Moisture and the Angle of Repose of Soils

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The angle of repose is an essential characteristic of granular materials, which refers to the angle at which a bulk material will be stable when piled up. This critical parameter affects numerous sectors such as geotechnical engineering, geology, or powder technology, together with various applications, spanning from slope stability or retaining wall design to the flow characteristics of industrial powders. The moisture content is another factor that defines the angle of repose because it changes the interparticle forces in granular media. Small amounts of moisture improve cohesion and increase the degree of compaction. However, high moisture levels reduce the inter-particle bond strength and decrease the angle of repose, leading to landslides and building collapse. This paper analyzes how soil moisture levels affect the angle of repose of specific soil types. Information from trustworthy Internet sources is required to determine and compare the angle of repose of different dry and wet or moist soils. The results of this study provide a better understanding of the relationship between moisture content and the angle of repose that shall help create safer and sustainable structures.

Research Question

Does increasing the moisture content in a material significantly decrease its angle of repose due to enhanced particle adhesion?

Hypothesis

H_0: There is no significant difference in the angle of repose between materials with higher moisture content and their dry counterparts.

H_1: Materials with higher moisture content will have a lower repose angle than their dry counterparts due to increased particle adhesion.

Background

The angle of repose is an essential characteristic of granular media, including soils, which plays a pivotal role in the observed behavior of these materials under different natural and artificial conditions. As the maximum angle for forming a stable slope of a particular material, the angle of repose is an important parameter in geotechnical engineering, geology, and powder technology (Elekes & Parteli, 2021). This angle defines the stability of ramps, the construction of retaining walls, the flowability of bulks and the formation of natural forms. There are several causes of the angle of repose, such as particle size and shape, the roughness of particles, and inter-particle forces. However, moisture content is one of the most critical factors. The presence of water in granular materials changes the forces acting between the particles or grains, hence changing its stability and repose angle.

Influence of Moisture on Interparticle Forces

The processes of water being adsorbed to soil particles are strictly physicochemical. Water forms menisci on the particle contacts at low moisture levels, leading to capillary forces holding the particles together (Mehan & Eslamian, 2023). This occurrence is called capillary cohesion, and it improves the stability of the material and even increases the angle of repose. Indeed, with increasing moisture content, the thickness of the water films increases parallel with the weakening of the capillary forces. In addition, at higher moisture content values, the water forms in the pores between particles and the contact area decrease, reducing the frictional forces that contribute to stability, as Mehan & Eslamian (2023) noted. In some instances, the particles also tend to disperse and separate with water, which leads to a fluid-like material and a very low angle of repose. An example of this is in landslides and soil liquefaction, where the strength of saturated soils reduces and thus moves by the force of gravity.

The Angle of Repose in Geotechnical Engineering

The angle of repose is an essential parameter in geotechnical engineering when considering the stability of the fill materials and structures created from such materials as embankments, slopes, and retaining walls; the angle of repose is a crucial measurement used to determine the stability of structures and structures involved in handling and transporting granules to avoid future mishaps that could lead to considerable losses in cash and the environment (Doan et al., 2023). For instance, in ordering the pile of granular materials, the angle of repose defined the maximum slope that can be achieved without slipping, which would cause danger to the workers.

Moisture Content and Geotechnical Design

Consequently, these findings can be of great significance to numerous geotechnical activities that involve actual values of the angle of repose, including the effect of moisture content on it. Different types of soil can affect the design: Rainfall, infiltration, drainages, and groundwater are some of the aspects of consideration for engineers (ElMouchi et al., 2021). Variations in moisture also affect slope stability because they may cause landslides or soil substance loss. Furthermore, for this reason, most geotechnical designs incorporate a drain or some means to regulate the water content in a given soil mass.

Literature Review

The angle of repose is one of the most widely studied values for granules. It has attracted much attention in the literature from different disciplines because of its significance in numerous natural occurrences and design structures. However, this review assesses prior studies related to the angle of repose, focusing on the moisture content and its implications for the stability of soils.

Factors Influencing Angle of Repose

Several parameters that influence the angle of repose are the size and shape of the particles, the arrangement and geometry of the surfaces, and the nature of other interfacial forces. Chen et al. (2020) have also stated that little particles have a low angle of repose since the cohesiveness factor is often high. Another factor that can be discussed is the particle shape: interlocking results in irregular particles having larger angles of repose than whirls, possibly due to rolling.

Moisture Content and Interparticle Forces

The proportion of water in the particulate solids influences the interparticle forces and, therefore, impacts the repose angle. When there are liquid bridges between the particles, capillary force enhances the cohesiveness, while the angle of repose increases when the moisture content is low (Chen et al., 2020). However, when the moisture content increases, the thickness of the capillary bridges increases, and there is a reduction in the cohesive forces, which may even decrease the angle of the repose.

Soil Mechanics and the Angle of Repose

In soil mechanics, this parameter is key in deciding slope stability and providing earthfill works in a construction project. It should also be noted that the steeper soils are more stable than the flatter ones since the latter often contains landslides and erosions (Gabor, 2023). The water content has a considerable impact on the stability of the soil as it is associated with internal friction and cohesiveness of the soil.

Recent Advances in Understanding Moisture Effects

Some of the advances that have been made in the recent past include the following: Several ways have been used to investigate the effect of moisture content on the angle of repose. DEM simulations have provided qualitative information on the behaviour of granules at a small scale under varying moisture content (Al-Khateeb et al., 2021). In such cases, using the above simulations, it has been realized that moisture is very crucial in particle packing, force distribution, and stability.

Experimental Studies on Moisture and Angle of Repose

From the above literature review, many researchers have ventured into establishing the effect of moisture content on the reposting angle of different materials. Yin et al. (2021) also employed the angle of repose to study different types of soil blends. They pointed out that when the amount of moisture was high, the repose angle was lower than the standard value, particularly in fine-grained soils. In another study by Zhang et al. (2024), they discussed the effect of rainfall intensity on the angle of repose in hillslope soils and how this leads to the occurrence of landslides as the intensity increases, but the angle of repose reduces.

Applications in Geotechnical Engineering

Thus, the relationship between the angle of repose and the moisture content must be understood in various geotechnical fields. Another issue with designing the embankments and slopes is how the strength of the soil changes with variations in moisture content, which has consequences on the stability of the slope (Gabor, 2023). Rainwater and increased moisture content are the primary agents that cause changes in the angle of repose, which proper drainage systems and soil reinforcement may eliminate.

Data collection

A comprehensive data collection process was undertaken for the study. The information was drawn from publicly available online resources. This section details the data acquisition, extraction, cleaning, and organization methodology.

Data Sources

Three primary online sources were identified and utilized for the collection of data on the angle of repose of various soil types:

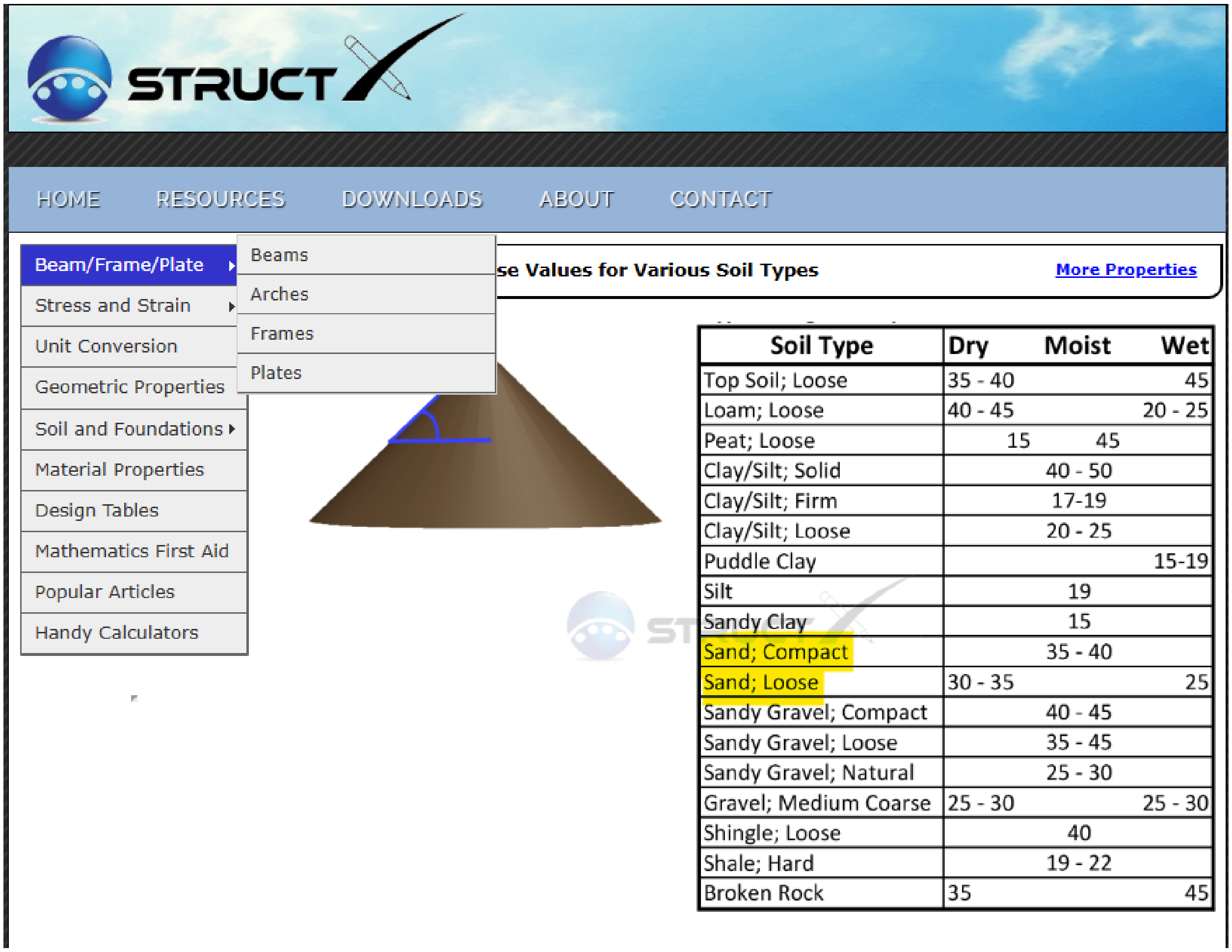
ResearchGate. Al-Hashemi & Al-Amoudi (2018) presented an extensive list of typical angles of repose in the table, and all kinds of soils were included in the list. This source was obtained from the Research Gate website, where the angle of repose for both dry and wet sand is given in Figure 1. This source was helpful because it provided highly reliable information and diverse subject matters.

Material (condition)	Angle of repose
Ashes	40°
Asphalt (crushed)	30–45°
Bark (wood refuse)	45°
Chalk	45°
Clay (dry lump)	25–40°
Clover seed	28°
Coconut (shredded)	45°
Coffee bean (fresh)	35–45°
Earth	30–45°
Flour (corn)	30–40°
Flour (wheat)	45°
Granite	35–40°
Gravel (crushed stone)	45°
Gravel (natural w/ sand)	25–30°
Malt	30–45°
Sand (dry)	34°
Sand (water filled)	15–30°
Sand (wet)	45°
Snow	38°
Wheat	27°

Typical values of angle of repose [30].

Fig. 1: Data from Research Gate's article by Al-Hashemi & Al-Amoudi (2018)

StructX. The website StructX provided more comprehensive data on soil properties, and information on the characteristic AC of various types of soil regarding the dry and saturated states was provided. This source was helpful because it explained the distinction between dry and moist soils regarding the angle of repose, a critical characteristic of this study (StructX, n.d.).



Soil Type	Dry	Moist	Wet
Top Soil; Loose	35 - 40		45
Loam; Loose	40 - 45		20 - 25
Peat; Loose	15	45	
Clay/Silt; Solid		40 - 50	
Clay/Silt; Firm		17-19	
Clay/Silt; Loose		20 - 25	
Puddle Clay			15-19
Silt		19	
Sandy Clay		15	
Sand; Compact		35 - 40	
Sand; Loose	30 - 35		25
Sandy Gravel; Compact		40 - 45	
Sandy Gravel; Loose		35 - 45	
Sandy Gravel; Natural		25 - 30	
Gravel; Medium Coarse	25 - 30		25 - 30
Shingle; Loose		40	
Shale; Hard		19 - 22	
Broken Rock	35		45

Fig. 2: Data from StructX (n.d.)

Engineering Toolbox. According to the Engineering Toolbox website, it contains dumping angles of different bulk materials equal to the angle of repose, including several soil types (Engineering Toolbox, n.d.). This source provided tangible, applicable information for the reader in an engineering setting.

atmosphere
mm H_2O
kg/cm^2
psi
inches H_2O
Convert!

Flow
1.0
m^3/s
m^3/h
US gpm
cfm
Convert!

12.6.9

Material	Angle of Repose (degrees)
Malt	30 - 45
Marble, broken	30 - 45
Mica, broken	30 - 45
Milk. powdered	45
Oats	32
Oats, rolled	30 - 45
Ore, dry	30
Ore, damp or fresh mined	37
Oyster shells, ground	30 - 45
Peanuts, shelled and not shelled	30 - 45
Potassium chloride	30 - 45
Rice grits	30 - 45
Rice, rough	30 - 45
Rubber, ground scrap	45
Rubble	45
Salt, coarse	30 - 45
Salt, fine	30 - 45
Saltpeter	30 - 45
Sand, dry	35
Sand, damp	40
Sand, with crushed stone	27
Shale, broken	30 - 45
Shingles	40
Slate, pulverized	30 - 45
Soap, chips	30 - 45
Soap. powder	30 - 45
Soda ash	30 - 45
Stone	30
Stone, broken	27
Stone, crushed	30
Sugar, granulated	30 - 45
Sugar, raw cane	45
Sulfur	30 - 45
Tobacco	45
Wheat	28
Zinc oxide	45

Fig. 3: Data from Engineering Toolbox (n.d.)

Data Extraction

Data extraction from the identified sources entailed an exhaustive process of reaching out for the required data from the source using proper channels to ensure accuracy and conformity to the research question asked. The following steps were undertaken:

1. **Targeted Extraction:** This study's primary emphasis was accorded to soil material. Accordingly, the data extraction process consisted of carefully examining and including only entries referring to soil types. This ensured that the dataset collected was precisely accurate and would guarantee an answer to the research question.
2. **Moisture-Based Categorization:** Since the purpose of the analysis was to understand the change in the angle of repose due to moisture, the data collected for the angle of repose was divided into two clear sets: “Dry” and “Wet/Moist.” This categorization was done to describe the moisture condition in either an implicit or pointed-out manner, depending on the angle of repose value documented from the existing source material.
3. **Data Cleaning:** In some cases, the sources provided a set of different values for the angle of repose for a specific soil type, which is entirely logical because this characteristic can easily vary due to natural factors. For easier comparison and to make each range’s variables statistically manageable, each range’s average or the arithmetic mean was computed. This mean value was then considered as the angle of repose representative of the given soil type and its degree of moisture.

Data Organization and Presentation

The data collected was organized using records in tables using Microsoft Excel. These columns included the material type, which had more details on compactness and particle size, size- the mean angle of repose for dry soil and the mean angle for wet or moist soil. This organization provided a route to make direct comparisons and evaluations of the effect of moisture on the angle of repose.

Data Analysis

A paired t-test was conducted to determine the effect of moisture content on the angle of repose. This statistical test was chosen because it is appropriate for comparing the means of two related groups, in this case, the angle of repose of the same soil types under dry and wet/moist conditions. The paired t-test assesses whether there is a statistically significant difference between the paired measurements. The analysis was performed using Microsoft Excel's built-in t-Test: Paired Two Sample for Means function. The data used for this analysis were the mean angles of repose for each soil type under dry and wet/moist conditions, as detailed in the Data Collection section.

Results

The analysis compared the mean angle of repose for five soil types under dry conditions to their corresponding mean angles under wet/moist conditions. The null hypothesis predicted no significant difference in the angle of repose between dry and wet/moist conditions. In contrast, the alternative hypothesis predicted a substantial decrease in the angle of repose with increased moisture content.

The results of the paired-samples t-test indicated that there was no significant difference in the angle of repose between dry soils ($M = 36$, $SD = 6.02$) and wet/moist soils ($M = 37$, $SD = 9.91$), $t(4) = -0.43$, $p = .688$. This finding fails to support the hypothesis that increased moisture content significantly decreases the angle of repose. Despite the non-significant result, descriptive analysis revealed a slight increase in the mean angle of repose for wet/moist soils compared to dry soils. However, this observed difference was not statistically significant. The data also showed a more considerable variance in the angle of repose for wet/moist soils ($SD = 9.91$) compared to dry soils ($SD = 6.02$). This suggests that the influence of moisture on the angle of repose may be more variable across different soil types.

Table 1. T-test Results Comparing Angle of Repose in Dry and Wet/Moist Soil Conditions

Condition	n	Mean	SD	t-cal	t-crit	df	p	Decision
Dry	5	36	6.02	-0.43	2.776	4	0.688	Reject
Wet/Moist	5	37	9.91					

These findings suggest that, based on the analyzed dataset, the effect of moisture content on the angle of repose may not be as pronounced as initially hypothesized. Further research with a more extensive and diverse sample of soil types, ideally with primary data collection under controlled conditions, is warranted to investigate this relationship further.

Observations

The analysis of the collected data revealed several key observations regarding the relationship between moisture content and the angle of repose of different soil types:

1. **No Consistent Trend**

It took work to point out a consistent and coherent trend as to how the angle of repose of the soil type fluctuated based on the moisture content and soil type across the different investigations. Upon comparison, some soils tended to have a slightly higher angle of repose when wet, while others did.

2. **Variability Among Soil Types**

The susceptibility of the various types of soils to moisture fluctuation was not constant. This implies that other parameters like particle size distribution, shape, and mineralogy may tremendously impact the spokesperson award by moisture. For instance, soils composed of sand had a sharper inclination in the angle of repose when wet compared to the inclination noted in gravelly soils.

3. **Influence of Compaction**

Moisture also seemed to be affected by the first compaction of the soil. It was also observed that the angle of repose decreased sharply with the moisture content in the case of loosely compacted sands, possibly due to increased inter-particle friction. However, a slight increase in the angle of repose with moisture was observed in compacted sands, primarily because of the increase in cohesion.

4. **Limited Effect of Moisture**

In general, the changes in the angle of repose due to moisture effects were relatively small and easily noted. This indicates that the moisture content within the ubiquitous extent of these soil types may not necessarily be the decisive factor governing the angle of repose.

Discussion

This research aimed to establish how their moisture content influences the angle of repose of different soil types. Thus, in contrast with the formulated hypothesis for the study, the results obtained from the paired-sample t-test suggested that there is not much difference in the angle of repose when working with dry and wet/moist conditions. Based on this finding, it can be concluded that, to some extent, moisture content does not cause the angle of repose to reduce significantly. The following could have contributed to the non-acceptance of the hypothesis: The relatively small set of results, where only five basic soil types were tested, contributed to the inability to define specific trends. Furthermore, using data collected from the internet added procedural variability in the measurement methods and soil properties, which might have concealed the influence of moisture. In addition, the analysis did not consider other factors that may also affect the angle of repose, such as particle size distribution and particle shape, which may interact with moisture content.

While the findings of this study do not support the initial hypothesis, they are consistent with some aspects of the existing literature. It is worth indicating that Li et al. (2020) showed that the connection between the level of moisture content and the angle of repose depends on the nature of the materials and presents non-linear properties. At low moisture contents, capillary forces improve cohesiveness and the angle of repose increases (Doan et al., 2023). However, these forces are reduced at higher moisture content, and water, which provides a lubricating effect, can reduce the angle of repose (Doan et al., 2023). The observed fluctuation in the response of various types of soil to moistening agrees with the concept that the properties of particles affect the response of granules in a sensible manner. The compaction forces add to this complexity as the initial density of the soil plays the role of interparticle forces and the moisture distribution within the material (Zhang et al., 2024).

Although the t-test a is not significant in this context, this research contributes to understanding the complex relationship between moisture content and angle of repose. Hence, it highlights the need to consider the variation of the soil properties and conditions in the environment while examining the stability of slopes and designing geotechnical structures. Future research should solve these study limitations by incorporating a sufficiently large and representative dataset encompassing a range of soil samples with well-defined characteristics. Using laboratory-controlled experiments, maintaining a standard moisture content and standard soil compaction would assist in establishing variation caused by moisture content on the angle of repose. Techniques such as DEM could be used to improve the understanding of the micromechanical behavior of the soils under different moisture regimes.

From the preceding limitations, future research can help in providing some additional insights into the relationship between the moisture content and angle of repose with the following: Gaining this knowledge will ultimately foster better approaches to geotechnical engineering as well as offer a better way of constructing safer infrastructures and managing natural disasters effectively.

Conclusion

The effect of moisture content on the angle of repose of soils was the focus of this study. Surprisingly, the study's results did not show any significant difference in the angle of repose in the dry and wet/ moist states. This indicates that, to some extent, the moisture content should not necessarily be used to predict the angle of repose definitively. That could be attributed to several factors, such as the small sample size, variation in data from different sites, and effect modifier variables. The study here does not support the hypothesis. However, it suggests that the relationship between moisture content and angle of repose is more complex depending on soil type and environment when used in geotechnical engineering. Future research should address these limitations by enlarging the sample size, running experimental studies, and using more sophisticated analysis tools to fully untangle this relationship for safer and more sustainable infrastructural construction.

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