Plastic limit (%)	Liquid limit (%)	Shear strength (kpa)
1	17.5	2.68	34	55	156.79
2	16.7	2.67	37.2	54	145.54
3	22	2.69	38	60	170.68
4	18	2.69	36	57	167.79
5	17.3	2.67	40	56	147.50
6	20	2.69	37	61	165.66
7	21.1	2.68	40	62	178.52
8	19	2.68	38.6	60	172.71
9	18.4	2.68	38	58	168.25
10	17.8	2.66	36	56	160.51
11	16.2	2.67	30.3	53	125.55
12	16.5	2.68	31.1	54.2	136.65
13	17.3	2.68	31.3	55	149.25
14	16	2.67	27	50.6	119.74

15	18.5	2.69	30.3	57	163.28
16	16.6	2.68	31	52	127.68
17	17.2	2.67	34	56	147.48
18	19	2.68	39	58	166.71
19	16	2.66	30.4	51	117.68
20	18.1	2.68	32.2	55.6	155.29

Table-5.2 Results of Red Cotton Soil

Sample No	Optimum moisture content (%)	Specific gravity	Plastic limit (%)	Liquid limit (%)	Shear strength (kpa)
1	16.4	2.69	20	37	204
2	15.2	2.68	17.3	36.8	202.35
3	17	2.69	18.5	38.2	205.54
4	18	2..70	20.2	40.4	211.53
5	18	2.68	16	38.6	206.15
6	17.5	2.68	20	40	206.58
7	17.8	2.67	16.5	35	201.66
8	18	2.68	19.6	39	205.81
9	20	2.68	20.2	40.4	211.53
10	18	2.69	19	36	204
11	16.4	2.66	18	35	197.11
12	15	2.66	20	37	198.55
13	15.1	2.68	15	36.5	197.10
14	16.3	2.68	16	36.8	198
15	18.2	2.68	17	37	199
16	16	2.69	20.2	39	201.58
17	18	2.69	16.6	36	200.51
18	15.4	2.66	18.2	35.7	199.65
19	19.4	2.68	15.6	34.4	200.21
20	19.4	2.67	21	40.5	202.99

(b) Results by Machine Learning Algorithm:

Random forest regressor is a robust machine learning algorithm used for regression tasks. It builds numerous decision trees while training and returns the average estimate of the various trees for regression issues. To minimize overfitting and boost generalization performance, each tree in the forest is constructed using a random part of training data and a random selection of features. The random forest regressor is notable for its flexibility, resilience, and capacity to handle huge datasets with high dimensionality. It is frequently employed in a variety of fields, including banking, healthcare, and e-commerce, because to its ability to produce exact forecasts and interpretable findings.

Random Forest Regressor can be applied to estimate soil shear strength depending on relevant features such as soil composition, moisture content, density, and other factors. By training the model on a dataset including characteristics as inputs and shear strength values as outputs, it is able to understand the complicated correlations between these variables and generate predictions for unknown soil samples. This may be very valuable in geotechnical engineering for determining soil stability and building infrastructure projects such as foundations and retaining walls.

An RF regressor is a machine learning algorithm that combines numerous decision trees. Each tree is built using a random subset of features (soil properties) from the training data. When a new data point is fed into the model, it undergoes processing through all of the trees, and the final prediction (shear strength) is computed as the average of the predictions produced by each tree.

Benefits of Random Forest Regressors:
1. High precision.
2. Manages complex relationships.
3. Resistant to noise
4. Less likely to overfit.
5. Rank the importance of features.
6. Relatively simple to use

Table-5.3-Results of Black Cotton Soil

Sample No	Optimum moisture content (%)	Specific gravity	Plastic limit (%)	Liquid limit (%)	Shear strength (kpa)
1	17.5	2.68	34	55	151.5
2	16.7	2.67	37.2	54	142.2
3	22	2.69	38	60	167.5
4	18	2.69	36	57	163.3
5	17.3	2.67	40	56	148.1
6	20	2.69	37	61	167.8
7	21.1	2.68	40	62	173.1
8	19	2.68	38.6	60	167.8
9	18.4	2.68	38	58	165.6
10	17.8	2.66	36	56	155.6
11	16.2	2.67	30.3	53	144.0
12	16.5	2.68	31.1	54.2	144.0
13	17.3	2.68	31.3	55	138.8

14	16	2.67	27	50.6	176.7
15	18.5	2.69	30.3	57	161.5
16	16.6	2.68	31	52	144.0
17	17.2	2.67	34	56	148.3
18	19	2.68	39	58	166.2
19	16	2.66	30.4	51	144.0
20	18.1	2.68	32.2	55.6	156.6

Table-5.4-Results of Red Soil

Sample No	Optimum moisture content (%)	Specific gravity	Plastic limit (%)	Liquid limit (%)	Shear strength (kpa)
1	16.4	2.69	20	37	203.2
2	15.2	2.68	17.3	36.8	200..6
3	17	2.69	18.5	38.2	203.4
4	18	2..70	20.2	40.4	209.8
5	18	2.68	16	38.6	203.3
6	17.5	2.68	20	40	203.6
7	17.8	2.67	16.5	35	199.7
8	18	2.68	19.6	39	202.6
9	20	2.68	20.2	40.4	209.8
10	18	2.69	19	36	202.7
11	16.4	2.66	18	35	199.8
12	15	2.66	20	37	202.1
13	15.1	2.68	15	36.5	200.5
14	16.3	2.68	16	36.8	200.5
15	18.2	2.68	17	37	202.4
16	16	2.69	20.2	39	204.0
17	18	2.69	16.6	36	201.3
18	15.4	2.66	18.2	35.7	201.3
19	19.4	2.68	15.6	34.4	199.5
20	19.4	2.67	21	40.5	210.0

7. GRAPHS

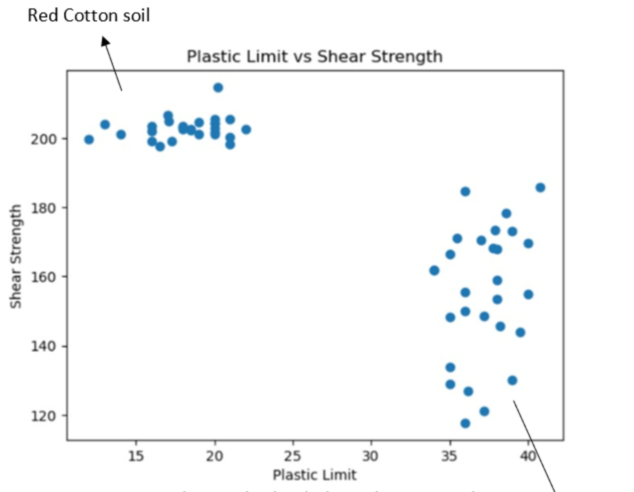

Fig-6.1 Plastic Limit vs Shear Strength

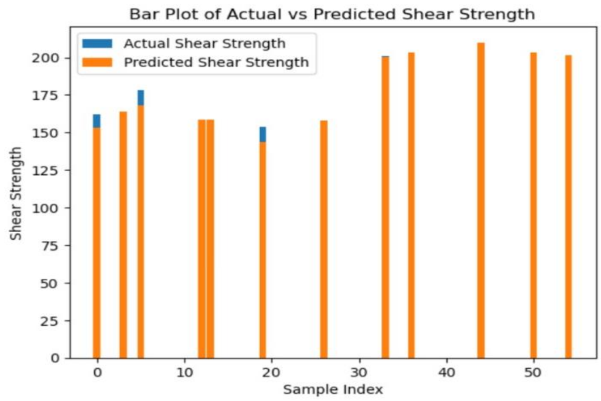

Fig-6.2 Actual vs Predicted Shear Strength

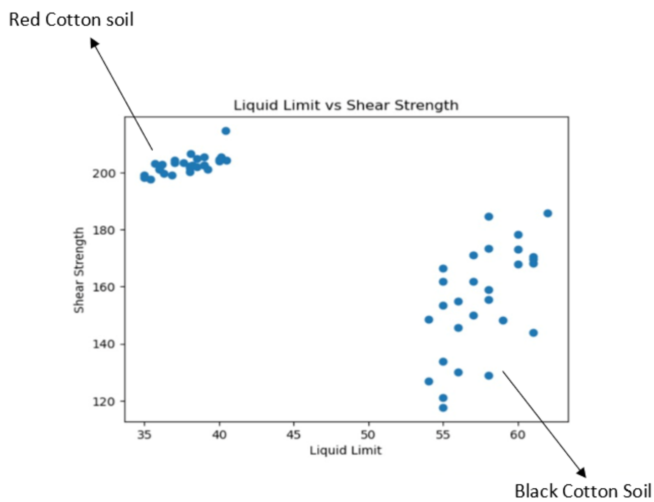

Fig-6.3 Liquid Limit vs Shear Strength

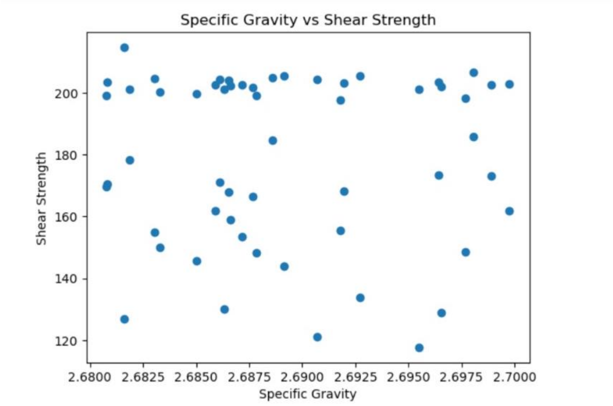

Fig-6.4 Specific Gravity vs Shear Strength

Comparison to Existing Systems:

Random Forest (RF) models provide a more rapidly and more economical to traditional laboratory tests for estimating soil shear strength. They are especially ef-fective at dealing with complicated, nonlinear correlations between soil parameters and shear strength, surpassing simpler models such as linear regression. Overall, random forest regression is a potent tool for estimating soil shear strength, with im-provements in accuracy, robustness, and usability over previous techniques.

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8. CONCLUSION

When predicting soil shear strength, machine learning models outperformed traditional approaches. Random forest regressors are a popular approach owing to its high accuracy, resilience, and capacity to deal with complicated correlations between soil parameters and shear strength. Support Vector Regression (SVR) might potentially be an effective solution, depending on the data and project needs. Machine learning provides a speedier and possibly more cost-effective alternative to existing approaches that rely on expen-sive and time-consuming laboratory testing.

8. REFERENCES

[1]. Elham Amiri Khaboushana, Hojat Emamia, Mohammad Reza Mo-saddeghib, Ali Rrza Astaraeia, "Estimation of unsaturated shear strength soil properties using easily-available soil properties", Springer, 2018, Volume-184, Pg no:118-127, https://doi.org/10.1016/j.still.2018.07.006.

[2]. Jun-Jie Wang, Hui-Ping Zhang, Hui-Bo Wen, Yue Liang, "Shear Strength of an Accumulation Soil from Direct Shear Test", 2015, Marine Geo resources & Ge-otechnology, Volume-33, Pgno:183-190, DOI:10.1080/1064119X.2013.828821, http://dx.doi.org/10.1080/1064119X.2013.828821.

[3]. MinhTu Cao, Nhat-Duc Hoang, Viet Ha Nhu, Dieu Tien Bui, "An advanced meta-learner based on artificial electric field algorithm optimized stacking ensem-ble techniques for enhancing prediction precision of soil shear strength", 2020, Springer, volume-38, Pgno:2185-2207, https://doi.org/10.1007/s00366-020-01116-6.

[4]. Hao Zou, Shu Zhang, Jinqi Zhao, Liuzhi Qin, Hao Cheng, "Investigating the Shear Strength of Granitic Gneiss Residual Soil Based On Response Surface Meth-odology", 2023, Sensors, Volume-23, Pg no-188-193, https://doi.org/10.3390/s23094308.

[5]. Zbigniew Muszy ´nski and Marek Wyjadłowski, "Assessment of the Shear Strength of Pile-to-Soil Interfaces Based on Pile Surface Topography Using La-ser Scanning", 2019, Sensors, Volume 19, Pages:101-122, https://doi.org/10.3390/s19051012.

[6]. O. N. Isaev and R. F, Sharafutdinov, "Soil shear strength at the structure in-terface", 2020, Springer, Volume-57, Pages:139-146, DOI 10.1007/s11204-020-09649-0.

[7]. G. R. Khanlari, M. Heidari, A.A. Momeni, Y. Abdilor, "Prediction of shear strength soil properties of soils using artificial neural networks and multivariate re-gression methods" 2012, Science Direct, Volume-131-132, Pages-11-18, https://doi.org/10.1016/j.enggeo.2011.12.006.

[8]. Hai-Bang, and Binh Thai Pham, "Prediction of Shear Strength of Soil Using Direct Shear Test and Support Vector Machine Model", 2020, The Open Construc-tion and Building Technology, Pages:268-277, DOI: 10.2174/1874836802014010268, 2020, 14, (Suppl-2, M2) 268-277, https://openconstructionandbuildingtechnologyjournal.com.

[9]. Mojtaba Mohammadi, Seyed Mahmoud Fatemi Aghda, Mehdi Talkhablou, Akbar Cheshomi, "Prediction of the shear strength soil properties from easily available soil properties using multivariate regression and artificial neural network methods", 2020, Geomechanics and Geoengineering, Volume-17, pages:442-454, https://doi.org/10.1080/17486025.2020.1778194.

[10]. A. Besalatpour, M. A. Hajabbasi, S. Ayoubi, M.Afyuni, A. Jalalian & R. Schulin, "Soil shear strength prediction using intelligent systems: ar-tificial neural networks and an adaptive neuro-fuzzy inference system", 2012, Soil science and Plant Nutrition, Volume-58, Pages:149-160, https://doi.org/10.1080/00380768.2012.661078.

[11]. Dieu Tien Bui, Nhat-Duc Hoang, Viet-Ha Nhu, "A swarm intelligence-based machine learning approach for predicting soil shear strength for road construction", 2018, Springer, Vollume-35, Pages:955-965, buitiendieu@tdt.edu.vn.

[12]. Viet Ha Nhu, Nhat-Duc Hoang, Van-Binh Duong, Hong-Dang Vu, Dieu Tien Bui, "A hybrid computational intelligence approach for predicting soil shear strength for urban housing construction: a case study at Vin homes Imperia project", 2019, Springer, Volume-36, Pages:603-616, https://doi.org/10.1007/s00366-019-00718-z.

[13]. E.A. Garven and S.K. Vanapalli, "Evaluation of empirical procedures for predicting the shear strength of unsaturated soils", 2006, Conference paper, Volume 22, Pages:303-320, DOI:10.1061/40802(189)219.

[14]. Hua Xu, Xin-Yu Wang, Chia-Nan Liu, Jian-Nan Chen, Chu Zhang, “A 3D root system morphological and mechanical model based on L- Systems and its ap-plication to estimate the shear strength of root-soil composites”, 2021, Elsevier, Volume-212, Pages-212-222, https://doi.org/10.1016/j.still.2021.105074.

[15]. Quang Hung Nguyen, Hai-Bang Ly, Lanh Si Ho, Nadhir Al-Ansari, Hiep Van Le, Van Quan Tran, Indra Prakash, Binh Thai Pham, “Influence of Data Splitting on Performance of Machine Learning Models in Prediction of Shear Strength of Soil”, 2021, Hindawi, Volume 2021, Article ID 4832864, pages-443-453, https://doi.org/10.1155/2021/4832864.

[16]. Binh Thai Pham, Trung Nguyen-Thoi, Hai-Bang Ly, Manh Duc Nguyen, Nadhir Al-Ansari, Van-Quan Tran, Tien-Thinh Le, “Extreme Learning Machine Based Prediction of Soil Shear Strength: A Sensitivity Analysis Using Monte Carlo Simulations and Feature Backward Elimination”, 2020, Sustainability, Volume-12, Pages:623-634, doi:10.3390/su12062339. 339, https://doi.org/10.3390/su12062339.

[17]. Md. Ikramul Hoque, Muzamir Hasan, Md Shofiqul Islam, Moustafa Hou-da, Mirvat Abdallah, Md. Habibur Rahman Sobuz “Machine Learning Methods to Predict and Analyse Unconfined Compressive Strength of Stabilised Soft Soil with Polypropylene Columns”, 2023, Cogent Engineering, Volume-10, Pages-444-456, https://doi.org/10.1080/23311916.2023.2220492.

[18]. Ahsan Rabbani, Pijush Samui, Sunita Kumari, “Optimized ANN-based Ap-proach for Estimation of Shear Strength of Soil”, 2023, Research Square, Volume-22, Pages-334-355, https://doi.org/10.21203/rs.3.rs-2963435/v1.

[19]. Longtu Zhu, Qingxi Liao, Zetian Wang, Jie Chen, Zhiling Chen, Qiwang Bian, Qingsong Zhang, “Prediction of Soil Shear Strength Soil properties Using Combined Data and Different Machine Learning Models”, 2022, Applied Science, Volume-12, https://doi.org/10.3390/app12105100.

[20] Binh Thai Phama, Le Hoang Sonb, Tuan-Anh Hoangb, Duc-Manh Ngu-yenc, Dieu Tien Buid, “Prediction of shear strength of soft soil using machine learning methods”, 2018, Elsevier, Volume-166, Pages:181-191, https://doi.org/10.1016/j.catena.2018.04.004..