Mathematical Correlations Between The Effective Diameter Of Soil And Other Properties

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Abstract

The equivalent or the "effective" diameter or size is a well-known parameter in soil classification and permeability determination. Hazen (1892) on the basis of his study of filter sands found that the diameter that which 10% by weight of soil grains are finer may cause same effects as the given soil. Denoted as *D*10, Hazen called this diameter the "effective diameter".

The goal of this study is to determine the value of the percent finer that corresponds to the equivalent diameter of soil grains that may be used directly to calculate as accurate as possible the surface area of the soil solids. The equivalent or the effective diameter would certainly vary according to the gradation of the soil grains, the wider the range of particle diameters included in the soil matrix the smaller would be the effective diameter.

It was concluded that the effective particle diameter of a soil can be related to other soil properties such as the liquid limit, plasticity index, the unconfined compressive strength and the standard penetration test number of blows (N).

علاقات رياضية بين القطر الفعال للتربة و خواصها الأخرى

الخلاصة

يعتبر القطر أو الحجم المكافئ أو الفعال للتربة معاملا مهما في تصنيف التربة و في إيجاد النفاذية. فقد وجد هازن (1892) من خلال دراسته على المرشحات الرملية أن قطر الحبيبات التي تكون نسـبة 10% وزنـا أنعم منها يسبب تأثيرات متشابهة لتربة معينة. و قد أطلق هازن على هذا القطر بالقطر الفعـال و أعطـاه الرمز D_{10}.

إن الهدف من هذه الدراسة هو إيجاد نسبة الأنعم (العابر) المقترنة بالقطر الفعال لحبيبـات التربـة التي يمكن استعمالها مباشرة لحساب المساحة السطحية لحبيبات التربة الصلبة بالدقة الممكنـة. إن القطـر المكافئ أو الفعال بالتأكيد سوف يتغير تبعا لتدرج حبيبات التربة, فكلما كان مدى أقطار حبيبات التربة واسعا كان القطر الفعال أصغر.

لقد وجد أن الفعال لحبيبات التربة يمكن ربطه بعلاقات مع بقية خواص التربة مثل حد السـيولة و مؤشر اللدونة و عدد ضربات فحص الاختراق القياسي (**N**).

Introduction:

The equivalent or the "effective" diameter or size is a well-known parameter in soil classification and permeability determination. Hazen (1892) on the basis of his study of filter sands found that the diameter than which 10% by weight of soil grains are finer may cause same effects as the given soil. Denoted as D_{10}, Hazen called this diameter the "effective diameter". The main consideration was the effect of this diameter on flow characteristics and a famous formula known as "Hazen's formula" was

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presented to estimate the coefficient of permeability. Related to soil classification the effective diameter is used with two other diameters D_{60} and D_{30} to describe the gradation behavior of the soil through the definition of the well-known coefficient of uniformity $Cu = D_{60}/D_{10}$ and the coefficient of curvature $Cc = (D_{30})^2/(D_{60}*D_{10})$ by which a granular soil may be classified.

Terzaghi and Peck (1948) suggested the use of D_{70}/D_{20} for the coefficient of uniformity and stated that the characteristics of fine-grained soils depend on the finest 20%. Anyhow, the above definition of effective diameter is related to the flow characteristics and to the classification of the soil and not exactly for the determination of the surface area of the particles.

Many soils undergo chemical reactions on the surface of their particles. These chemical reactions may be dissolution, adsorption, reaction of the grains with surrounding chemicals, decay, etc. Most of these reactions depend on the surface area of the soil particles as one of the parameters controlling the rate of the process.

The goal of this study is to determine the value of the percent finer that corresponds to the equivalent diameter of soil grains that may be used directly to calculate as accurate as possible the surface area of the soil solids. The equivalent or the effective diameter would certainly vary according to the gradation of the soil grains, the wider the range of particle diameters included in the soil matrix the smaller would be the effective diameter.

The grading curve is a graphical representation of the particle-size distribution and is therefore useful in itself as a means of describing the soil. From the grading curve we can provide a descriptive term for the type of soil.

A further quantitative analysis of grading curves may be carried out using certain geometric values known as grading characteristics. First of all, three points are located on the grading curve to give the following characteristic sizes (Fig. 1):

D_{10} = maximum size of the smallest 10% of the sample

D_{30} = maximum size of the smallest 30% of the sample

D_{60} = maximum size of the smallest 60% of the sample

From these characteristic sizes, the following grading characteristics are defined:

Effective size, D_{10}

Uniformity coefficient

$$Cu = \frac{D_{60}}{D_{10}}$$

Coefficient of gradation (curvature)

$$Cu = \frac{(D_{30})^2}{D_{60}.D_{10}}$$

Cu < 3 indicate a uniform soil.

Cu > 5 indicate a well-graded soil.

Most well graded soils will have grading curves that are mainly flat or slightly concave, giving values of Cc between 0.5 and 2.0.

Cc <0.1 indicate a possible gap-graded soil.

Hazen’s equation is the most common correlation equation used to estimate hydraulic conductivity for sands ($k > 10^{-3}$ cm/s). This equation is written as:

$$k = C\,(D_{10})^2$$

where: k is the hydraulic conductivity in cm/s;

C = coefficient ranging from 0.4 to 1.2 depending on sand size/sorting; and D10 = effective grain size in mm at 10% passing by weight.

This equation is based solely on grain size and it requires input (D10) from particle size distribution curves and the use of a coefficient estimated based on sand type (e.g., fine sand, poorly sorted, etc.).

Hazen’s equation should be used with caution since it only provides very approximate k estimates applicable only to clean sands (with less than 5% passing the No. 200 sieve) with D10 sizes between 0.1 and 3.0 mm. Table 1 contains a comparison of Hazen’s equation estimates with slug test information from an alluvial sand aquifer. One can see that in this deposit, the error ranged from slight to over one order of magnitude. The error would be expected to decrease as the sand becomes more uniform. Local knowledge of the soil conditions can allow site specific values of C to be established.

A procedure was developed by Al-Mufty and Al-Hadidi (2004) to calculate an equivalent diameter for soil grains to be used to calculate the specific surface of the soil. The typical grain size distribution curve is expressed as a normal probability distribution cumulative curve and the frequency corresponding to the equivalent diameter is accordingly found as shown in Fig. 2. This frequency is adopted as the percent finer corresponding to the equivalent diameter. A relation is given for the calculation of the specific surface using the equivalent diameter. Grain size distribution curves of many soil samples are collected. A value for the specific surface of each soil is determined summing the surface area of subintervals in the distribution curve. The values of specific surface obtained from these gradation curves are compared to those calculated using the proposed values of the equivalent diameter for each soil. The results have shown good agreement.

Case Study:

The site chosen for soil investigation is the site of the proposed University of Technology which is located approximately 16K.m North-West of the center of Baghdad. It is situated near Baghdad –Mosul high way and its Eastern border is approximately 1 km from Tigris river. The area of this site is 154 Hectars .

A total of (41) boreholes were drilled at this site. All the boreholes were (152) mm diameter Nordmeyer type drilling rigs were used for drilling. Sampling included collection of sub-soil and water samples from boreholes. The number and type of soil samples collected from each borehole varied from borehole to another. The soil samples included the following types:

i) Partly to wholly disturbed samples .

ii) Undisturbed samples.

The first type samples were obtained from the standard split spoon having an inside diameter of (35) mm and outside diameter of (50.8) mm used in a standard penetration test (S.P.T).

Undisturbed samples were collected from cohesive layers generally by using thin-walled Shelby tubes of (76) mm and (102) mm diameter as per procedure of ASTM. Standard D-1587.

Standard penetration test was made at number of depths in each bore hole to assess the relative density of a cohesionless soil layer and consistency of a cohesive soil layer .This test was made by adopting the procedure of ASTM Standard D-156-67 .

Mathematical Correlations:

From the test results described in the previous section which were carried out by NCCL (1982), several relationships were obtained between the effective particle diameter (D_{10}) and soil properties.

Fig.3 shows relationships between the liquid limit and the effective diameter. It can be noticed that soils having low liquid limit exhibit larger effective diameters. From this figure, the following relation is suggested:

$$D_{10} = 3x10^{-5}(LL)^2 - 0.002(LL) + 0.0394$$

A similar relationships was obtained between the effective diameter and the plasticity index (PI) as shown in Fig. 4. Form this figure, the following relation is obtained:

$$D_{10} = 2x10^{-5}(PI)^2 - 0.0006(PI) + 0.0059$$

Fig. 5 shows that a small increase in the effective diameter takes place with the increase in the SPT (N values). Fig. 5 is drawn for values of N<35 from which, the following relation is obtained :

$$D_{10} = 0.001(N)^{0.0858}$$

Fig. 6 shows the relationship between the effective diameter and the unconfined compressive strength (q_c). The effective diameter increases with the increase of (q_c), then decreases at higher values of (q_c). The following relation is obtained:

$$D_{10} = -8x10^{-6}(q_c)^2 + 0.0012(q_c) - 0.035$$

Conclusions:

1. The effective particle diameter of a soil can be related to other soil properties such as the liquid limit, plasticity index, the unconfined compressive strength and the standard penetration test number of blows (N).
2. Soils having low liquid limit and plasticity index exhibit large effective diameters.
3. A small increase was obtained in the effective diameter when the number of blows (N) in the (SPT) increases.

References:

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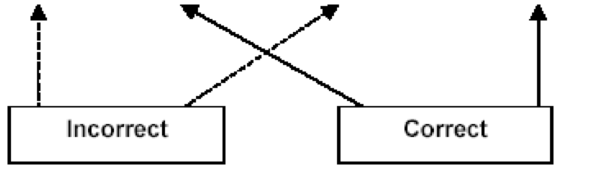
[3]NCCL (1982), Subsoil Investigation for the Site of University of Technology – Taji”, Unpublished Report, The National Center for Construction Laboratories, Iraq.

[4]Terzaghi, K. and Peck, R.B. (1948). Soil Mechanics in Engineering Practice. John Wiley and Sons, New York, 566 pp.

Table 1.
Comparison of hydraulic conductivity from empirical and field methods.

Effective Particle Size, d_{10} (mm)	Coefficient, C (Hazen)	Hydraulic Conductivity (Hazen) (cm/s)	Log of k (Hazen)	Slug Test k Results (cm/s)	Log of k from Slug Test
0.8	1	6.4E-1	-0.194	4.3E-3	-2.367
0.3	1	9.0E-2	-1.046	1.3E-2	-1.886
0.9	1	8.1E-1	-0.092	2.2E-3	-2.658
1.3	1	1.7E0	0.230	1.2E-2	-1.921
2.0	1	4.0E0	0.602	1.6E-2	-1.796
0.3	1	9.0E-2	-1.046	6.9E-3	-2.161
0.8	1	6.4E-1	-0.194	1.8E-3	-2.745
0.5	1	2.5E-1	-0.602	2.0E-3	-2.699
	Average	**2.8E-1**	**5.0E-1**	**1.0E-2**	**9.4E-3**



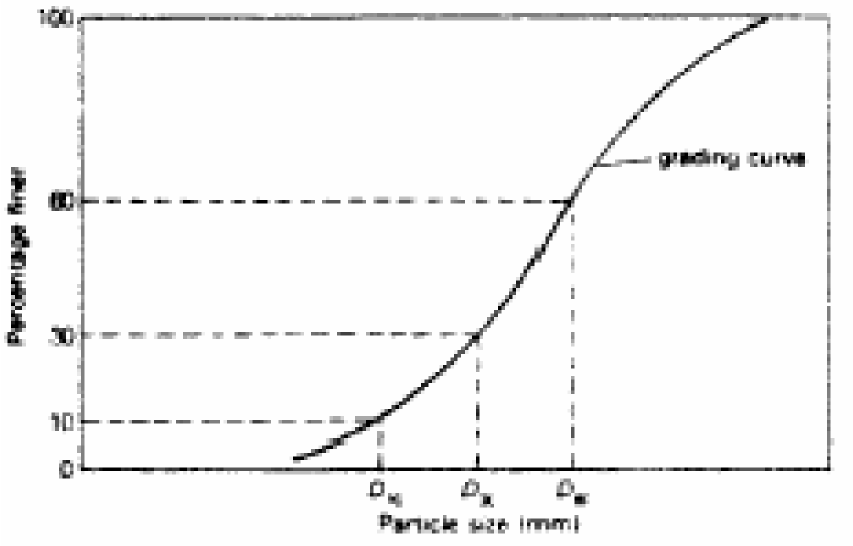


Fig 1. Grading characteristic.

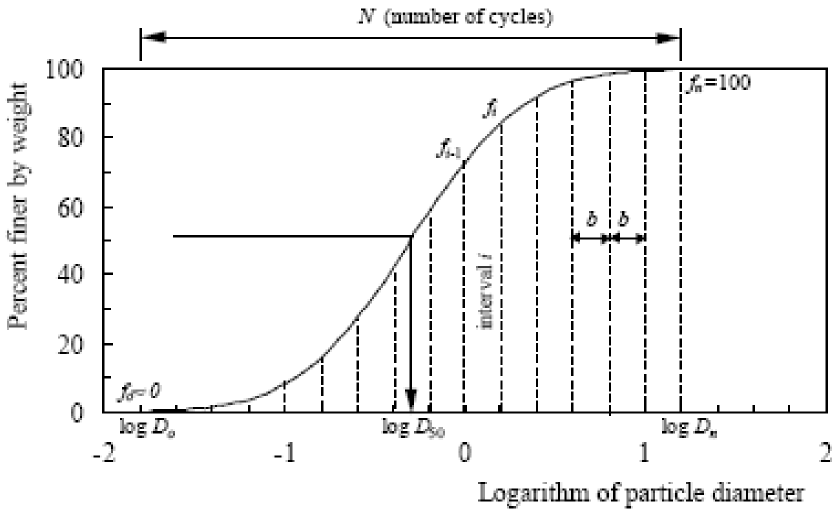


Fig. 2. A typical gradation curve of a soil divided into *n* equal intervals (after Al-Mufty and Al-Hadidi, 2004).

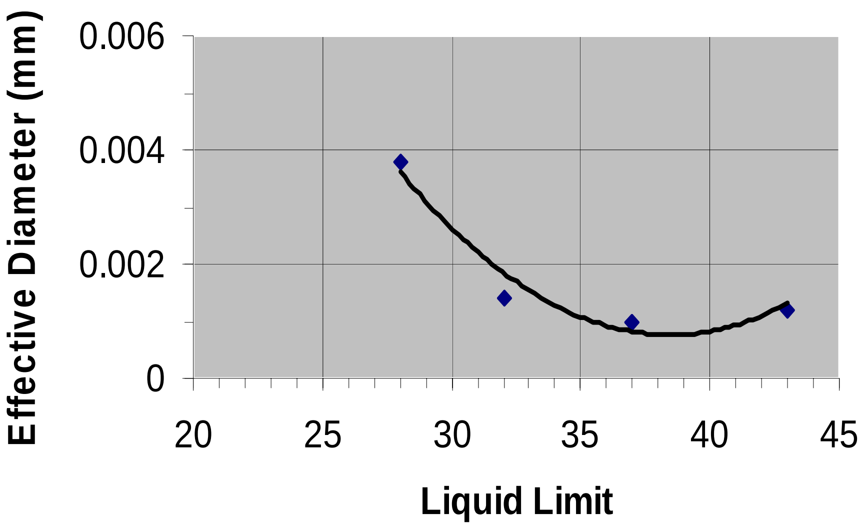


Fig. 3 Relationship between the effective diameter and the liquid limit.

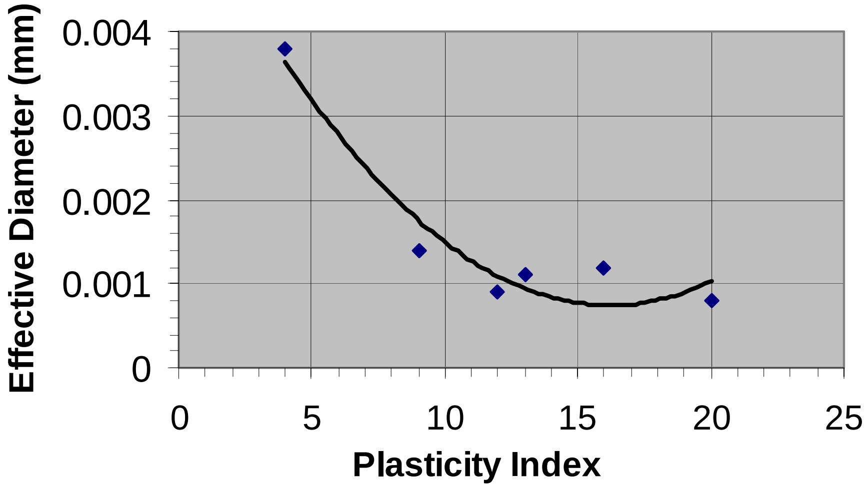


Fig. 4 Relationship between the effective diameter and the plasticity index.

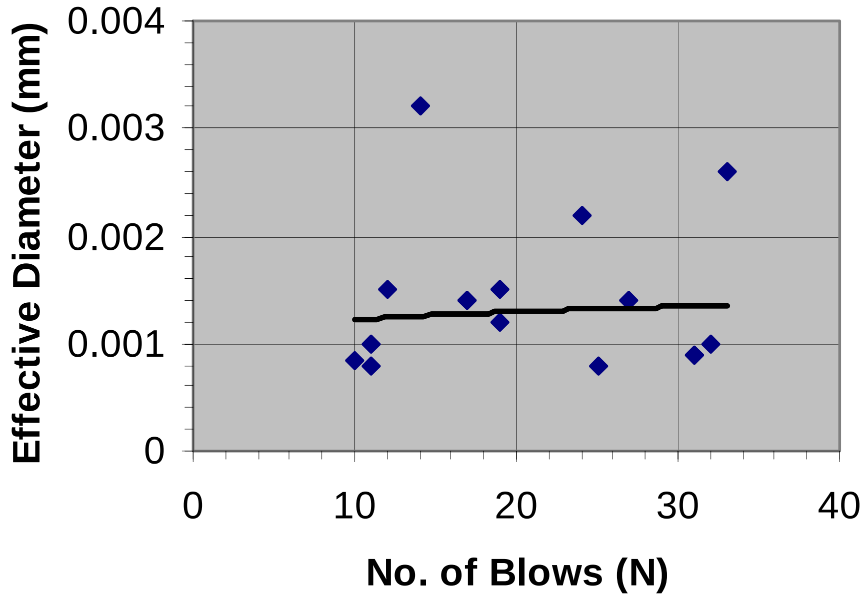


Fig. 5 Relationship between the effective diameter and the SPT number of blows (for N<35).

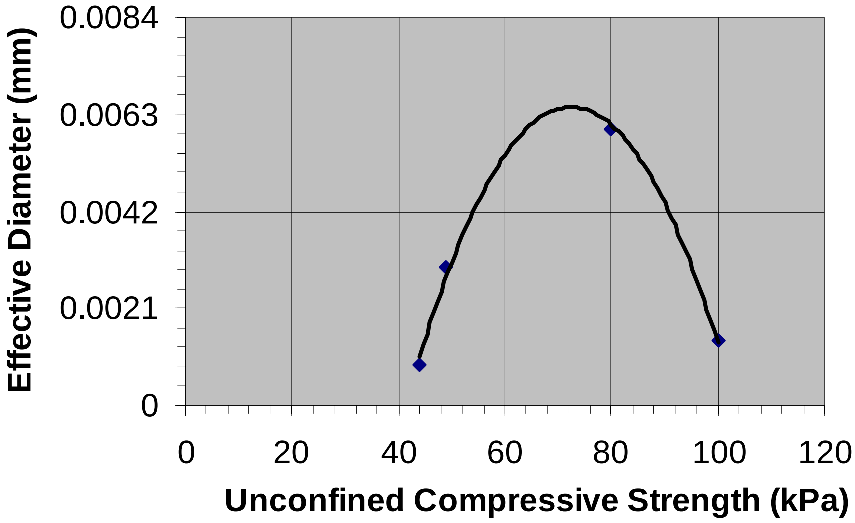


Fig. 6 Relationship between the effective diameter and the unconfined compressive strength.