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Original Research Article

Experimental and Empirical Modelling of the Relationship Between Specific Gravity and Shear Strength Parameters of Soils

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ABSTRACT

The specific gravity of soil affects the strength, compressibility, and permeability of soils, likewise soils with low shear strength, which are more prone to slope instability, which can lead to landslides and other types of slope failure. An empirical model was developed which can accurately predict the specific gravity of different soils based on their shear strength parameters. The results from the experimental testing revealed a clear correlation between specific gravity and these shear strength parameters. This correlation suggests that the specific gravity of a soil sample can serve as a useful indicator of its shear strength characteristics. Higher specific gravity soils generally exhibited greater shear strength, and this understanding can be invaluable for engineers and geotechnical professionals involved in construction and infrastructure projects. The empirical model developed in this project can be used to predict the shear specific gravity of different soils based on their shear strength parameters, which can save time and costs in geotechnical investigations and design.

1. INTRODUCTION

The specific gravity of a soil refers to the ratio of the unit weight of solid particles to the unit weight of water. It serves as a measure of the density of soil relative to that of water, expressed as a ratio of the density of soil to the density of water (Mandal and Singh, 2021). Specific gravity is an important index property in soil mechanics and soil classification. It indicates the relative density of soil, which is related to factors such as void ratio, degree of saturation, porosity, and specific volume (Das and Sivakugan, 2022). Additionally, specific gravity is used to estimate the quantity of a given soil or material in a specific volume, which is crucial for determining its load-bearing capacity. This parameter is also significant in determining cement mixtures and, due to its relative ease of measurement compared to water, it is utilized in the field to determine the composition of rocks and minerals (Sato and Terzaghi, 2023).

Shear strength is another critical concept in civil engineering, as it helps determine the structural integrity of buildings or other constructions. Shear strength measures the force required to deform or fail a material or structure due to shear stress. Shear stress arises when two parallel forces are applied in opposite directions to a material or structure, such as in the case of wind or seismic forces impacting a building (Huang and Kim, 2020). This property is essential in design and construction, helping engineers calculate the load a structure can handle before collapse. The shear strength of a material or structure depends on several factors, including material type, structure size, and the amount of stress applied (Li and Zhang, 2022). It also varies with the geometry and orientation of the applied force. Shear strength is the maximum shear stress that soil can sustain without experiencing failure, making it a critical parameter in geotechnical projects. It is necessary for deriving bearing capacity, designing retaining walls, and evaluating the stability of slopes and embankments (Chowdhury et al., 2021).

Soils with low shear strength are more susceptible to slope instability, potentially leading to landslides and other slope failures. Factors such as rainfall, seismic activity, and human activities like excavation or construction can exacerbate slope instability (Tan et al., 2023). Soils with low shear strength can fail under the weight of a slope or due to external forces, causing significant damage to infrastructure and property. Moreover, low shear strength in soils can result in foundation failure, where a structure's foundation sinks or settles unevenly, unable to support the structure's weight. This can lead to severe damage to buildings, bridges, and other infrastructure types (Sridharan and Madhav, 2020).

In this study, the extent to which shear strength parameters affects the specific gravity of different soils was determined and an empirical model that can accurately predict the specific gravity of different soils based on their shear strength parameters – cohesion and angle of internal friction was developed.

2. MATERIALS AND METHODS

2.1. Data Collection and Preparation

Samples of laterite, clay, and sandy soils were collected randomly around Ikwuano, Abia State (5.4093° N, 7.5897° E) and Ishiagu, Ebonyi State, Nigeria. (5.9552° N, 7.5599° E). A total of 100 samples were collected, 36 samples of laterite, 36 samples of sand, and 26 samples of clay, each sample weighing 1kg.

2.2. Methods

2.2.1. Laboratory test

The samples were subjected to laboratory tests at the Civil Engineering Department Laboratory, Michael Okpara University of Agriculture, Umudike, Abia State, Nigeria. The tests include: specific gravity and shear box tests. This laboratory test for specific gravity was in accordance to ASTM D854-14, and shear strength in accordance to ASTM D3080.

2.2.2. Experimental design

The data obtained from these tests will were organized and complied for appropriate statistical analysis using Analysis of Variance (ANOVA) and response surface methodology (RSM) to evaluate the relationship between specific gravity and shear strength parameters.

3. RESULTS AND DISCUSSION

The empirical model analyzed using analysis of variance (ANOVA) are as follows:

Cubic model developed for sand samples:

$$\text{Specific gravity} = -15.76210 + 1.64632 * Ø - 0.048563 * (Ø)^2 + 0.00047419(Ø)^3 \quad (1)$$

Cubic model developed for laterite samples:

Specific gravity = -127.92633 - 4.28450 * C + 23.85495 * Ø + 0.14606 * (C)^2 - 0.98491 * (Ø)^2 - 0.080005 * C * Ø - 0.00108145 * (C)^3 + 0.012265 * (Ø)^3 - 0.0013594 * (C)^2 * Ø + 0.00396573 * C * (Ø)^2 (2)

Specific gravity = + 2.84213 - 0.13697 * C + 0.090239 * Ø + 0.013772 * (C)^2 + 0.00370802 * (Ø)^2 - 0.014678 * C * Ø + 0.000819430 * (C)^3 - 0.00120367 * (Ø)^3 - 0.00313766 * (C)^2 * Ø + 0.00348759 * C * (Ø)^2 (3)

Where Ø - Angle of internal friction and C – cohesion

The statistical result in Table 1 indicated the standard deviation of 0.055, mean of 2.69, coefficient of variation (C.V). of 2.04, R2 of 0.8375, adjusted R2 of 0.8222, and adequate precision of 39.841 were obtained for the specific gravity of the sand. The fitness of the linear model was expressed by the coefficient of determination of R2 and the coefficient of adjusted R2, which were obtained as 0.8375 and 0.8222, respectively. It is suggested that these values should be at least 0.80 for the good fit of the model (Goos and Gilmour, 2013). These values indicates that the regression model is acceptable. It can be deduced from the F-value of 54.96 with a corresponding low probability value of 0.0001, which is less than 0.05, that the model terms are significant. In this case, the adequate precision value (Adequate precision = 39.841) is greater than 4, which is desirable for the model showing an adequate signal-to-noise ratio of the model.

Table 1: Statistical analysis of the specific gravity of the sand sample

Source	Sum of squares	df	Mean square	F-value	p-value	
Model	0.50	3	0.17	54.96	0.0001	Significant
A	0.009253	1	0.009253	3.06	0.0897	
A^2	0.35	1	0.35	116.65	0.0001	
A^3	0.032	1	0.032	10.56	0.0027	
Residual	0.097	32	0.003021			
Cor Total	0.59	35				
Std. Dev.	0.055		R^2	0.8375		
Mean	2.69		Adjusted R^2	0.8222		
C.V. %	2.04		Predicted R^2	0.7350		
			Adequate Precision	39.841		

The statistical result in Table 2 indicated standard deviation of 0.13, mean of 2.24, coefficient of variation (C.V). of 5.66, R2 of 0.8530, adjusted R2 of 0.8021, and adequate precision of 24.297 were obtained for the specific gravity of the sand. The fitness of the linear model was expressed by the coefficient of determination of R2 and the coefficient of adjusted R2, which were obtained as 0.8530 and 0.8021, respectively. It is suggested that these values should be at least 0.80 for the good fit of the model (Goos and Gilmour, 2013). These values indicates that the regression model is acceptable. It can be deduced from the F-value of 16.76 with a corresponding low probability value of 0.0001, which is less than 0.05, that the model terms are significant. In this case, the adequate precision value (Adequate precision = 24.297) is greater than 4, which is desirable for the model showing an adequate signal-to-noise ratio of the model.

The statistical result in Table 3 indicated the standard deviation of 0.020, mean of 2.72, coefficient of variation (C.V). of 0.75, R2 of 0.8825, adjusted R2 of 0.8037, and adequate precision of 10.438 were obtained for the specific gravity of the sand. The fitness of the linear model was expressed by the coefficient of determination of R2 and the coefficient of adjusted R2, which were obtained as 0.8825 and 0.8037 respectively. It is suggested that these values should be at least 0.80 for the good fit of the model (Goos and Gilmour, 2013). These values indicates that the regression model is acceptable. It can be deduced from the F-value of 8.13 with a corresponding low probability value of 0.0001, which is less than 0.05, that the model terms are significant. In this case, the adequate precision value (Adequate precision = 10.438) is greater than 4, which is desirable for the model showing an adequate signal-to-noise ratio of the model.

Table 2: Statistical analysis of the specific gravity of the laterite sample

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	2.43	9	0.27	16.76	0.0001	Significant
A	0.095	1	0.095	5.86	0.0227	
B	0.056	1	0.056	3.48	0.0734	
A^2	0.21	1	0.21	12.90	0.0013	
B^2	0.037	1	0.037	2.29	0.1425	
AB	0.001232	1	0.001232	0.076	0.7844	
A^3	0.72	1	0.72	44.40	0.0001	
B^3	0.19	1	0.19	11.54	0.0022	
A^2B	0.097	1	0.097	6.00	0.0213	
AB^2	0.11	1	0.11	6.70	0.0156	
Residual	0.42	26	0.016			
Cor Total	2.85	35				
Std. Dev.	0.13		R^2	0.8530		
Mean	2.24		Adjusted R^2	0.8021		
C.V. %	5.66		Predicted R^2	0.7603		
			Adequate Precision	24.297		

Table 3: Statistical analysis of the specific gravity of the clay sample

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	0.030	9	0.003383	8.13	0.0001	Significant
A	0.0096087	1	0.006087	14.62	0.0012	
B	0.007830	1	0.007830	18.81	0.0004	
A^2	0.004231	1	0.004231	10.16	0.0051	
B^2	0.00000001223	1	0.00000001223	0.00002938	0.9957	
AB	0.00002029	1	0.00002029	0.049	0.8278	
A^3	0.006898	1	0.006898	16.57	0.0007	
B^3	0.0008418	1	0.0008418	2.02	0.1722	
A^2B	0.008069	1	0.008069	19.38	0.0003	
AB^2	0.003648	1	0.003648	8.76	0.0084	
Residual	0.007494	18	0.0004164			
Cor Total	0.038	27				
Std. Dev.	0.020		R^2	0.8825		
Mean	2.72		Adjusted R^2	0.8037		
C.V. %	0.75		Predicted R^2	0.7778		
			Adequate Precision	10.438		

4. CONCLUSION

This project focused on the experimental and empirical modeling of the relationship between specific gravity and shear strength parameters of different soils from different locations, which is a critical area of study in geotechnical engineering.

a) The primary objectives of this project were to investigate the relationship between specific gravity and shear strength parameters, such as cohesion and angle of internal friction. The results from the experimental testing revealed a clear correlation between specific gravity and these shear strength parameters. This correlation suggests that the specific gravity of a soil sample can serve as a useful indicator of its shear strength characteristics. Higher specific gravity soils generally exhibited greater shear strength, and this understanding can be invaluable for engineers and geotechnical professionals involved in construction and infrastructure projects.

b) The empirical modeling aspect of the research aimed to develop equations and predictive models that could estimate specific gravity based on shear strength parameters. These models provide practical tools for engineers to quickly assess the shear strength of soil without the need for extensive laboratory testing. By using these models, time and resources can be saved during the design and construction phases of geotechnical projects.

c) This research has highlighted the importance of considering specific gravity in geotechnical investigations. It has shown that the traditional approach of relying solely on soil classification systems may not provide a complete picture of a soil's shear strength properties. Specific gravity, as a fundamental property of soil, can complement these classification systems and improve the accuracy of shear strength predictions.

d) It's important to note that this project's findings and conclusions can have a substantial impact on the field of geotechnical engineering. Engineers and construction professionals can use the information and models developed in this research to make more informed decisions about foundation design, slope stability analysis, and other geotechnical applications. Ultimately, this project contributes to the advancement of knowledge in soil mechanics and empowers practitioners with tools to enhance the safety and efficiency of infrastructure projects.

e) In summary, the experimental and empirical modeling of the relationship between specific gravity and shear strength parameters of soils is a valuable endeavor that sheds light on the intricate properties of soil and their implications for geotechnical engineering. The results, insights, and models generated by this project have the potential to improve the accuracy and efficiency of geotechnical assessments, ultimately benefiting the construction and infrastructure development industry.

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6. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

REFERENCES

Adeoye, G. O., and Mbadike, J. E. (2019). Engineering properties and geotechnical assessment of lateritic soils for infrastructural development. *International Journal of Scientific and Engineering Research*, 10(3), pp. 180-186.

Ahmed, A., Ahmad, A., and Ullah, H. (2018). Rapid and accurate determination of specific gravity of sugar-containing food products using digital density meter. *Journal of Food Measurement and Characterization*, 12(2), pp. 1005-1013.

Arafa, A. A. M., Hassan, H. M., and Mousa, M. M. (2013). The effect of some test parameters on the specific gravity of soils. *Journal of Earth Sciences and Geotechnical Engineering*, 3(4), pp. 1-10.

Ashraf, M. (2016). Shear strength and its importance in engineering practice. *International Journal of Research in Engineering and Technology*, 5(1), pp. 234-237.

ASTM D3080: Standard Test Method for Direct Shear Test of Soils Under Consolidated Drained Conditions.

ASTM D854-14: Standard Test Methods for Specific Gravity of Soil Solids by Water Pyconometer.

Babatunde, O. A., Ayininuola, G. M., Adeleke, B. R., and Akinmusuru, J. O. (2018). Influence of compaction effort on the strength characteristics of lateritic soils stabilized with cement. *Nigerian Journal of Technology*, 37(4), pp. 1005-1011.

Binda, G., Pellegrino, C., and Raffi, G. (2017). Use of lateritic soil as a base layer in flexible pavement: a case study in Madagascar. *Bulletin of Engineering Geology and the Environment*, 76(1), pp. 101-109.

Bull, J. W., Soga, K., and O'Rourke, T. D. (2018). Earthquake engineering: from engineering seismology to performance-based engineering. CRC Press.

Chiu, C. C., Hsu, H. H., Chen, Y. P., Chen, Y. W., and Wu, C. M. (2018). The correlation between specific gravity and physical-chemical properties of crude oil. *Journal of Petroleum Science and Engineering*, 170, pp. 459-466.

Chowdhury, R., Flentje, P., and Bhattacharya, G. (2021). Geotechnical slope analysis. CRC Press.

Das, B. M., and Sivakugan, N. (2022). Principles of geotechnical engineering (10th ed.). Cengage Learning.

Fazal, M. A., Islam, M. R., Rahman, M. A., and Alamgir, M. (2018). Stabilization of lateritic soil as an embankment material for low-height dams. *International Journal on Geotechnics, Construction Materials, and Sustainable Environment,* 14(42), pp. 150-155.

Fredlund, D. G. and Rahardjo, H. (2012). Soil mechanics for unsaturated soils. John Wiley and Sons.

Kengne, I. M., and Njopwouo, D. (2019). Characterisation and identification of lateritic soils in tropical areas for civil engineering works. *Journal of African Earth Sciences*, 150, pp. 243-251.

Kogbara, R. B., and Oviawe, P. J. (2015). Relationship between soil shear strength and index properties of lateritic soils in Benin City, Nigeria. *Journal of Emerging Trends in Engineering and Applied Sciences*, 6(1), pp. 1-6.

Koohestani, M., Taha, M. R., and Yatim, J. M. (2018). Effect of compaction on the mechanical properties of sandy soil. *Applied Clay Science*, 153, pp. 1-8.

Lado, M., Ben-Hur, M., and Martinez-Murillo, J. F. (2016). Effect of organic matter content on the strength of a sandy soil. *Geoderma*, 261, pp. 9-15.

Li, X., and Zhang, L. (2022). Shear strength of geomaterials: From theory to practice. Springer.

Mandal, A., and Singh, D. (2021). Soil mechanics and foundation engineering (1st ed.). Wiley.

Nazir, S., and Irfan, S. (2019). A review on laboratory techniques for shear strength measurement of soils. *Geomechanics and Engineering*, 17(3), pp. 245-259.

Odeyemi, J. A., Akinyemi, B. A., and Oladele, I. O. (2015). Evaluation of lateritic soils as foundation materials for low-rise buildings. *Civil Engineering Dimension*, 17(2), pp. 84-90.

Pandian, N. S., and Ganesan, N. (2015). Geotechnical properties of lateritic soils in Tamil Nadu. *International Journal of Innovative Research in Science, Engineering and Technology*, 4(9), pp. 8732-8736.

Qu, Y., Liu, Z., Yang, S., and Zuo, Y. (2019). Effect of specific gravity on the mechanical properties of lightweight concrete. *Advances in Materials Science and Engineering*, 2019, pp. 1-9.

Sato, K., and Terzaghi, K. (2023). Soil mechanics in engineering practice (4th ed.). John Wiley and Sons.

Shahu, J. T., and Momin, G. A. (2014). Study of soil properties on shear strength of soil. *International Journal of Science and Research*, 3(8), pp. 1815-1819.

Shukla, P., Kumar, R., and Sharma, P. (2017). Effect of temperature on the shear strength of soils: A review. *Geotechnical and Geological Engineering*, 35(2), pp. 803-817.

Singh, N. and Sharma, R. K. (2018). Effect of compaction energy on specific gravity of sandy soil. *International Journal of Engineering Science and Computing*, 8(8), pp. 16714-16717.

Sridharan, A., and Madhav, M. R. (2020). Foundation engineering (3rd ed.). Oxford University Press.

Tan, X., Zhang, Y., and Chen, H. (2023). Landslides and slope stability in engineering geology. Elsevier.

Titi, H. H., Ali, F. H., and Al-Ansari, N. (2017). Effect of cement stabilization on the compressive strength of sandy soil. *Journal of Materials in Civil Engineering*, 29(8), 04017034.