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Development of soil Particle size distribution model and determination of all related coefficients

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Abstract

Soil difficulties are mainly related to soil moisture and voids in soil. Tests on soil in laboratory are dealt with in different ways to develop analyses. Some of them deal with engineering properties, like shear strength, soil composition and structure. Soil composition is different from other materials. Soil consists of three phases: solid, liquid, and gaseous. There are special diagrams for expressing particle size distribution (Cu), uniformity coefficient (Cc) and coefficient of gradation (Gc). A real soil rarely contains similar-size particles only, but different sizes are mixed together. For any soil, there is a rather flat zone in the size distribution curve. For example, by the particle size distribution curve (D_{10}). Such soils are described as gap-graded because they are missing particles in a certain size range. Gap-graded soils are sometimes considered a type of poorly graded soil. Aggregates used to make concrete are typically gap-graded soils.

Key words: composition of soils, particle size distribution curve, particle size distribution (D10), Uniformity coefficient (Cu), and Coefficient of gradation (Cc).

Introduction

Real soil rarely contains only particles that fall completely within only one of the categories. There must be an effective means of presenting the distribution of soil particle sizes. This is the grain size distribution curve, such as those are shown in Figure 1. They are plots of the particle size versus the percentage of the particles by weight smaller than that size. A curve on the left side of the diagram in Figure 2, such as that for Soil A, indicates a primarily fine-grained soil (Donald P. et al., 2007).

For some soils, there is a nearly flat zone in the particle size distribution curve, as shown for example by the particle size distribution curve for Soil E in Figure 1. These soils are described as gap-graded because they are missing particles in a certain size range. Gap-graded soils are sometimes considered a type of poorly graded soil. Aggregates used to make concrete are typically gap-graded.

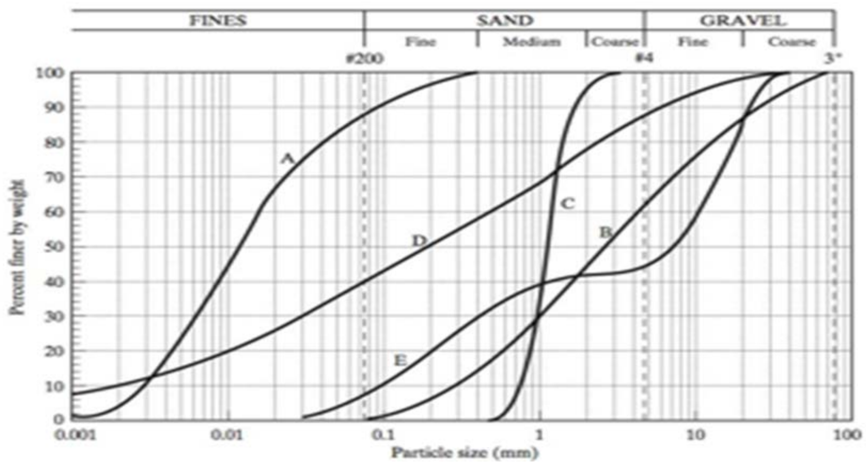


Figure-1 Particle size distribution curves for five soils (Soil A through Soil E)

The percentage of each type of soil particle can be determined by weight by comparing the percent passing the appropriate sieve sizes as listed in Table -1. For instance, divide the percentage passing through the #4 **in.** sieve by the percentage passing through the #200 **in.** sieve to find the amount of sand in a soil. The D-sizes are the sizes of particles that, for a certain soil, correlate to specific percent-passing values. The particle size that corresponds to 10% passage, for instance, is D10. In other words, 10% of the soil particles are finer than D_{10}. Two additional parameters, the coefficient of uniformity, Cu, and the coefficient of curvature, Cc, are based on the D-sizes (Donald P. et al., 2007):

Cu = (D60 /D10) …………………………..Eqn,(1)

Cc= (D30) 2/ (D10* D60) ……………………………..Eqn,(2)

Cu levels are low on steep curves, which represent poorly graded soils, and high on flat curves, which represent well-graded soils. Cc values for smooth-curving soils range between 1 and 3. Curves that are irregular have high or low values. For instance, the majority of soils with gaps have Cc values outside of this range.

Table 1. ASTM Particle Size Classification (ASTM D2487)

Sieve Size		**Particle Size**		**Soil Classification**	
Passes	Retained on	(inch)	(mm)		
	12 in.	>12	>300	**Boulder**	**Rock**
12 in.	3 in.	3-12	75-300	**Cobble**	**Fragments**
3 in.	¾ in.	0-75-3	19.0-75	Coarse gravel	soil
¾ in.	#4	0.19-0.75	4.75-19.0	Fine gravel	
#4? unit	#10	0.079-0.19	2.00-4.75	Coarse sand	
#10?	#40	0.017-0.079	0.425-2.00	Medium sand	
#40?	#200	0.003-0.017	0.075-0.425	fine sand	
#200?		<0.003	<0.075	Fines (silt + clay)	

Fine-grained soils have at least 50% passing through the #200 sieve. They are primarily silt and/or clay.

Most sand particles that may be present will be floating in a silt or clay matrix. In order to easily distinguish between clays and silts there is the plasticity chart in Figure 2 that uses the Atterberg?? limits as the basis for classifying these soils. This chart uses the Atterberg limits to distinguish between clays and silts. Although most fine- grained soils contain both clay and silt, and possibly sand and gravel as well, those that plot above the A-line are classified as clays, whereas those below this line are silts. It usually consists of two letters, which are interpreted as follows:

First Letter M Predominantly silt,
C Predominantly clay,
O Organic, Second Letter Low plasticity,
H High plasticity

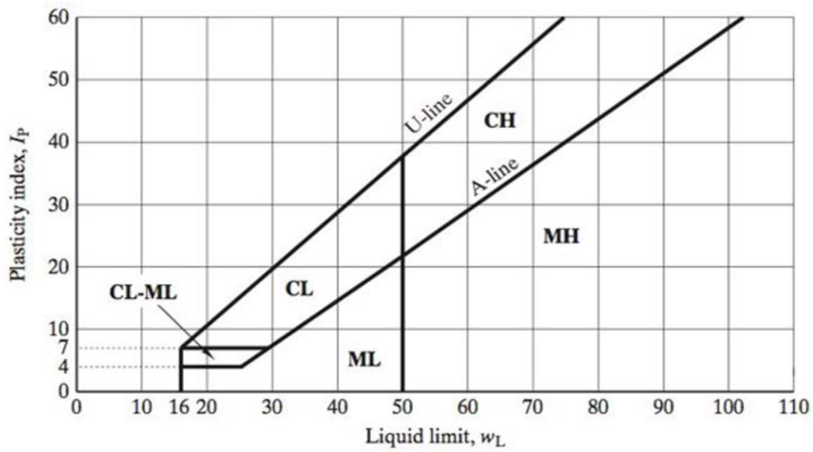


Figure -2

CL soils are known as lean clays, whereas CH soils are fat clays. The corresponding terms for ML and MH soils are silt and elastic silt, respectively, even though the stress–strain behavior of MH soils is no more elastic than any other soil. In this context, an organic soil is one that has a noteworthy percentage of organic matter, yet consists primarily of inorganic material. This differs from a highly organic soil, as described earlier (group symbol Pt), which contains much more organic material. With experience, one can usually determine whether a fine-grained soil is inorganic (M or C) or organic (O) by visual inspection. Alternatively, we could perform two liquid limit tests, one on an unmodified sample from the field and another on a sample that is first oven-dried. The drying process alters any organics that might be present, and thus changes the liquid limit. If the liquid limit after oven-drying is less than 75% of the original value, then the soil is considered to be organic. If not, then it is inorganic. Do not use the Atterberg limits from the oven dried sample to classify the soil. The tests on the oven dried sample are used only to determine whether or not the soil classifies as organic approaching zero can be found in very arid areas.

The individual solid particles in a soil can have different sizes and shapes, and these characteristics also have a significant effect on its engineering behavior. Therefore, geotechnical engineers often assess the distribution of particle sizes in a soil and the shapes of the particles in the soil.

Several systems have been developed to classify a soil particle based on its size. We will examine only one: the ASTM system, as described in Table -1. According to this system, particles are classified according to their ability to pass through a series of standard sieves. A sieve consists of a carefully manufactured mesh of wires with a specified opening size. Particles larger than 3 in. (76.2 mm), or more precisely, particles that cannot go through the 3 in. sieve, are known as rock fragments. Smaller particles are defined as soil.

As for the shape of silt, sand, and gravel particles they vary from very angular to well rounded, which is classified as, very angular, angular, subangular, subrounded, rounded, and well- rounded (Youd, 1973). The particle shape has some effect on soil properties. For example, everything else being equal, a soil with angular particles has a greater shear strength than one with rounded ones because it is more difficult to make angular particles slide or roll past one another. Some nonclay particles are substantially flatter than any of the samples displayed here. Mica is one example; it has a plate-like form. Although mica is never a significant fraction of the total weight, even a little amount might influence soil behavior. Sands with mica are referred to as micaceous sands.

Material and Methods:

Laboratory Tests:

Two laboratory tests are commonly used to provide more precise assessments: the sieve analysis and the hydrometer analysis Soil physical measurements are numerous, depending on the objective of the study. These measurements generally include soil water purpose on the content (Sparks et al., 1966), particle size, bulk density, aggregate stability, particle size distribution and other measurements. Once the percentage of sand, silt, and clay is determined the soil texture is fixed. The soil was classified by using soil textural triangle USDA (Richard, 1954).

The arrangement of soil particles is referred to as soil structure. When it comes to structure, soil particles include both the aggregate or structural elements that have been created by the aggregation of smaller mechanical fractions, as well as sand, silt, and clay. The soil structure can be cube-shaped, prismatic, or platter-like, and it can also vary in size, shape, and personality. The soil structure is divided into five categories based on size: extremely coarse (>10 mm), coarse (5–10 mm), medium (2–5 mm), fine (1-2 mm), and very fine (1 mm). The structure is classified as poorly developed, weekly developed, moderately developed, well developed, and highly developed based on the stability of the aggregate and the ease of separation. Particle size distribution was carried out by using the pipette method which described by Richards (1954), where sodium hexametaphosphate was used as dispersing agent. This analysis was carried out with and without CaCO3, total and different fractions of calcium carbonate were measured volumetrically by using Collins calcimeter (Nelson, 1982).

A sieve analysis is a laboratory test that determines a soil's particle size distribution by passing it through a succession of sieves. The diameters of the openings help identify the larger sieves. For instance, a spherical with a diameter of 3/4 in will hardly pass through a 3/4 in sieve. Smaller sieves have numbers that correspond to the number of apertures per inch. A #8 in sieve, for instance, has 64 apertures per square inch or 8 openings per inch. However, due to the thicknesses of the wires, each opening is smaller than 1/8 in. Table 1 lists the opening sizes of typical North American sieves.

Most people can just barely see 0.1 mm diameter objects without using a magnifying glass, and this nearly equals the #200 sieve size. This size also represents the border between gritty and smooth textures.

Although the sieve analysis works very well for particles larger than the #200 sieve (sand, gravel, and coarser particles) and it determines the total amount of fines, it does not give the distribution of finer particles (silt and clay particles). The smallest clay particles are only about (1 * 10-4 mm) in size, which is about the same size as a smoke particle. Practically speaking, it would be very difficult to separate the silt and clay particles into different size ranges by sieving because it would require very fine sieves that are almost impossible to manufacture.

To classify fine particles (sand, silt, and clay), we must employ another approach that provides us with the particle size distribution indirectly- hydrometer analysis. This process (ASTM D422) entails inserting a known Ws soil sample into a 1000 ml graduated cylinder and filling it with water. The laboratory technician violently shakes the container to suspend the dirt particles. When the suspension's density is uniform.

The soil particles begin to settle to the bottom of the cylinder after it has been positioned upright. Stoke's Law (Stokes, 1851) is used to describe this downward motion:

$v = (D^2 * \Upsilon_w (G_s - G_L)) / (18 \eta)$ …………………………..Eqn, (3)

Where:

v = velocity of settling soil particle

D = particle diameter

Υ_w = unit weight of water

G_s = specific gravity of solid particles

G_L = specific gravity of soil-water mixture

η = dynamic viscosity of soil-water mixture

Because velocity is proportional to particle dimension squared, larger particles settle significantly faster than smaller ones. Furthermore, we may calculate the mass of particles still in suspension by measuring the specific gravity of the soil-water mixture with a hydrometer. As a result, by taking a series of specific gravity measurements over a 24-hour period and applying Stoke's equation, we may establish the particle size distribution in the soil sample (Donald P. et al., 2007).

The hydrometer analysis is inefficient for particles larger than about #100 sieve size because they settle faster than the specific gravity can be measured with a hydrometer. However, we can determine the distribution of particle sizes for practically any soil by performing a sieve study, a hydrometer analysis, or both.

The percentage of each type of soil particle can be calculated by weight by adding the percentages that pass through the various sieve sizes mentioned in Table -1. To calculate the amount of sand in a soil, subtract the percentage that passes the #200 sieve from the percentage that passes the #4 sieve. The D-sizes are the particle sizes that correspond to specific percent-passing values for a given soil. D_{10}, for example, is the particle size corresponding to 10% passage. To put it another way, 10% of the soil particles are finer than D_{10}. Based on the D-sizes, two additional parameters, the coefficient of uniformity, C_u, and the coefficient of curvature, Cc, are calculated:

Silt, sand, and gravel particle shapes range from highly angular to well rounded, and are categorized as very angular, angular, subangular, subrounded, rounded, and well-rounded. (Youd, 1973). A soil with angular particles is most commonly found near the parent rock from which it is produced., while a soil containing rounded particles is most often found farther away as the particles have experienced more abrasion during the transportation process. The particle shape has some effect on soil properties. For example, everything else being equal, because it is more difficult to make angular particles slide or roll past one another, soil with angular particles has greater shear strength than soil with rounded particles. This is one of the reasons aggregate base materials used beneath highway pavements are frequently constructed of rocks that have been crushed by a rock crusher to produce very angular gravel. Clay particles have a completely different shape, which is covered in the following section. Nonclay particles can be significantly flatter than the samples shown here. Mica, for example, is a plate-shaped mineral. Although mica is never a significant fraction of the total weight, even a little amount might influence soil behavior. Micaceous sands are sands that include mica.

Systems have been applied to classify a soil particle based on its size mechanically, as the ASTM system, as described in Table -1 According to this system, particles are classified according to their ability to pass through a series of standard sieves. A sieve consists of a carefully manufactured mesh of wires with a specified opening size. Particles larger than sieve No. 4, (4.75 mm), or more precisely, particles that cannot go through the 4.75mm. sieve, are known as rock fragments. Smaller particles are defined as soil.

Results and Discussion:

Laboratory Tests:

Although particle size distribution may typically be assessed visually, two laboratory tests are usually performed to provide more precise assessments: sieve analysis and hydrometer analysis.

A- Sieve Analysis

1- A sieve analysis is a laboratory test that measures the particle size distribution of a soil by passing the soil through a series of sieves number. The passing particles from each sieve were reported.

2- Fine particles which their sizes less than 200 were also classified by technique of hydrometer test.

3- The ratio of quantity of sand, silt and clay were reported.

B- **Data analysis, calculations and results**

The following Table – 2 illustrates the how to develop the particle size distribution of the soil sample and how to develop the D_{10}, D_{30}, and D60. :

Table 2: Given data of sieve and texture analysis of soil

	Percentage passing of particle size						Percentage of fines		
Mish size	0.075	0.15	0.425	2	3.35	4.75	(Sand)	(Silt)	(Clay)
Max	**0**	21.714	75.697	95.618	98.406	100.000	63.300	32.700	26.300
Min	**0**	11.151	52.878	76.978	79.496	82.374	48.900	17.400	16.800
Average	**0**	17.900	62.893	85.351	88.615	91.533	58.633	21.392	19.975

Calculations are performed using average data by plotting a chart diagram between particle size (mm) in an x axis coordinate and percent finer in y coordinate.

And by regression analysis method develop the equation that relates them. Draw the fitting diagram between particle size and percent finer, logarithmic, and polynomial 3rd degree for improving R^2. The following diagrams illustrate Figure (4), Figure (5) and Figure (6).

To calculate D_{10}, D_{30} and D_{60} and the results are shown in table (3). To get D_{10} draw a line at 0.10 on (y) axis which indicates the percent finer parallel to x axis which indicates the particle size (mm) till meeting and intersecting the curve at coordinate of x-axis, as illustrated in Figure 5.

The results in model (1) are:

D_{10} = 0.117 mm

D_{30} = 0.224 mm

D_{60} = 0.407 mm

Then Calculate **the** coefficient of uniformity, $C_u = (D_{60} / D_{10}) = 3.484$

and the coefficient of curvature (gradation), $Cc = (D_{30})^2 / (D_{10} * D_{60}) = 1.0533$.

A well graded soil has Cc between 1 and 3, as long as C_u is also greater than 4 for gravels and 6 for sands.

Table 3. Calculation of D_{10}, D_{30} and D_{60} and the results. Calculation of D_{10}, D_{30} and D_{60} and the results.

	Opening (mm) (1)	Passed from each sieve	Opening (mm) (1)	Given % passed on each sieve (2)	Given % Passed on each sieve	Given % Retained on each sieve (3)	Cumulative Retained on each sieve (4)	Model Percent finer (5)	Model Percent finer (style-1) as polynomial curve	Model Percent finer (stylel-2) as Logarithmic curve	(DX) values Using developed Model percent finer	Using model of Percent finer
				100	1	0	0	1				
Mechanical Sieve Analysis	4.75	0.915	4.750	91.533	0.915	0.085	0.085	0.915	0.934	0.884	10.000	0.117
	3.35	0.811	3.350	88.615	0.886	0.029	0.114	0.886	0.824	0.835	20.000	0.163
	2	0.756	2.000	85.351	0.854	0.033	0.146	0.854	0.955	0.763	30.000	0.224
	0.425	0.537	0.425	62.893	0.629	0.225	0.371	0.629	0.471	0.546	40.000	0.285
	0.15	0.113	0.150	17.900	0.179	0.450	0.821	0.179	0.240	0.400	50.000	0.346
	0.075	0.000	0.075	0.000	0.000	0.179	1.000	0.000	0.168	0.303	60.000	0.407
Hydrometer classification Test	Pan	Sand	0.060	58.633	0.586	0.414	0.414	0.483	0.152	0.272	70.000	0.923
		Silt	0.040	21.392	0.214	0.372	0.786	0.018	0.132	0.215	80.000	1.625
		Clay	0.002	19.975	0.200	0.014	0.800	0.000	0.092	-0.204	90.000	4.014
Sum of Mechanical samples				346.292	4.049	1.000	2.537			Uniformity Coefficient Cu	D_{60}/D_{10}	3.484
Sum of Hydrometer samples				100.000	1.000	0.800	2.000			Gradation Coefficient Cc	$(D_{30})^2/(D_{10}*D_{60})$	1.053
total Sum				41.367		1.800	4.537					

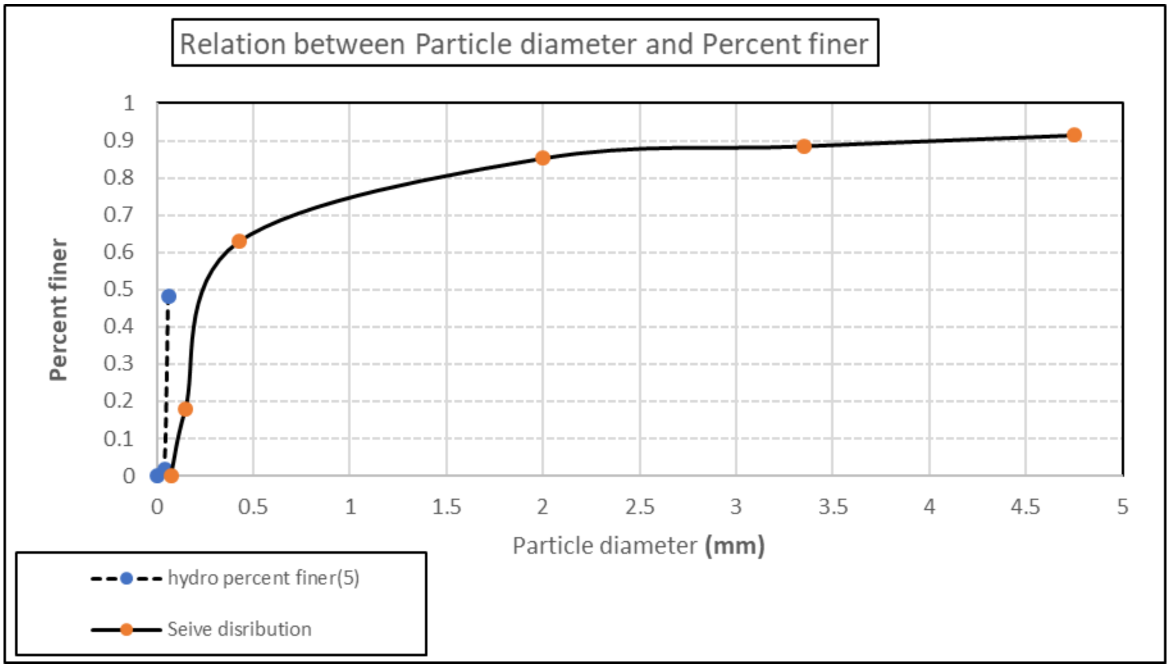
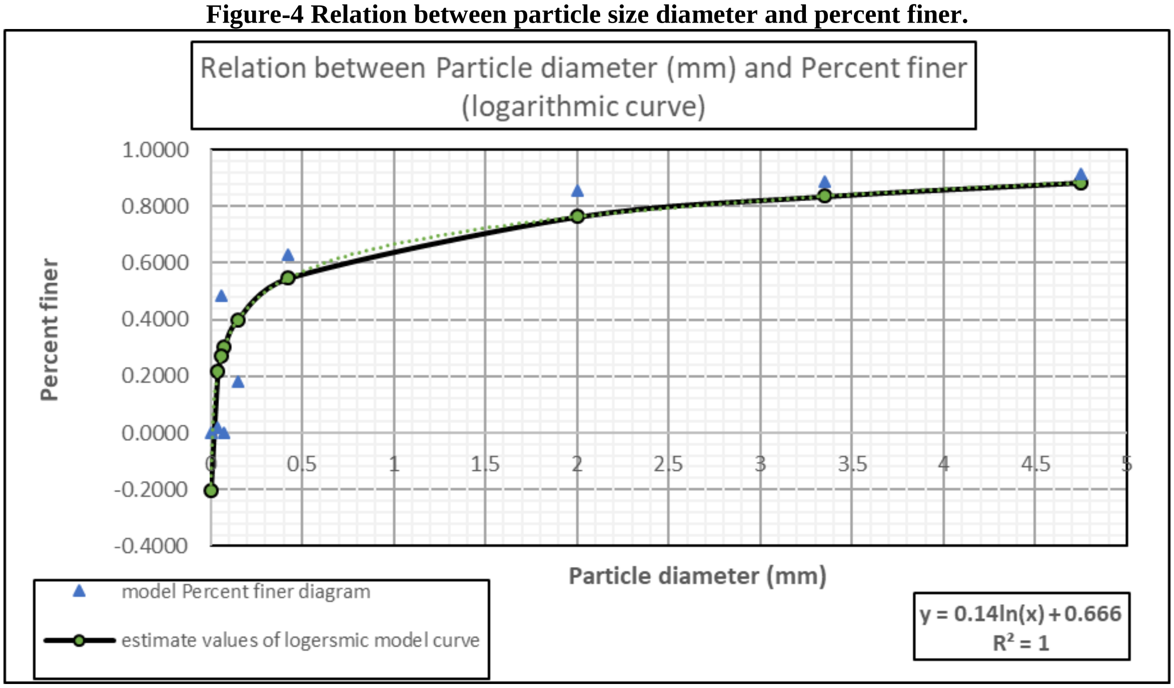


Figure-4 Relation between particle size diameter and percent finer.



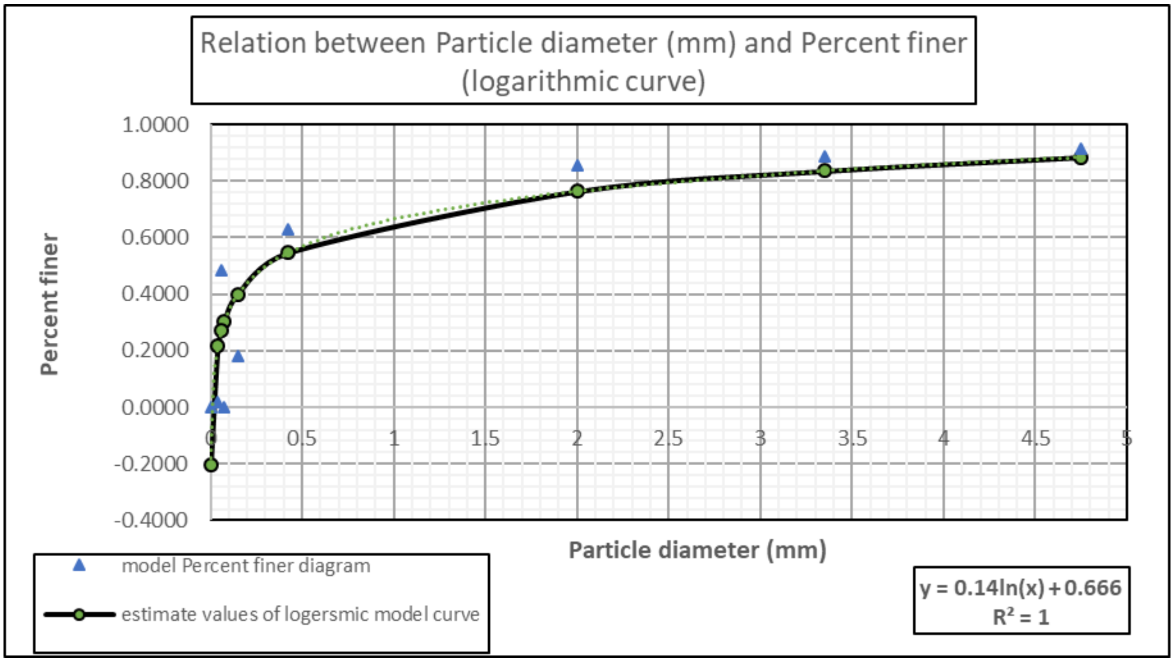
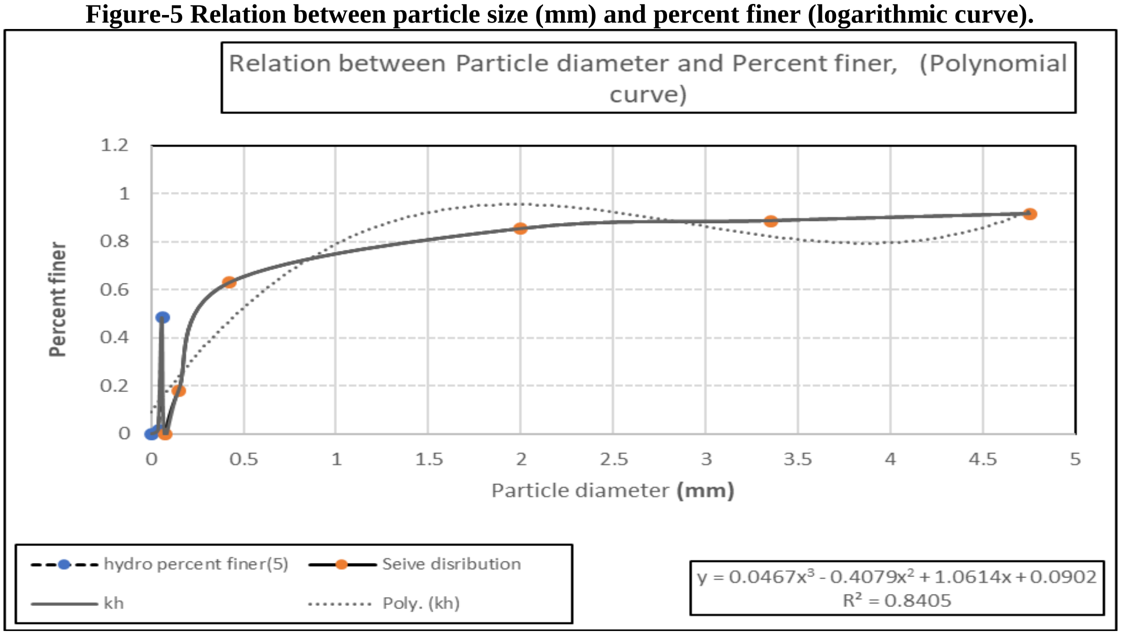


Figure-5 Relation between particle size (mm) and percent finer (logarithmic curve).



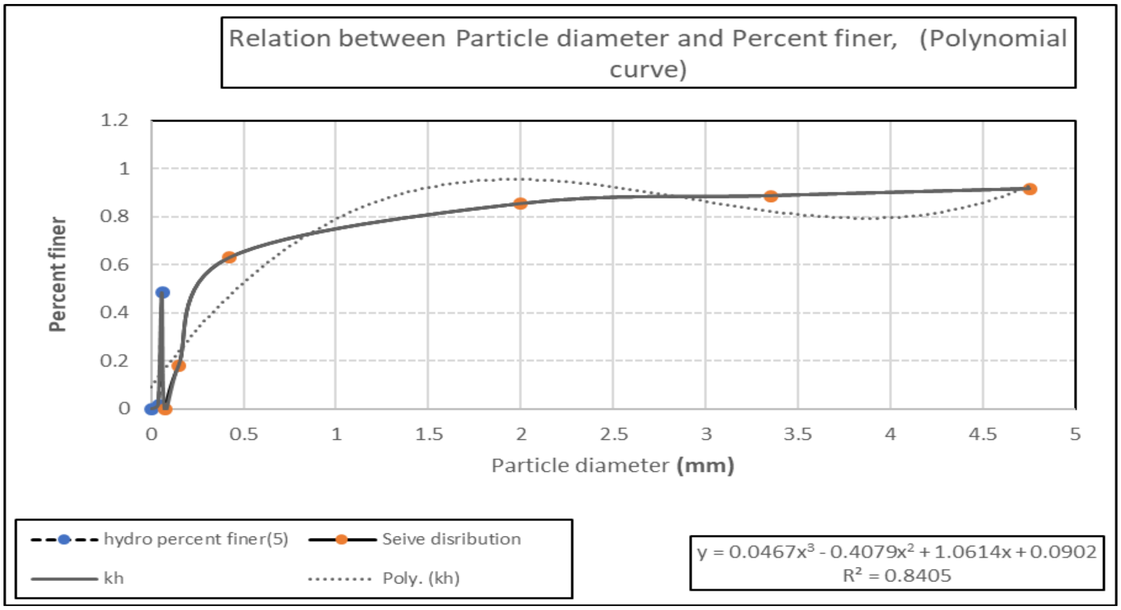


Figure-6: Relation between particle size (mm) and percent finer (polynomial curve)

References

American Society for Testing and Materials (2014). Annual Book of ASTM Standards, Sec. 4, Vol. 04.08. West Conshohocken, Pa.

Braja M. Das, Khaled S. Principles of Geotechnical Engineering. Ninth edition, 2018.

CASAGRANDE, A. 1948. "Classification and Identification of Soils," Transactions, Vol. 113, 901-930.

Donald P. Coduto • Man-chu Ronald Yeung • William A. Kitch (2007). **Geotechnical engineering, principles and practices, second edition.** AMERICAN SOCIETY FOR TESTING AND MATERIALS. Annual Book of ASTM Standards Sec. 4, Vol. 04.08, West Conshohoken, Pa.

Nelson, R.E. 1982. Carbonate and Gypsum. Methods of Soil Analysis. Part II. Chemical and Microbiological properties. 191-197.

Richards, L. A 1954. Diagnosis and improvement of saline and alkali soils. US salinity United **USDA** 1954. United States Department of Agriculture (USA) **Handbook** 60, Washington DC,.

Sparks, D. L., Page, A. l. Helmke, P.A. Loeppert, R.H. Soltanpour, P.N.. Tabatabai, M.A. Johnson, C.T. and Sumner, M. 1966. Methods of Soil Analysis: Part 3—chemical methods.

SSSA Book Series, USA.

Stokes, G. G. (1851). "On the effect of internal friction of fluids on the motion of pendulums". Transactions of *the Cambridge Philosophical Society. 9, part ii: 8–106.*

تطوير نموذج توزيع حجم حبيبات التربة وتحديد جميع المعاملات ذات الصلة به

شيماء عبد المنعم عوض خاطر
باحث مساعد بمعهد بحوث الصرف, المركز القومى لبحوث المياه
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استاذ متفرغ بقسم علوم الاراضى كلية الزراعه جامعة الزقازيق
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استاذ بقسم الهندسة الزراعية بكلية الزراعة جامعة بنها
ا.د / على أحمد عبد السلام
استاذ متفرغ بقسم الاراضى والمياه بكلية الزراعة جامعة بنها

ترتبط صعوبات التربة بشكل أساسي برطوبة التربة والفراغات الموجودة في التربة. يتم التعامل مع الاختبارات المعملية على التربة بطرق مختلفة لتطوير التحليلات. هذه التحليلات يتعامل بعضها مع الخصائص الهندسية ، مثل مقاومة القص وتكوين التربة وهيكلها. يختلف تكوين التربة عن المواد الأخرى. تتكون التربة من ثلاث مراحل: (1) صلبة ، (2) سائلة ، (3) غازية. توجد مخططات خاصة للتعبير عن توزيع حجم الجسيمات (Cu) ، وتوحيد المعامل (Cc) ومعامل التدرج .(Gc) نادرًا ما تحتوي التربة الحقيقية على جزيئات متشابهة الحجم فقط ، ولكن يتم خلط أحجام مختلفة معًا. بالنسبة لأي تربة ، توجد منطقة مسطحة نوعًا ما في منحنى توزيع الحجم. على سبيل المثال ، ضع في اعتبارك منحنى توزيع حجم الجسيمات. (D_{10})
يشار إلى هذه التربة بأنها متدرجة الفجوات لأنها تفتقر إلى جزيئات ذات نطاق حجم معين. تعتبر التربة المتدرجة الفجوات أحيانًا نوعًا من التربة المتدرجة بشكل سيئ. معظم الركام المستخدم في الخرسانة عبارة عن تربة متدرجة الفجوات.