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Empirical Correlations between Shear Strength Parameters and Slope Angle

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Abstract

Empirical correlation serves as a guide for designers especially if there are urgent works that need to be done and a limited time to conduct extensive laboratory tests. This study defines the procedures and analysis used in order to evaluate the validity of the existing empirical correlation between the shear strength parameters i.e. cohesion and angle of friction with the slope angle by increasing the number of data points. Throughout the study, an additional of 20 sampling points were added and the soil samples were delivered to the soil laboratory for various tests such as grain size analysis, fall cone test, and direct shear test. The obtained slope angle values from field investigation and the data from laboratory testing were then analyzed and correlated. The results correlations from regression analysis showed that the coefficient of determination, R^2, for cohesion-slope angle and friction angle-slope angle were found to be 0.064 and 0.019, respectively, using the power series model. The values imply that there is no conclusive correlation evidence that the cohesion and angle of friction of the soil can be predicted through its respective slope angle.

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I. INTRODUCTION

In a mountainous area, the study of soil strength properties, such as cohesion and angle of friction, is significantly important in assessing the slope instability [1]. These parameters are used to determine the angle of rupture, shear strength and factor of safety of the soil. In the study of [2], the angle of friction is to the degree of friction and interlocking existing among soil particles, and cohesion denotes the ionic bond and chemical cementation between soil particles. However, according to [3], acquisition of these data is difficult and challenging due to time-consuming field sampling and expensive laboratory testing.

The correlation serves as a guide for designers especially if there are urgent works that need to be done and a limited time to conduct extensive laboratory tests. Knowledge of the influence of one soil property to another through correlation is fundamental to quickly assess and interpret the soil properties for engineering design and geotechnical purposes. Various researchers conducted a study on the prediction of shear strength parameters by correlating it with other engineering soil properties. These include clay content – shear strength correlation of the sandy soil [4]; angle of internal friction - fines content correlation of lateritic soils [5]; water content – shear strength, and degree of compaction - shear strength correlations of clay soil material [6]; unit weight – soil cohesion, and unit weight - friction angle of soil correlations [7]; shear strength - friction angle correlation with simple soil index properties [8]; and among others.

Meanwhile, the slope of soil formation is an important physical attribute of land surface which expressed in terms of percent of rise or fall of the soil surface from the horizontal.

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Several researchers have published correlations between soil thickness and slope angle. These were presented in the study of [9], [10], [11], and [12]. Thus, this study defines the procedures and analysis used in correlating of shear strength parameters with slope angle as suggested in the research paper of [12] by increasing the number of data points in order to evaluate the validity of the presented empirical equations.

II. METHODS

The areas selected for this study are the same study area of [3]. The said areas are located in the Municipality of Kibawe, Bukidnon, Philippines specifically, the Barangay New Kidapawan and Barangay Kiorao, which underlie in Pliocene-Pleistocene type of geology (Fig. 1). The center of Barangay New Kidapawan is geographically situated at 7° 33' 24.12" N latitude and 124° 55' 18.12" E longitude with an elevation above mean sea level of 347.8. The center of Barangay Kiorao is geographically situated at 7° 31' 42.24" N latitude and 124° 55' 8.76" E longitude with an elevation above mean sea level of 303.0 meters. The primary economic activity in the two barangays is agriculture.

Prior to the conduct of field surveys, detailed planning and mapping of sampling points were conducted at the University of Science and Technology of Southern Philippines (USTP). The working map or slope map was used to establish the sampling point for soil sampling. Based on the predetermined 20 slope ranges, the location of the sampling points was identified by pinning through the GIS. The slope angle of the study area was obtained through a processed DEM from Phil-LIDAR (Philippine-Light Detection and Ranging). Fig. 2 shows the location of the sampling points including the 10 sampling points from [12] study. A reconnaissance survey was conducted to evaluate the condition and accessibility of the sampling points that are being identified in the working map. During filed sampling, positions of soil samples were ascertained from the Global Positioning System (GPS) readings and fit the corresponding latitudes and longitudes obtained from the GIS. A clinometer was used to verify the slope angle in the site and during the change of location other than those being pinned in the working map since it was found that some of the predetermined sampling points were not accessible. A total of 20 soil samples were obtained based on identified 20 slope ranges and delivered to soil testing laboratory for grain size analysis (ASTM D 422), fall cone test (ASTM D 4318), and direct shear test (ASTM D 3080).

The regression analysis was used to interpret the relationship between the shear strength parameters i.e. cohesion and angle of friction with the slope angle. The correlation was conducted using a Microsoft Excel application. To evaluate the strength and level of the correlation, Table 1 by [13] is used to interpret the size of correlation based on the obtained coefficient of determination (R^2) values.

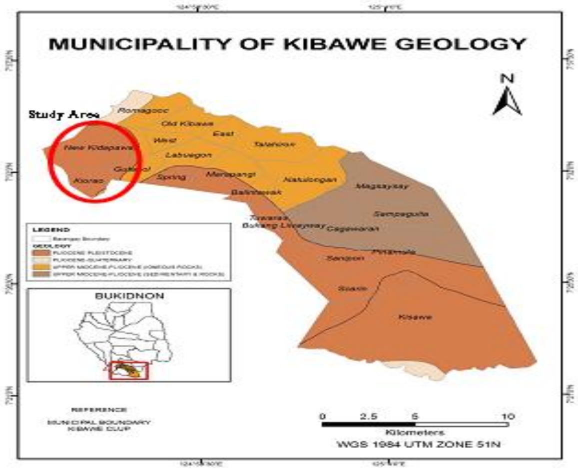

Fig. 1. Geology Map of Kibawe, Bukidnon

Table 1: Correlation coefficient analysis

Size of correlation	Strength of correlation
0.9 – 1.0	Highly Perfect/Very Strong
0.7 – 0.9	Perfect/Strong
0.5 – 0.7	Moderate
0.3 – 0.5	Weak
0.0 – 0.3	No Association

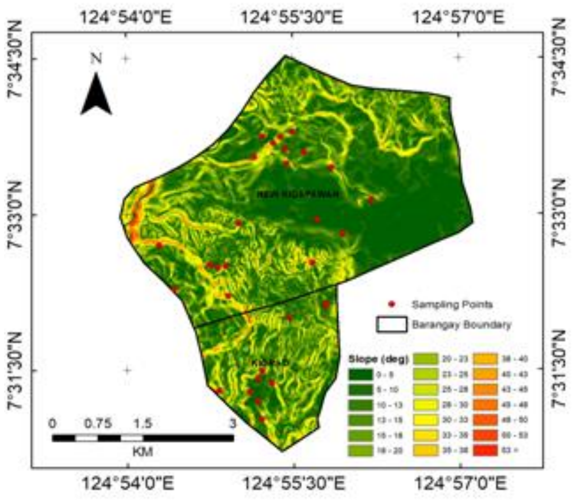

Fig. 2. Location of the sampling points

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III. RESULTS AND DISCUSSION

Table 2 shows the data of the shear strength parameters based on respective slope angles. The values of cohesion and angle of friction ranged from 4.6kPa – 52.9kPa and 11.7^o – 31.0^o, respectively.

Table 2. Shear strength parameters

Borehole No.	Slope Range (°)	Actual Slope (°)	Cohesion (kPa)	Friction Angle (^{o})
BH1	0 - 5	2	52.9	19.9
BH2	10-May	9	28.6	25
BH3	13-Oct	12	23.4	29.2
BH4	13 - 15	15	22.8	27
BH5	15 - 18	17	10.5	30.6
BH6	18 - 20	20	20.2	22.1
BH7	20 - 23	22	25.9	15.9
BH8	23 - 25	25	22.6	21.1
BH9	25 - 28	27	26.1	18.2
BH10	28 - 30	29	14.1	26.2
BH11	30 - 33	33	25.6	21.5
BH12	33 - 35	35	20.6	24.2
BH13	35 - 38	37	32	11.7
BH14	38 - 40	40	32.7	15.3
BH15	40 - 43	42	9.7	22.3
BH16	43 - 45	44	14.6	23.7
BH17	45 - 48	46	16	24.1
BH18	48 - 50	49	4.6	31
BH19	50 - 53	52	34.9	21.7
BH20	> 53	54	16.9	26

3.1 Equation for Updated Cohesion - Slope Angle Empirical Correlation

Fig. 3 presents the correlation between cohesion with the slope angle from the 20 boreholes data. The result shows that the fitting model that can describe the relationship between cohesion and slope angle is power series. The computed value for the coefficient of determination (R^2) is equal to 0.226, which implies "no association" in terms of the strength of the correlation.

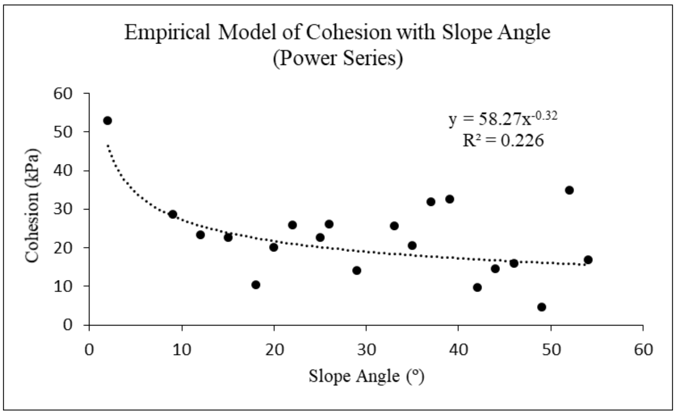

Fig. 3. Cohesion - slope angle correlation based on the 20 boreholes data

However, from the study of [11], the value of R^2 for this correlation based on the 10 boreholes is 0.7326 using the same regression analysis function which is the power series. Thus, by combining the boreholes data, it can be noticed from the 30 boreholes data that there was no conclusive evidence of correlation between cohesion and slope angle since the resulted value of R^2 is 0.064 (Fig. 4).

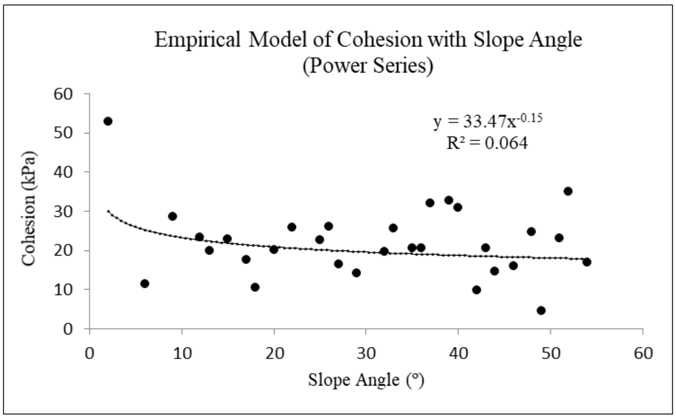

Fig. 4. Cohesion - slope angle correlation based on the 30 boreholes data

The two correlations of cohesion and slope angle, with 20 and 30 boreholes, are characterized by a large amount of scattered data hence, according to [14], these types of correlation results are useful to evaluate the trends but not for practical applications and cannot be general. This denotes that the cohesion of the soil is not dependent on its slope angle. However, [2] discussed some factors that have a direct effect on the shear strength of cohesive soil which includes clay content, clay mineralogy, plasticity index, water content, dry density, and strain rate. This implies that the cohesion of the soil is not dependent on its respective slope angle but can be predicted through its various properties.

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3.2 Equation for Updated Friction Angle - Slope Angle Empirical Correlation

In this section, a correlation developed between friction angle and slope angle based on the 20 soil samples in a form of power series relationship is shown in Fig. 5. From the figure, it can be noticed a scatters data thus, resulting in a value of R^2 of 0.002. In comparison with the predicted result of R^2 equal to 0.4711 (based on the 10 soil samples) of the previous study, the present results affirm to this correlation which shows a weak or no association in correlation. The same result can be observed by combining both data, a total of 30 soil samples, as shown in Fig. 6. The value of R^2 is 0.019 which entails that there is no consensus for the influence of slope angle on the friction angle of the soil. From the investigation conducted by [15], the findings revealed that with the increase of clay content and plasticity index of the soil, the friction angle decreases.

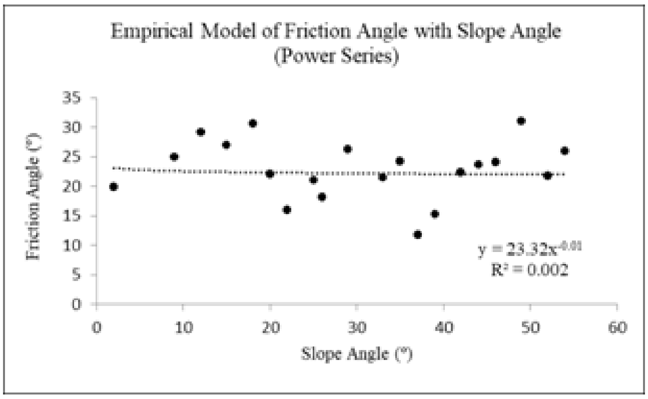

Fig. 5. Friction angle - slope angle correlation based on the 20 boreholes data

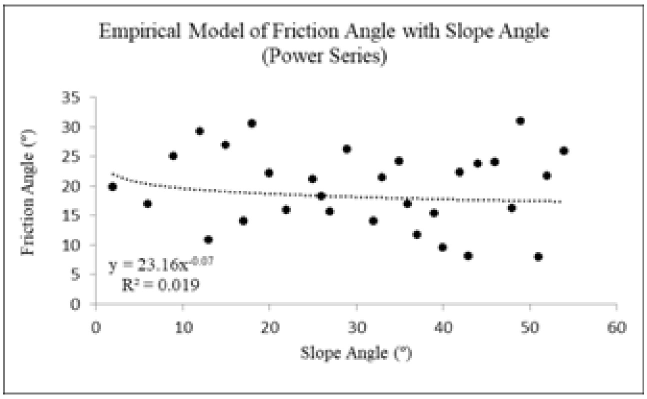

Fig. 6. Friction angle - slope angle correlation based on the 30 boreholes data

3.3 Correlation between cohesion and slope angle relationship based on soil classification

The relationships between the cohesion and slope angle per soil classification are shown in Fig. 7-9. Classification of soils is in accordance with the Unified Soil Classification System (USCS) based on the laboratory results of the physical property and the degree of plasticity.

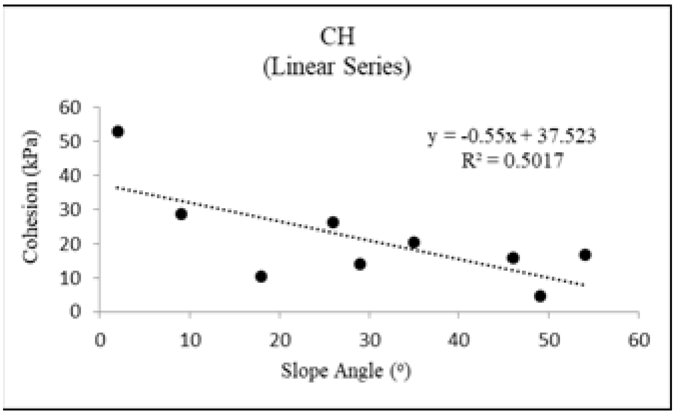

Fig. 7. Cohesion - slope angle correlation based on the CH type of soil

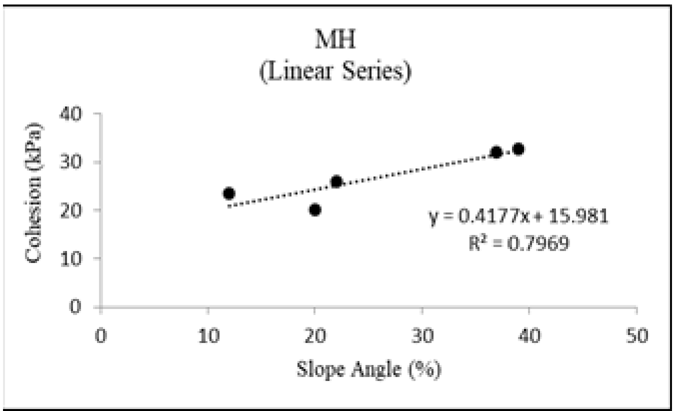

Fig. 8. Cohesion - slope angle correlation based on the MH type of soil

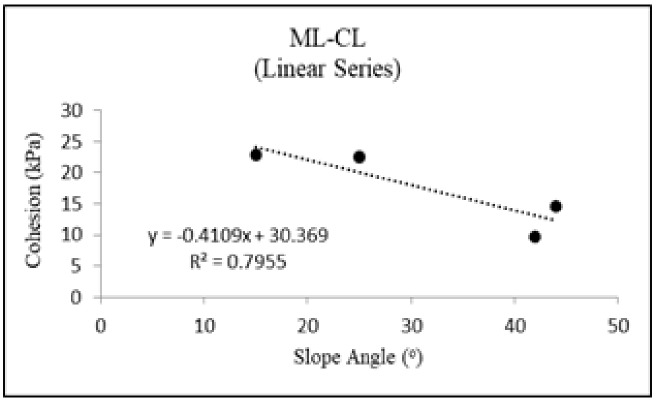

Fig. 9. Cohesion - slope angle correlation based on the ML-CL type of soil

The soil samples were group into three classifications, namely: CH, MH, and CL-ML. The results revealed a moderate to a perfectly strong correlation between the two

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variables based on the linear series regression analysis function. The CH and ML-CL types of soil have the same correlation cases in which the cohesion decreases as the slope angle increases. Meanwhile, the MH type of soil displays proportional results where the cohesion of the soil increases as the slope angle increases.

3.4 Correlation between friction angle and slope angle relationship based on soil classification

The relationships between the friction angle and slope angle based on soil classification are shown in Fig. 10-12. The MH and ML-CL types of soil showed a moderate to a perfectly strong correlation between the two variables however, the CH type of soil reveals no correlation evidence since the value of R^2 is equal to 0.051. Hence, the slope angle cannot be directly used to predict the value of friction angle.

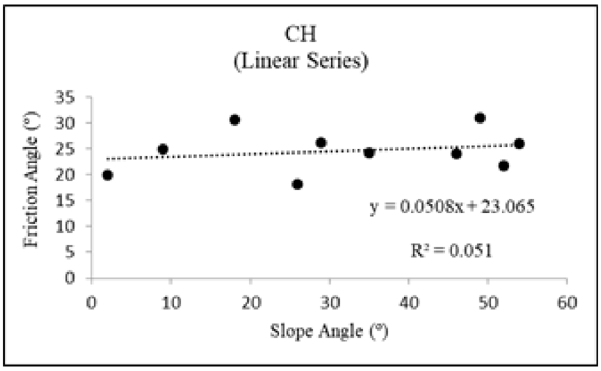

Fig. 10. Friction angle - slope angle correlation based on the CH type of soil

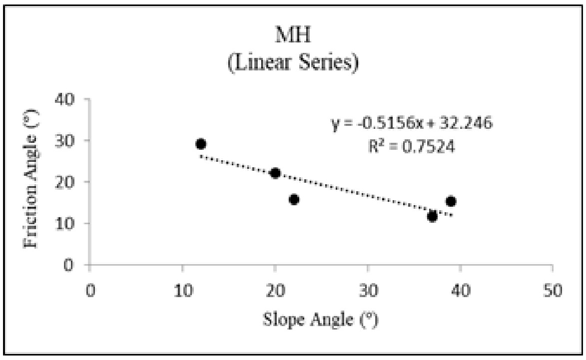

Fig. 11. Friction angle - slope angle correlation based on the MH type of soil

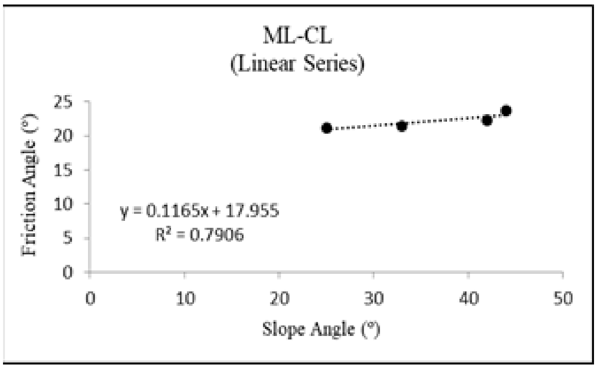

Fig. 12. Friction angle - slope angle correlation based on the ML-CL type of soil

IV. CONCLUSIONS

This study presented an updated empirical correlations of the cohesion – slope angle and friction angle – slope angle. The developed correlations in the form of power series function were very different from the conclusion of the previous study by [4]. Moreover, the values of cohesion and angle of friction depends on the in-situ and laboratory results of the soils that is why it varies in every slope range. Therefore, results have clearly indicated that the slope angle cannot sufficiently be used to predict the cohesion and angle of friction of the soil.

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VI. REFERENCES

[1] Sujit, M. (2015). Assessing cohesion, friction angle and slope instability in the Shivkhola Watershed of Darjiling Himalaya. *International Research Journal of Earth Sciences*, Vol. 3(8), 1-7.

[2] Zumrawi, M. & Mohammed, L. (2016). Correlation of placement conditions and soil intrinsic properties with shear strength of cohesive soils. 7th Annual Conference for Postgraduate Studies and Scientific Research, Vol.1.

[3] Obasi, N. L. and Anyaegbunam, A. J. (2005). Correlation of the undrained shear strength and plasticity index of tropical clays. *Nigerian Journal of Technology*, Vol. 24(2).

[4] Akayuli, C., Ofosu, B., Nyako, S. & Opuni, K. (2017). The influence of observed clay content on shear strength and compressibility of

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residual sandy. *International Journal of Engineering Research and Applications.* Vol. 3(4), 2538-2542.

[5] Adunoye, G.O. (2014). Fines content and angle of internal friction of a lateritic soil: an experimental study. *American Journal of Engineering Research.* Vol. 3(6), 16-21.

[6] Huzhu, Z., Hanbing, L., Jing, W. & Weizhi, D. (2017). Investigation of the effect of water content and degree of compaction on the shear strength of clay soil material. *Functional Materials*, Vol. 24(2), 290–297.

[7] Parker, C., Simon, A. & Thorne, C. (2008). The effects of variability in bank material properties on riverbank stability: Goodwin Creek, Mississippi. *Geomorphology,* Vol. 101, 533-543.

[8] Roopnarine, R., Eudoixe, G. & Gay, D. (2012). Soil physical properties as predictors of soil strength indices: Trinidad case study. *Geomaterials*. Vol.2, 1-9.

[9] De Rose, R. C. (1996). Relationships between slope morphology, regolith depth, and the incidence of shallow landslides in eastern Taranaki hill country. Zeitschrift fur Geomorphologie Supplementband. 105, 49–60.

[10] Salciarini, D, Godt, J. W., Savage, W. Z., Conversini, R., Baum, R. L., & Michael, J. A. (2006). Modelling regional initiation of rainfall-induced shallow landslides in the eastern Umbria Region of central Italy. Landslides, Vol.3, 181–194.

[11] Tan, C. H., Ku, C. Y., Chi, S. Y., Chen, Y. H., Fei, L. Y., Lee, J. F., & Su, T. W. (2008). Assessment of regional rainfall-induced landslides using 3S-based hydro-geological model. Landslides and Engineered Slopes: From the Past to the Future. *Chinese Inst Soil Mech & Geotech Chinese Nat*., Vol. 1 & 2.

[12] Daleon, C. & Lorenzo, G. (2018). Empirical models for predicting the spatial variation of soil thickness and shear strength. *Journal of Nepal Geological Society,* Vol. 55, 85-91.

[13] Mukaka M. (2012). A guide to appropriate use of Correlation coefficient in medical research. *Malawi Medical Journal,* Vol. 24(3), 69–71.

[14] Collotta. T., Cantoni, R., Pavesi, U., Ruberl, E. & Moretti, P. C. (1989). A correlation between residual friction angle, gradation and the index properties of cohesive soils. *Geotechnique,* Vol. 39(2), 343-346.

[15] Laskar, A. & Pal, S. (2012). Geotechnical characteristics of two different soils and their mixture and relationships between parameters. *The Electronic Journal of Geotechnical Engineering,* Vol.17, 2821-2832.

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