Characterization of Index Properties of Biochar made from Rice Hull for Permeability Test

Joshua Talento
Department of Civil Engineering, Gokongwei College of Engineering, De La Salle University

Jan Andrei Olayon
Department of Civil Engineering, Gokongwei College of Engineering, De La Salle University

Alexandra Gaile Samson
Department of Civil Engineering, Gokongwei College of Engineering, De La Salle University

Jaime Salvador Clamor
Department of Civil Engineering, Gokongwei College of Engineering, De La Salle University

他

https://doi.org/10.5109/7395536

出版情報：Proceedings of International Exchange and Innovation Conference on Engineering & Sciences (IEICES). 11, pp.325-330, 2025-10-30. International Exchange and Innovation Conference on Engineering & Sciences
バージョン：

Characterization of Index Properties of Biochar made from Rice Hull for Permeability Test

Joshua Talento[1], Jan Andrei Olayon[1], Alexandra Gaile Samson[1], Jaime Salvador Clamor[1], Joenel Galupino[1], Irene Olivia Ubay-Anongphouth[1]
[1]Department of Civil Engineering, Gokongwei College of Engineering, De La Salle University.
Corresponding author email: gio_talento@dlsu.edu.ph

Abstract: *Rice hull, a by-product of the processing of rice, is plentiful in countries such as the Philippines. This study assesses whether Rice Hull Biochar (RHB) is a potential sustainable additive to soils. Specific gravity and relative density tests were conducted with procedures provided by the American Society for Testing and Materials (ASTM). Results of the tests showed that the specific gravity of RHB is 1.86, and a maximum and minimum void ratio of 2.467 and 1.900 respectively, indicating a less dense with more organic content and a higher degree of compaction.*

Keywords: Rice hull, Void ratio, Specific gravity, Relative density, Sustainable additive

1. INTRODUCTION

Numerous countries, especially in the Philippines, have a common product used in basic necessities known as rice. The processing of rice produces a by-product known as rice husks or rice hull [1]. This by-product becomes abundant in these countries as almost every meal has some form of rice dish that goes with it. In the Philippines, the amount of rice hull produced by rice mills across the country is estimated at 2 million tons every year. Considering rice hulls aren't commonly used, especially in animal feed, these by-products are usually burned which can cause health hazards in the surrounding areas. With the amount of rice being processed throughout the country, the amount of by-products produced is just as great, if not greater. These rice hulls can be used in other applications such as in soils. Soil additives utilizing sustainable materials such as by-products from agricultural processes aren't new practices, but the use of biochar made from rice hulls can be a potential additive for its permeability properties when mixed.

When rice hulls are processed and turned into biochar, the carbonized rice hulls have a potential with water remediation within soil [2]. Percolation of water in soil can have adverse effects on its properties such as its stability, a sustainable soil additive can be added to improve the water remediation in a soil which may also have an effect on its stability. The effects of the specific material of biochar from rice hulls can be studied when it's added to alluvial soil and clay to determine whether or not it will reduce or increase the permeability of the sample. A controlled pyrolysis process can be applied to achieve optimal effectiveness of RHB [3]. When certain conditions are met and maintained for a certain amount of time, the desired properties can be achieved for the intended purpose of water remediation as mentioned earlier.

A study by Chuyaco et. al. (2024) used ash from the horsetail plant for it's known to have a high silica content and tested to confirm if it could be a sustainable additive for infrastructure materials [4]. The study concluded that when incinerating the horsetails to 700 °C, the carbon content and amorphous silica content is a good additive for soil stabilization. Another study by Jansomboon et. al. (2016) stated that rice hulls can be transformed into silica particles through calcination [5]. With carbon content already present, RHB can potentially be another sustainable additive for soil stabilization and water remediation. In addition, amorphous silica also improves soil stability in coarse-grained soils when dry as well [12]. The addition of amorphous silica overall tends to improve the stability of soil in both wet and dry conditions, this proves as useful information regarding the behavior of soil additives when mixed in with similar types of soil in future studies and tests. Another study stated that the biochar of rice straw, another by-product of rice processing, had much silica content which came with carbon content as well [13]. There is a correlation between the presence of carbon and silica in soil additives to prove as good quality.

A study by Adajar, Cacho, De Castro, & Robles (2024) utilized rice husk ash as an additive to address the shrink-swell potential of expansive soil [6]. The study concluded that rice husk ash mixed with coconut shell ash yielded improvement in the California Bearing Ratio (CBR) when it soaked up tap water. As this study used ash instead of biochar, the material used also being rice husk could also have similar results to biochar. The concept of using rice husks or hulls being mixed in with another ash from a by-product of food processing in this study has given insight toward how RHB will fare in the subsequent tests that will be done in this paper. Similarly, this could also lead to further improvements in future studies that involve these by-products.

Rice hull biochar, being an organic material, has different minerals within its chemistry. These minerals include sodium, calcium, magnesium, potassium and silicon and are in high portions [9]. As mentioned previously, the presence of silica content may have an effect on the performance of organic soil additives with regards to hydraulic conductivity and soil stability. Amorphous silica does have an effect in the hydraulic conductivity, it also improves a soil's capacity of the soil to hold water [10]. Water retention also directly affects the permeability of the soil, more water retention means the less likely water will percolate through that soil layer. Aside from minerals found in RHB, it also raised the pH level of soils stated by an article by Jinhua & Renkou (2010) [14]. The increase of acidity in the soil, reducing the chances of plant growth, which could decrease the stability of the soil. For future experiments regarding the permeability of alluvial soil and low plastic clay with RHB added to the mixture, it's possible for there to be a significant change in the performance of these soils in terms of their permeability.

2. MATERIALS

2.1 Rice Hull Biochar

Biochar made out of rice hull, a by-product of rice processing which was put through pyrolysis sourced from the official biochar making center of the Philippines, Sambali Beach Farm in Botolan, Zambales.

3. METHODOLOGY

This research will be using a quantitative experimental approach, utilizing laboratory-based testing to obtain data for analysis of the outcomes (see Figure 1). The American Society for Testing and Materials (ASTM) will provide the standards for sampling techniques and procedures for these experiments. All experimental work will be done at the Geotechnical Engineering Laboratory located in room M103 found in St. Miguel Building of De La Salle University - Manila, situated at 2401 Taft Avenue, Malate, Manila, 1004 Metro Manila.

The tests that will be done for this specific material in comparison to alluvial soil and low plastic clay are only limited to the specific gravity of the RHB and its relative density as provided by ASTM.

3.1 Specific Gravity Tests

The procedure of the specific gravity test starts by weighing an Erlenmeyer flask then filling it with 500mL of distilled water and weighing it again. After the flask containing the water is weighed, 250mL of water is removed from it and 150g of RHB is mixed in. The flask is then connected to a vacuum, which will be turned on while the mixture is being agitated for 30 minutes to remove air bubbles from it. After 30 minutes has elapsed and the mixture is homogeneous, more distilled water is added to the mixture until the 500mL line and will be weighed. Afterwards, the contents of the flask is transferred into a pan and placed in an oven for drying. The procedure is repeated until 3 trials meet the range of the specific gravity of the RHB. The setup for the testing procedure is shown in Figure 2.

The specific gravity of soil is defined as the ratio of the weight of a given volume of soil to the weight of an equal volume of water, both measured in air. It is a key parameter in evaluating the void ratio and the degree of saturation of the soil.

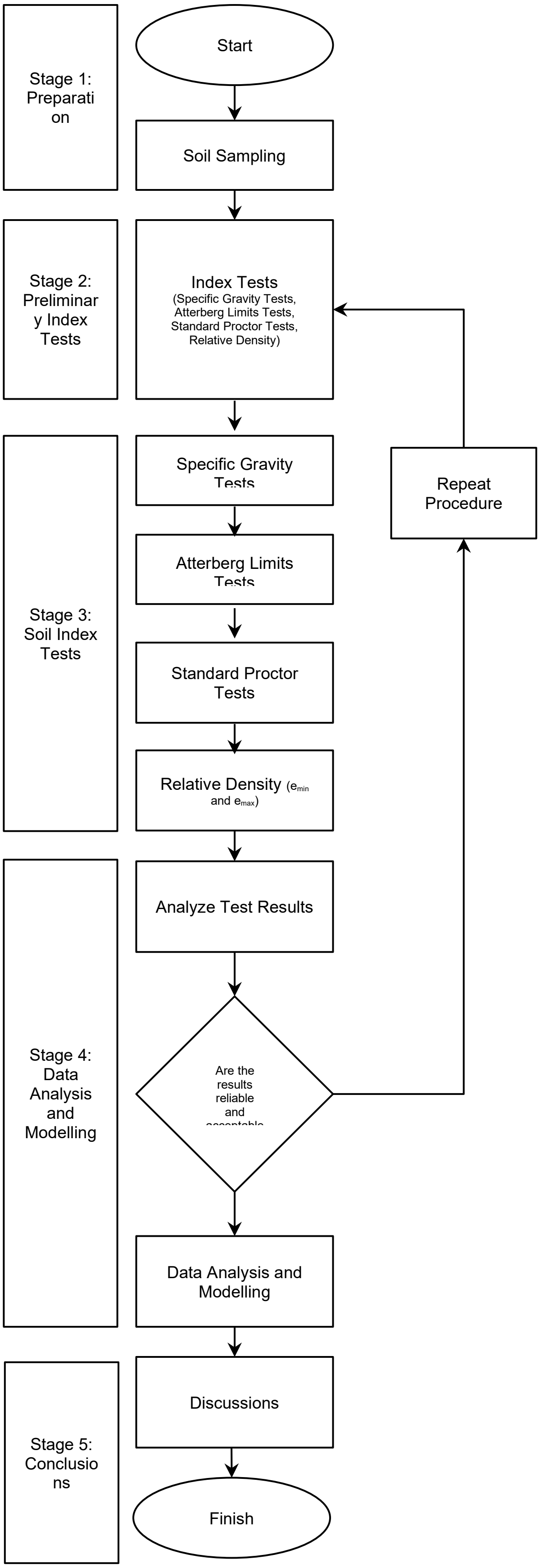

Figure 1. *Flowchart of Experiment.*

3.2 Relative Density Test

Determining the maximum index density (emin) begins by weighing and measuring the mold to be used for the test. Biochar is then placed inside the mold which is poured in 1 layer. A surcharge weight is positioned on top of the soil simulating overburden pressure. The mold is placed on a vibrating table and subjected to vibration at 60 Hz for 8 minutes. Afterwards, the mold with the compacted biochar is weighed, and the value of emin is calculated based on the volume and mass. see Figure 3 for the setup for the test

Figure 2. *Specific Gravity Test Setup*

Figure 3. *Maximum Index Density Test Setup*

Minimum index density (emax) under ASTM D4254 also starts with weighing and recording the dimensions of the mold. The biochar is then introduced into the mold which is poured from approximately 25 mm above the mold. No compaction, tamping, or vibration is to be done in this procedure. Once the mold is filled, a straightedge is used to level the soil surface. The mold with the soil is then weighed, computing emax accordingly. The setup for this test is seen in Figure 4.

Figure 4. *Minimum Index Density Test Setup*

The relative density test evaluates the degree of compactness of granular soils, comparing them to the states where they're loosest and densest. This involves determining the maximum index density (emin), and the minimum index density (emax), following ASTM D4253 and ASTM 4254 respectively.

4. DISCUSSION

4.1 Specific Gravity

The experiment procedure required multiple trials in order to achieve the desired specific gravity within the range of 1.5 to 2.0. A total of 3 trials that yielded a specific gravity within the desirable range were accepted to be averaged to determine the specific gravity of RHB. Table 1 shows the data used in calculating the accepted trials during the procedure. The density of the water was interpolated using the density of water below and above the actual temperature. The weight of the dish was recorded just before the water and soil were transferred into it in order to reduce any discrepancies due to aspects such as leftover water from cleaning the pan when weighing it at the start of the procedure.

Table 1. *Data Used in Calculating Specific Gravity of RHB*

Specific Gravity Test Data			
	Trial 1	Trial 2	Trial 3
Sample	RHB	RHB	RHB
Flask, g	519.96	519.62	515.05
Flask + Water + Biochar, g	1075.45	1083.28	1101.54
Temperature, °C	22.7	20.5	22.9
Flask + Water, g	1022.19	1003.37	1041.77
Dish + Dry	346.81	369.78	360.98

Biochar, g			
Dish, g	213.42	222.95	219.33
Weight of the Dry Biochar	133.39	146.83	141.65
Water Density, g/mL	0.9976	0.9981	0.9976

The specific gravity that was assumed for RHB is 1.86, which is the average of the three accepted trials found in Table 2. A specific gravity of 1.86 would mean it's 1.86 times heavier than water unlike Alluvial Soil which is 2.75 times heavier. The determination of the specific gravity of a soil sample is essential in determining the void ratio of the sample as well as for determining the grain size distribution [15]. As the biochar needed to be mixed with water for the test and also mixed with soils for permeability tests, the rice husk biochar sample had to be ground beforehand with the use of a motorized soil grinder. As the sample was ground, this material's grain size distribution was not assessed as the material is closer to ash than soil. Specific gravity (Gs) is a dimensionless value representing the ratio of the unit weight of soil solids to that of water, with RHB falling under a specific range as mentioned previously.

Table 2. *Summary of Results of Specific Gravity of Rice Hull Biochar*

Specific Gravity Test Results			
	Trial 1	Trial 2	Trial 3
Specific Gravity	1.66	2.19	1.73
Average		1.86	

The RHB having a specific gravity of 1.86 would mean that the sample has less dense particles with more organic content within them [7]. With rice hull biochar being an organic material, it has more carbon and silica content than minerals such as alluvial soil. As alluvial soil can be regarded as miniscule bits of sediment and rock, ground rice hull biochar will be significantly less dense and lighter than it [16]. Additionally, comparing a coarse-grained soil such as alluvial soil to a ground organic material that has undergone pyrolysis will result in having a significantly higher specific gravity, being denser as well as heavier. Having a relatively lower specific gravity could mean that adjustments may have to be made for subsequent tests when biochar is mixed in with coarse-grained alluvial soil and fine-grained low plastic clay as too much of the material will lead to negative results when adding it by weight instead of by volume.

4.2 Relative Density

Similarly to the specific gravity tests, testing for the minimum and maximum void ratios of RHB required 3 trials in order to determine a value to be assumed in subsequent tests. The heights and diameters of the proctor mold used for the experiment have been recorded to ascertain the dimensions to reduce any discrepancies in the data gathering procedure. Q1 to Q4 represents that height of the biochar in each quadrant of the proctor mold. As there isn't a guarantee that all quadrants of the proctor mold will have the same height as each other, getting each quadrant is a method to be done to assume a value to be used in subsequent computations. As completing 3 trials for this test uses the same proctor mold, remeasuring its dimension would still be ideal in case of any small changes such as how the mold sits into the plate or how tight the mold is set up. The dry unit weights of the sample were also recorded and listed in Table 3 along with the data recorded prior to computation.

Table 3. *Data Used in Calculating Minimum Void Ratio (emin) of RHB*

Index Test Data			
	Trial 1	Trial 2	Trial 3
Height of the Mold, mm	116.4	116.4	116.4
Diameter of the Mold, mm	101.5	101.5	101.5
Q1	19.9	17	19.6
Q2	20.8	17.6	20
Q3	20.7	18	19.5
Q4	20.8	20	18.7
Change in Height, mm	20.55	18.15	19.45
Compacted Height, mm	95.85	98.25	96.95
Volume	0.000776	0.000795	0.000784
Biochar + Mold, kg	4.583	4.605	4.567
Weight of Biochar, kg	0.502	0.524	0.486
Dry Unit Weight, kN/m^3	6.350	6.466	6.071

Based on the results of three trials to determine the minimum void ratio tests, the average of emin and emax will be used to compute the relative density, see Table 4. The average of the three trials of the minimum void ratio is 1.90. Additionally, the average dry unit weight of RHB was found to be 6.296 kN/m^3. The minimum void ratio is when the sample is in its densest state, it's a parameter that shows how compressible a soil is [17]. How much a soil is compressible can help predict the soil's performance in conditions involving placing a heavy object on top of it. This property of a soil or any granular material such as rice hull biochar can influence its compressibility when mixed with alluvial soil and clay.

Table 4. *Summary of Results of Relative Index Density Tests of RHB*

Relative Index Density Test Results			
	Trial 1	Trial 2	Trial 3
Minimum Void Ratio	1.874	1.822	2.005
Average		1.900	
Dry Density of the Biochar, kN/m³	6.350	6.466	6.071
Average		6.296	

The test for the maximum void ratio isn't as complicated as the test for the minimum void ratio as the goal is to maximize the amount of voids in a sample as naturally as possible, which means no agitation of the sample after putting it into the mold is allowed. Table 5 shows the data used for computation of the maximum void ratio of the biochar.

Table 5. *Data Used in Calculating Maximum Void Ratio (emax) of RHB*

Index Test Data			
	Trial 1	Trial 2	Trial 3
Height of the Mold, mm	116.4	116.4	116.4
Diameter of the Mold, mm	101.5	101.5	101.5
Volume, m	0.000942	0.000942	0.000942
Biochar + Mold, kg	4.585	4.607	4.569
Biochar, kg	0.504	0.526	0.4875
Dry Unit Weight, kN/m³	5.244	5.479	5.078

The 3 accepted trials for the maximum void ratio are summarized in Table 6, with an average of 2.468. The minimum dry densities of the 3 trials are also listed in Table 6 with an average of 5.267 kN/m^3. Along with the minimum void ratio determined previously, these two parameters can put into perspective the compressibility of the soil, or the rice hull biochar sample in this case [18]. With the emin and emax values determined, the void ratio of the biochar was computed to be 1.957 and will be used in future tests if needed. When the rice hull biochar is mixed with alluvial soil and low plastic clay, the void ratios will change and more tests may need to be performed.

Table 6. *Summary of Results of Relative Index Density Tests of RHB*

Relative Index Density Test Results			
	Trial 1	Trial 2	Trial 3
Maximum Void Ratio	2.479	2.330	2.593
Average		2.468	
Dry Density of the Soil, kN/m³	5.244	5.479	5.078
Average		5.267	
Accepted Void Ratio		1.957	

Given the maximum and minimum void ratios of RHB, the void ratio of RHB to be used in subsequent experiments will be 1.957. Having a higher void ratio can mean that the sample has a higher degree of compaction [8]. A higher degree of compaction means that the sample can be compacted more and can have a lower void ratio if compacted enough. The comparison between the maximum and minimum void ratios indicate how much rice hull biochar can be compacted, its compressibility may have a significant effect towards the compressibilities of alluvial soil and low plastic clay when it's mixed in for permeability tests in the future.

5. CONCLUSION

In summary of findings, the study has been successful in evaluating the index properties of Rice Hull Biochar (RHB) with regards to its specific gravity and relative density in determining its potential as a soil additive for permeability or stability. The results of the specific gravity tests showed an average of 1.86, confirming that its particles are less dense than other soils such as alluvial soils and low plastic clay with its organic origin. Rice hull biochar contains more amounts of carbon and silica than denser minerals in sediments such as in alluvial soil.

In addition, the relative density tests conducted determined that RHB had an average minimum void ratio of 1.9 and an average maximum void ratio of 2.468, which resulted in the void ratio to be used being 1.957. This would indicate that RHB is a relatively porous material with a higher degree of compaction which can lead to greater water retention properties when mixed with soil. The compressibility of rice hull biochar can be seen by the difference between the maximum void ratio and the minimum void ratio as its loosest and densest states respectively.

In conclusion, these findings show that rice hull biochar has a potential to be a viable sustainable additive to soil for water retention and enhancing hydraulic conductivity. As claimed by other previous related literature, the by-product of rice processing can be added to soil samples for stability and water retention, which in this case would be rice hull biochar instead of rice straw or rice hull ash. As this specific sustainable material is to be used for permeability tests when mixed with alluvial soil and low plastic clay, its characteristics are fit to be used for these subsequent tests to study its performance.

6. REFERENCES

Cite at least two relevant articles from previse IEICES Proceedings (http://www.tj.kyushu-u.ac.jp/en/igses/ieices/proceedings.php)

Reference to a journal publication:

[1] Dutt, A., Lata, N., & Nagar, B.B. (2020). Rice Husk Ash and Uses: A Brief Review. *Journal of emerging technologies and innovative research*.

[2] Li, Z., Zheng, Z., Li, H., Xu, D., Li, X., Xiang, L., & Tu, S. (2023). Review on Rice Husk Biochar as an Adsorbent for Soil and Water Remediation. *Plants*, *12*(7), 1524. https://doi.org/10.3390/plants12071524

[3] Lobzenko I, Burachevskaya M, Zamulina I, Barakhov A, Bauer T, Mandzhieva S, Sushkova S, Minkina T, Tereschenko A, Kalinichenko V, et al. Development of a Unique Technology for the Pyrolysis of Rice Husk Biochar for Promising Heavy Metal Remediation. *Agriculture*. 2022; 12(10):1689. https://doi.org/10.3390/agriculture12101689

[4] Chuyaco, F. M., Warren, C. O., Tan, F., Vasquez, A. K., Ubay-Anongphouth, I. O., Galupino, J., & Uy, E. E. (2024). Assessing the potential of horsetail ash as a sustainable additive in infrastructure materials through ignition testing. EnPress Publisher. https://doi.org/10.24294/jipd.v8i10.5376

[5] Jansomboon, W., Boonmaloet, K., Sukaros, S., & Prapainainar, P. (2016). Rice Hull Micro and Nanosilica: Synthesis and Characterization. Key Engineering Materials, 718, 77–80. https://doi.org/10.4028/www.scientific.net/kem.718.77

[6] Adajar, M. A., Cacho, E. A., De Castro, M. J., & Robles, P. J. (2024). *Utilization of Agricultural Wastes in Enhancing Strength and Reducing Shrink-Swell Potential of Expansive Soils*. Kyushu University Library. https://catalog.lib.kyushu-u.ac.jp/opac_download_md/7323252/2024_p121.pdf

[7] Dreshaj, A., Orqusha, N., Berlajolli, V., Osmanaj, A. (2024). Quality Assessment Through Land Use Change, Land Surface Temperature - An Environmental Factors Analysis. *Ecological Engineering & Environmental Technology*, *25*(6), 200-207. https://doi.org/10.12912/27197050/187041

[8] *Relative density - Soil mechanics - Civil engineering*. (2024, September 3). MADE EASY Study Material for GATE, ESE and PSUs Exams 2025-26. https://study.madeeasy.in/ce/soil-mechanics-foundation-engineering/relative-density/

[9] Prakongkep, N., Gilkes, R.J., Wiriyakitnateekul, W., Duangchan, A., Timtong, & Darunsontaya (2013). The Effects of Pyrolysis Conditions on the Chemical and Physical Properties of Rice Husk Biochar.

[10] Zarebanadkouki, M., Hosseini, B., Gerke, H. H., & Schaller, J. (2022). Amorphous silica amendment to improve sandy soils' hydraulic properties for sustained plant root access under drying conditions. *Frontiers in Environmental Science*, *10*, 935012.

[11] Fung, V. W. (2003). Biomass power development for the Philippines. In *2003 ASAE Annual Meeting* (p. 1). American Society of Agricultural and Biological Engineers.

[12] Barbosa, L. A. P., Stein, M., Gerke, H. H., & Schaller, J. (2024). Synergistic effects of organic carbon and silica in preserving structural stability of drying soils. *Scientific Reports*, *14*(1), 8330.

[13] Guo, J., & Chen, B. (2014). Insights on the molecular mechanism for the recalcitrance of biochars: interactive effects of carbon and silicon components. *Environmental Science & Technology*, *48*(16), 9103-9112.

[14] Jinhua, Y., & Renkou, X. (2010). Effects of Rice-Hull-Based Biochar Regulating Acidity of Red Soil and Yellow Brown Soil. *Journal of Ecology and Rural Environment, 26*, 472-476.

[15] Mir, B.A. (2021). Specific Gravity of Soil Solids. *Manual of Geotechnical Laboratory Soil Testing*.

[16] Singh, G.S., & Sharma, A.K. (2023). A Study on the Engineering Behaviour of Grouted Alluvial Soil.

[17] Kim, J., Kawai, T., & Kazama, M. (2019). Minimum void ratio characteristic of soils containing non-plastic fines. *Soils and Foundations*, *59*(6), 1772-1786.

[18] Zhong, H., Zhu, Z., Zhao, J., Wei, L., Zhang, Y., Li, J., Wang, J., & Yao, W. (2024). Influence of Fine Content and Mean Diameter Ratio on the Minimum and Maximum Void Ratios of Sand–Fine Mixtures: A Discrete Element Method Study. *Buildings*.