SOIL SCIENCE AND POLLUTION

Syllabus:

1) Origin and composition of soils.
2) Soil structure.
3) Chemical and physical properties of soil.
4) Soil permeability and flow of water through soils.
5) Soil behavior under stress.
6) Compressibility.
7) Shear strength.
8) Environmental geo-technology.
9) Soil erosion and pollution.
10) Ion exchange in soils.
11) Soil as an aid to waste disposal.

References:

1) **Contaminant Hydrogeology (1999) by Fetter.**
2) **Geo-environmental Engineering (2000) by Reddi**.

1) Origin and composition of soils

No construction material has both engineering and physical properties which are more variable than the ground. These properties vary both laterally and vertically and often by large order of magnitude. These properties include:-

1) Strength parameters (stress-strain modulus, shear modulus, Poisson’s ratio, cohesion and angle of internal friction).
2) Compressibility indexes (deformation, settlement).
3) Permeability
4) Gravimetric-Volumetric data (unit weight, specific gravity, void ratio and water content).

Some knowledge about these properties allows the engineer to make estimate for:-

1) Bearing capacity.
2) Settlement including both the amount and rate.
3) Earth pressure including both vertical and lateral.
4) Pore pressure and dewatering quantities.

Most of soils have been formed by the disintegration of rock as a result of weathering processes (***mechanical*** or ***chemical***).

- **Mechanical weathering: -** is the fragmentation of the rock by physical forces [temperature, stresses, formation of ice, wind]. It leaves the crystal structure of material unchanged and clearly identifiable will that of the parent rock.
- **Chemical weathering: -** is the fragmentation of the rock as a result of attack on the rock minerals by [water, oxygen, acid dissolved in the soil water, alkaline].

The soils can be classified according to origin into two types;

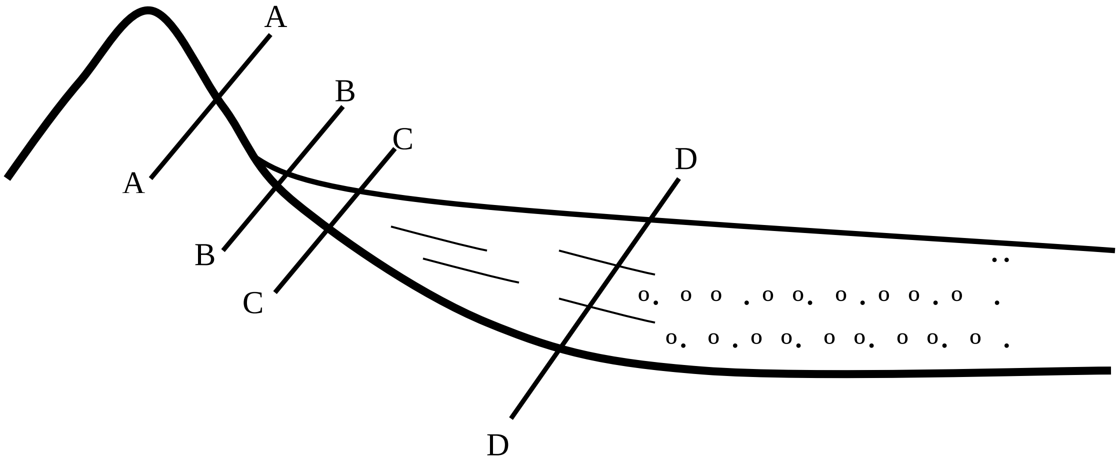
1) **Residual soils are formed in site by weathering of the original rock.**
2) **Sedimentary (transported) soils (الترب الرسوبية أو المنقولة)**
    - Alluvial Deposits الرواسب الغرينية
    - Marine Deposits الرواسب البحرية
    - Glacial Deposits الرواسب الجليدية
    - Aeolian Deposits الرواسب المنقولة بالرياح
    - Organic Deposits الرواسب العضوية

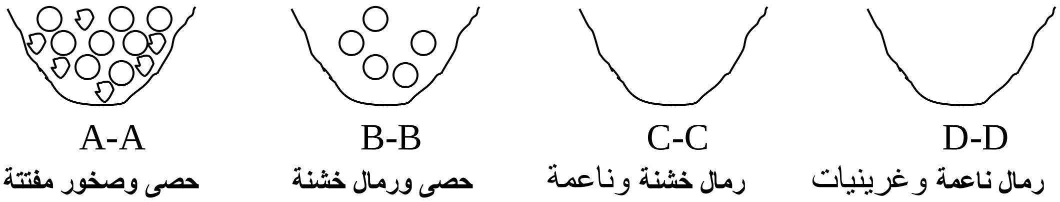
الرواسب المنقولة بالرياح

تلتقط الرياح القوية كميات كبيرة من جزيئات الغرين "الغبار" من السطح وتنقلها إلى مسافات طويلة وعند خمول شدة الرياح تترسب حبيبات الغبار فتشكل رواسب اللوس Loess soil وغالبا تتلاحم هذه الرواسب بواسطة بيكاربونات الكالسيوم وتكون مساميتها عالية في العادة وخاصة عندما تتشبع تربة اللوس تحت الأساسات يحدث هبوط مفاجئ إضافي حيث يذوب عامل التلاحم بين الحبيبات. تعد تربة اللوس غير جيدة لإقامة المنشآت عليها لذلك يجب معالجتها قبل البدء بالعمل.

الرواسب العضوية

بفعل الرياح وماء المطر وتجمع الرسوبيات في نفس الوقت في البحيرات والخزانات الداخلية وعلى السهول الفيضية للأنهار وفي مصبات الأنهار حيث تترسب جزيئات المعادن لتشكل رواسب الطين الغرينية والبحرية وفي نفس الوقت تترسب غالبا كميات كبيرة من المواد العضوية لتشكل رواسب الطين العضوية والمعروفة بالبوغائيات "الطين والغرينيات العضوية".





أن مياه الجداول الجبلية ذات الجريان السريع ليست قادرة فقط على نقل الحبيبات الصغيرة بل الشظايا الصخرية الكبيرة أيضا ونتيجة لعمليات الحك والتآكل تطحن الشظايا الصخرية حيث تشكل القطع الكبيرة منها الحبيبات المستديرة والأكثر خشونة "الحصى والرمال الخشنة" تشكل الرواسب التي تتواجد غالبا في ضفاف الأنهار العليا بينما تتواجد الرمال المتوسطة في الأجزاء الوسطى في مجاري الأنهار بينما تنتشر الرمال الناعمة والغرينيات في السهول المنخفضة.

2) Soil structure (constituents)

Any soil will be found to contain some or all of the following:-

A) Soil (solid) phase

i. Primary rocks minerals (produce by mechanical weathering).

ii. Clay minerals (produce by chemical weathering).

iii. Inter-granular cement (the mineral cement between the particles increasing the shear strength and reducing the compressibility of the soil. Calcite, iron oxide and silica are examples of cementing materials.

iv. Organic matter (the soil derived from plant or animal remains in the top 0.3-0.5 meter of the soil, but leaching may carry it down much further in permeable soil.

B) Liquid phase

i. Water (change in the water content of the soil is lead to the variation of the engineering properties; such as shear strength, compressibility and permeability, which are all, directly or indirectly, related to the water content).

ii. Dissolved salts (when the water of the river passes through the soil, it can transport salts in solution).

C) Gaseous phase

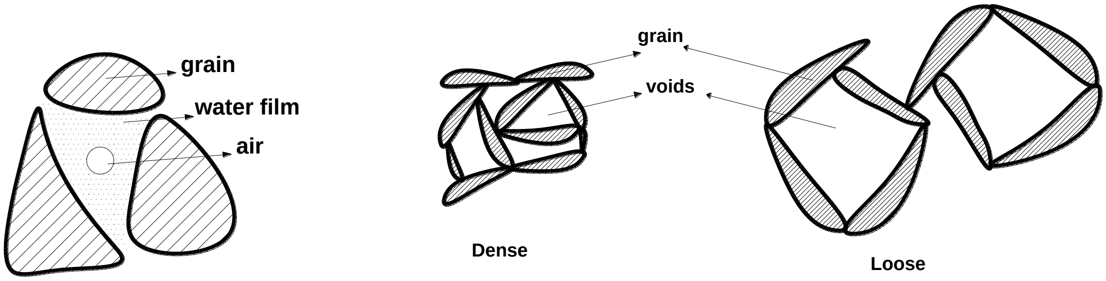
i. Air and sometimes other gases (not all soils are fully saturated; i.e. the voids between the soil particles are not entirely filled with water. The air may be expelled by an influx of water into the voids causing a reduction in shear strength, particularly, in the case of the clay soils).

ii. Water vapor (the vapor pressure may vary from place to place because of difference in temperature or for other reasons. If the degree of saturation is low, so that the air spaces are mainly continuous, there may be considerable migration of water in the form of water vapor).

The soils can be classified into two types; 1) Course grained soil (cohesionless soil) such as Boulders, Gravel and Sand. 2) Fine grained soil (cohesive soil) such as silt and clay.

Particle arrangement

يكون البناء الحبيبي للتربة خشنة الحبيبات تحت تأثير قوى الجذب الأرضي (وزن الحبيبات) وتأثير الشحنات الكهرومغناطيسية المتواجدة على أسطحها والتي يزداد تأثيرها بتواجد نسبة رطوبة بين تلك الحبيبات مكونة أغشية مائية تمتلك شد سطحي (surface tension) يعمل على تجاذب الحبيبات إلى حد ما ويتراوح هذا البناء في التربة غير المتماسكة من بناء كثيف إلى بناء سائب.



single grained structure

أما التربة ناعمة الحبيبات يكون بناءها متأثر بقوى التجاذب والتنافر بين تلك الحبيبات نظرا للصغر المتناهي لتلك الحبيبات حيث يصل حجم حبيبة الطين إلى أجزاء المايكروميتر لذلك وزنها ضئيل وتأثيره مهمل أذا ما قورنت بالشحنات الكهروستاتيكية المتكونة على أسطحها. أن ترتيب الحبيبات يعتمد على نوع تلك الشحنات والتي قسمها العالم الألماني(Terzaqi) إلى:-

i. Oriented

وهي تربة ناعمة ذات بناء مرتب تكون الشحنات على أسطح الحبيبات متشابه مما يسبب تنافرها وتتكون عادة عن ترسب الحبيبات في المياه العذبة كالبحيرات العذبة.

ii. Flocculent

وهي تربة ناعمة ذات ترتيب عشوائي بسبب اختلاف الشحنات مما يؤدي إلى تجاذب الحبيبات وتتكون عادة عن ترسب الحبيبات في المياه المالحة كالبحار.

iii. Honey comb (cellular)

وهي تربة ناعمة ذات بناء خلوي لنوع من أنواع الحبيبات في التربة المالحة تكثر فيها الفراغات وبالتالي تقل مقاومتها للأحمال.

Preview of soil behavior (nature and cause of soil deformation)

إضافة أحمال على التربة يؤدي إلى هبوط فيها بسبب التغير في حجمها والذي يتراوح من الحدود المسموح بها إلى الحدود غير المسموح بها ويرجع هذا الهبوط إلى الأسباب الآتية:-

a) Climatic

التحركات الأرضية التي تحدث بتأثير الطقس نتيجة لتجمد المياه أو تبخرها في فراغات التربة مسببة الانتفاخ (swelling) أو الانكماش (shrinkage) ويتم التغلب على هذا التأثير بالاختيار المناسب لمنسوب الأساس.

b) Subsidence

هبوط سطح الأرض نتيجة لأوزانها بسبب عمليات ضخ البترول أو التنجيم أو ضخ المياه مما يسبب عدم قدرة الأرض الطبيعية على حمل وزنها فيحدث هبوط مفاجئ نتيجة لوجود فراغات في باطن الأرض وغالبا ما تكون كبيرة وذات تأثير واسع.

c) Elastic-plastic deformation

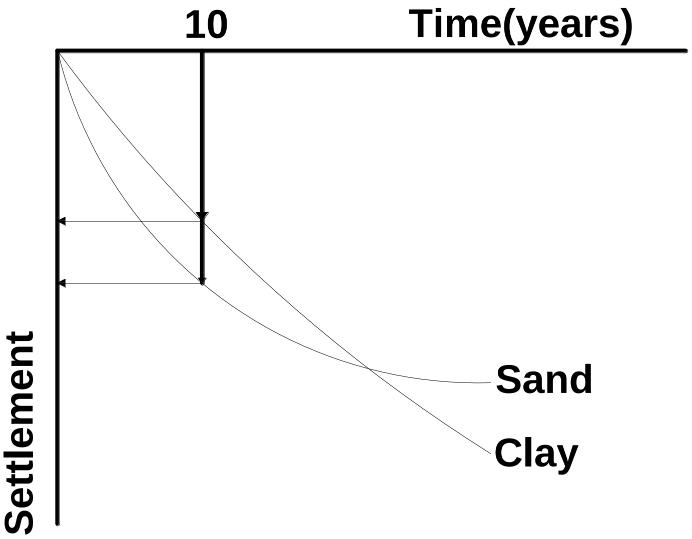
التربة كأي مادة إنشائية معرضة للتشكل المرن-اللدن عند تعرضها لأحمال أضافية فإذا كانت ضمن الحدود المسموح بها فلا ضرر منها ويمكن للمنشأ أن يستمر معها أما إذا زادت عن الحد المسموح فيجب اخذ الاحتياطات اللازمة للتحكم بتلك التشكيلات إما بتحسين خواص التربة أو بتقليل الاجهادات بحيث لا تسبب تلك التشكيلات فشل كامل للأساس.

d) Shear displacement

أن زيادة الأحمال المنقولة للتربة وضعف مقاومتها للقص يؤدي إلى انهيارها في معظم الأحيان على مستويات قص معينة مما يسبب فشلا كاملا للأساس لذا يجب اخذ معامل أمان ضده.

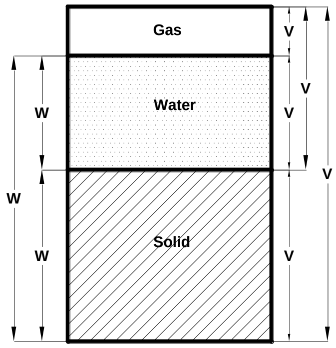
e) Consolidation

يحدث الانضغاط مع الزمن في الترب الناعمة المتماسكة ببط شديد نتيجة لزيادة الأحمال المنقولة للطبقات القابلة للانضغاط والتي يكون سببها أما حمل المنشأ أو تخفيض منسوب المياه الجوفية بسبب الإنشاء أو لأسباب أخرى مما يسبب استمرار الهبوط بعد اكتمال المنشأ بعشرات السنين.

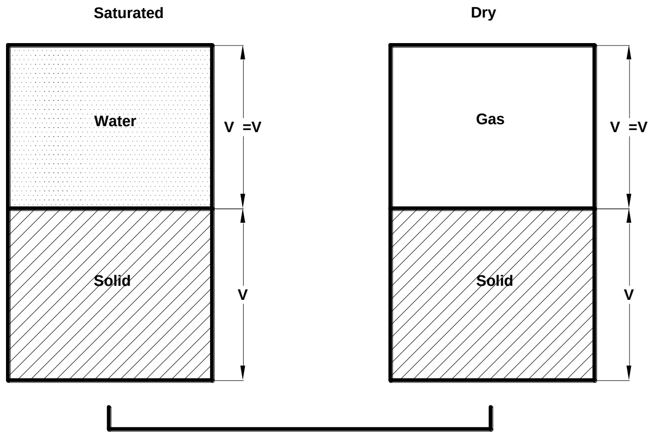


3) Physical properties of the soil

3-1) Soil volume and density relationship



Three-phase system



Two-phase system

$$V_T = V_a + V_w + V_s$$

$$W_T = W_w + W_s$$

*<u>Unit weight γ</u> is the ratio of the weight of the soil to the corresponding volume with units of force per unit volume.

$$\gamma = \frac{W}{V} = \rho g$$

*<u>Unit density ρ</u> is the ratio of the mass of the soil to the corresponding volume with units of mass per unit volume.

$$\rho = \frac{M}{V}$$

*<u>Dry unit weight γ_d</u> is the ratio of the weight of the solid to the volume.

$$\gamma_d = \frac{W_s}{V}$$

*<u>Saturated unit weight $\gamma_{sat.}$</u> : - obtained when W_T is based on a state when all the soil voids are filled with water.

$$\gamma_{sat.} = \frac{W_s + V_v \gamma_w}{V}$$

*<u>Buoyant (Effective or submerged) unit weight</u> $\gamma_{sub.}$, $\gamma_{b.}$, γ'

$$\gamma_{sub} = \gamma_{sat.} - \gamma_w$$

أن هذه الكثافة ناتجة عن نظرية ارخميدس حيث في حالة التربة المغمورة يقل الوزن الذاتي للحبيبات بمقدار كثافة الماء ويستفاد من هذه الكثافة في حساب الأجهادات والضغوط الفعالة.

*<u>Void ratio e</u> is the ratio of the volume of voids to the volume of solids in a given volume of the material.

$$e = \frac{V_v}{Vs}$$

*<u>Porosity n</u> is the ratio of the volume of voids to the total volume V_T of a soil mass.

$$n = \frac{V_v}{V_T}$$

*<u>Water content</u> ω is the ratio of the weight of water W_w in a given soil mass to the weight of soil solids W_s.

$$\omega = \frac{W_w}{W_s}$$

*<u>Degree of saturation</u> S_r is the ratio of the volume of water to the volume of soil voids.

$$S_r = \frac{V_w}{Vv}$$

Where S_r=0 % for dry soil.

S_r=100 % for fully saturated soil.

*<u>Specific gravity</u> G is the ratio of the unit weight of a material in air to the unit weight of distilled water.

The average specific gravity of the mass of the soil grains G_s is computed as:-

$$G_s = \frac{\gamma_s}{\gamma_w}, \quad \gamma_w = 1\ gm/cm^3 \text{ or } 1000\ kg/m^3.$$

Percentage of air content $A = \frac{V_a}{V_t} \times 100$

*<u>Relative density</u> R_D

In the case of the sand and gravel, the relative density is used to express in the relationship between the void ratio in the field and the limiting value.

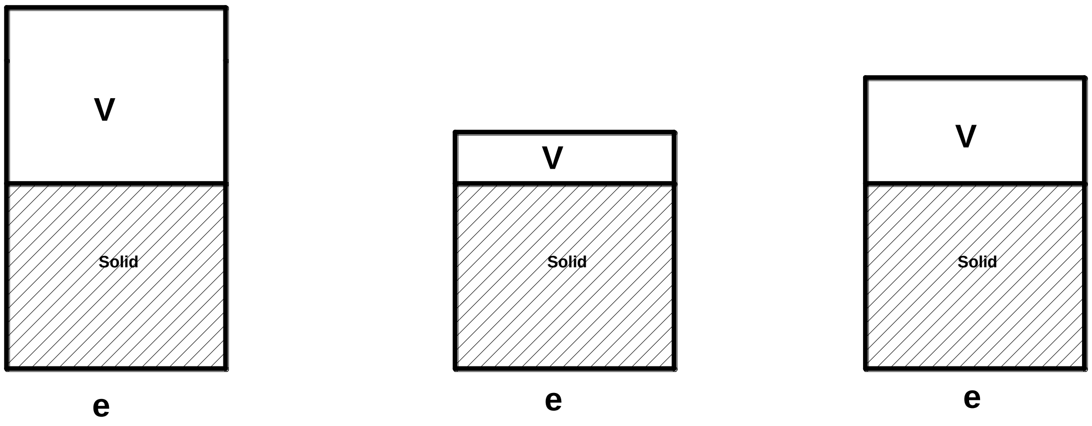
$$R_D = \frac{e_{\max} - e_{field}}{e_{\max} - e_{\min}}$$

Where e_{max}(Loosest state) and e_{min}(Densest state). ***$R_D \le 0.33$ →Loose; $0.67 \ge R_D > 0.33$ →Medium; $1 \ge R_D > 0.67$ →Dense.***

When:- $e_{field}=e_{max}$→$R_D=0$ Loose state

$e_{field}=e_{min}$→$R_D=1$ or 100% Dense state

تستخدم نسبة الفراغات للتربة الرملية في حالتها الطبيعية للحكم على مدى صلاحيتها للاستخدام في المشاريع الهندسية المختلفة وذلك بمقارنة الفراغات الطبيعية بالفراغات الدنيا والعظمى لنفس النوع من الرمل.



*<u>Volumetric change</u>

أن أي زيادة في الحجم يعزى إلى التغير في حجم الفراغات باعتبار أن حبيبات التربة غير قابلة للانضغاط أو التمدد وعليه فان حجم الأجزاء الصلبة V_s يعتبر ثابت ومنه يمكن التعبير عن التغير في الحجم بدلالة العلاقة الآتية:-

$$\frac{\Delta V}{V_o} = \frac{e_o - e_1}{1 + e_o}$$

<u>Either:-</u> $e_o > e_1$ →shrinkage (+) ; <u>Or</u> $e_o < e_1$ →swelling (-)

Where:-

e_o=initial void ratio and e_1=void ratio at the end of the test ($e_o=e_1+\Delta e$).

Homework

Q1) Derive the following equations:-

1) $e=\frac{G\gamma_w V}{W_s}-1$ **;** **2)** $n=1-\frac{W_s}{G\gamma_w V}$ **;** 3) $n=\frac{e}{1+e}$ **;** 4) $S_r=\frac{\omega G}{e}$

5) $\gamma_d=\frac{W}{V(1+\omega)}$ **;** 6) $\gamma_d=\frac{G\gamma_w}{1+e}$ **; 7)** $\gamma=G_s\gamma_w\frac{1+\omega}{1+e}$ **;** 8) $\gamma_d=\frac{\gamma}{(1+\omega)}$

9) $\gamma_d=\frac{G_s+S_r e}{(1+e)}\gamma_w$ **;** 10) $A=n(1-S_r)$ **; 11)** $\gamma_{sat}=\frac{G_s+e}{1+e}\gamma_w$

12) $\gamma_d=\frac{G}{(1+e)}\gamma_w$ **;** 13) $\gamma_{sub}=\gamma_w\left(\frac{G-1}{1+e}\right)$

Q2) A fully saturated sample has a volume 60cc and porosity 0.37. After drying, the total volume becomes 45cc of G_s=2.6. Find initial water content, air content in the dry state and S.L? (Where: - $S.L=\frac{W_w}{W_s}$)

Q3) The soil sample has the following properties: - V_T=460cc, W_T=793gm, W_s=735 and G_s=2.68. Find e, n, ω and S_r?

Q4) A fully saturated sample has: - G_s=2.65, ω=40%, W_T=130gm n=0.35 (after drying). Find $e_{initial}$, γ_d and S.L?

Q5) Given 1870gm of wet soil compacted into a mold with a volume of 1000cc. The soil put in the oven and dried to a constant weight of 1677gm. The specific gravity G_s is assumed to be 2.66. Find ω, γ_d, n, S_r and γ_{sat}?

Q6) Find the void ratio and dry unit weight for the soil which n=0.32 and G_s=2.7?

Q7) Soil sample has e=1.2, Sr=70% and G_s=2.65. Find air and water content?

Q8) The saturated unit weight of the clay is 1.95gm/cm^3, After drying unit weight becomes 1.62gm/cm^3 and G_s=2.65, find the volumetric change?

Q9) The saturated clay sample put into the wax with unit density of 0.8gm/cm^3 and its weight 8gm. The total volume of the sample 227cm^3 and its weight 394gm, find the unit weight of the clay?

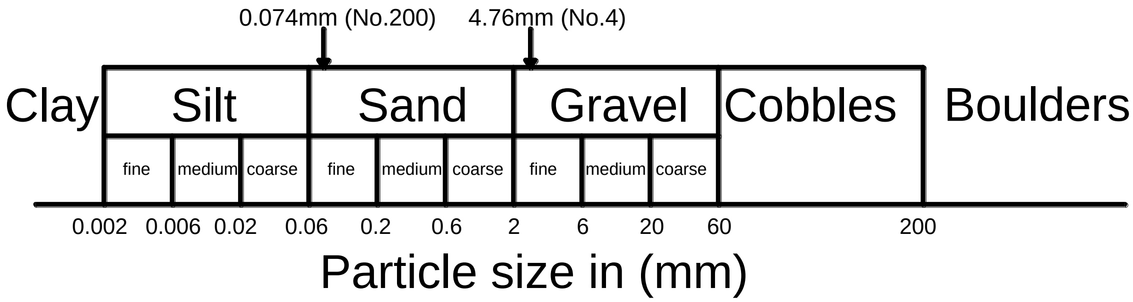
3-2) Particle size distribution in soils

There are adopted unified systems for classified of soils. These systems are:-

1) Coarse-Grained Soil;
2) Fine-Grained Soil;
3) Highly-Grained soil.

The range of particle sizes in engineering of soils is very large. Several systems for classification of particle size exist in use. They are basically the same, but differ in details only. The particle size distribution for a **Coarse-Grained Soil** can be determined by the **Dry Mechanical Analysis (Sieve test)**. While, the particle size distribution for a **Fine-Grained Soil** or the **Fine-Grained fraction of a Coarse-Grained Soil** can be determined by the **Wet Mechanical Analysis (Hydrometer test or method of Sedimentation**).

Soils can be classified according to particle size, gradation or compressibility for agriculture, geologic or engineering purposes:-



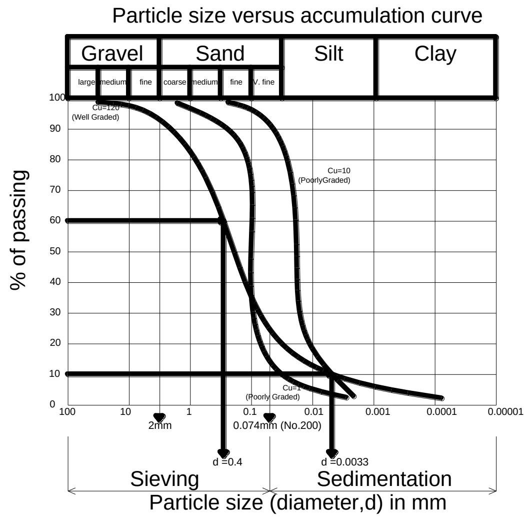
The particle size analysis of a soil sample involves determining the percentage by weight of particles within the different size ranges. The weight of soil retained in each sieve is determined and the cumulative percentage by weight passing each sieve is calculated.

3-2-A) Dry Mechanical Analysis (Sieve test)

Pass the soil sample through the set of standard sieves from No.4 to No.200 to obtain the percentage of passing (% of finer) from certain opening with respect to total dry weight of the sample; this called **the percentage of finer by weight** or in sometimes **the percentage of cumulative passing**.

US Standard		**Retained on Sieve**		**Cumulative Retained**		**Cumulative Passing**		**Soil Texture Classification**	
Sieve No.	**Opening in mm**	**gm**	**%**	**gm**	**%**	**gm**	**%**	**Designation**	**Size in mm**
4		0	0	0	0	200	100		
	4.76							Medium	Gravel
10		2.84	1.42	2.84	1.42	197.16	98.58		
	2								
20		5.66	2.83	8.5	4.25	191.5	95.75	Fine	
	0.84								
40		46.04	23.06	54.54	27.27	145.96	72.72		
	0.42							Coarse	Sand
60		44	22	98.54	49.27	101.48	50.73		
	0.25								
100		23.64	11.82	122.18	61.09	77.82	38.91		

	0.149							Medium
140		11.26	5.63	133.44	66.72	66.56	33.28	
	0.105							
200		63.16	31.58	196.6	98.3	3.4	1.7	Fine
	0.074							
pan		3.4	1.7	200	100			
		200	100%					Very fine silt & clay



-d₁₀ or D₁₀ (10% from total weight has particle size less than d (=0.0033mm))

- **Semi-logarithmic relationship:-**the semi-log plot is used so that the grain diameter scale is extended to give all grain size.

-**A Coarse-Grained Soil** is described as **Well Graded** if there is no excess of particles in any size range and if no intermediate size are lacking. In general, a well graded soil is represented by a **smooth concave distribution curve**.

- **A Coarse-Grained Soil** is described as **Poorly Graded** if;

- A high proportion of the particles have sizes within narrow limits (**a uniform soil**).

- A particles of both large and small sizes are present but with a relatively low proportion of the particles of intermediate size (**a gap-Graded soil**).

-**Effective Size (d_{10})** is the size such that 10% of the total weight of particles have smaller than that size denoted by D_{10}. Other sizes such as D_{30}&D_{60} can be defined in a similar way.

-The general slope and shape of the distribution curve can be described by means of the **Coefficient of Uniformity, Cu**.

$$Cu = D_{60} / D_{10}$$

For Well-Graded sample;

- ***Cu>4 for gravel.***
- ***Cu>6 for sand.***

- **The Coefficient of Curvature, Cc**

$$C_c = \frac{D_{30}^2}{D_{10} \times D_{60}}$$

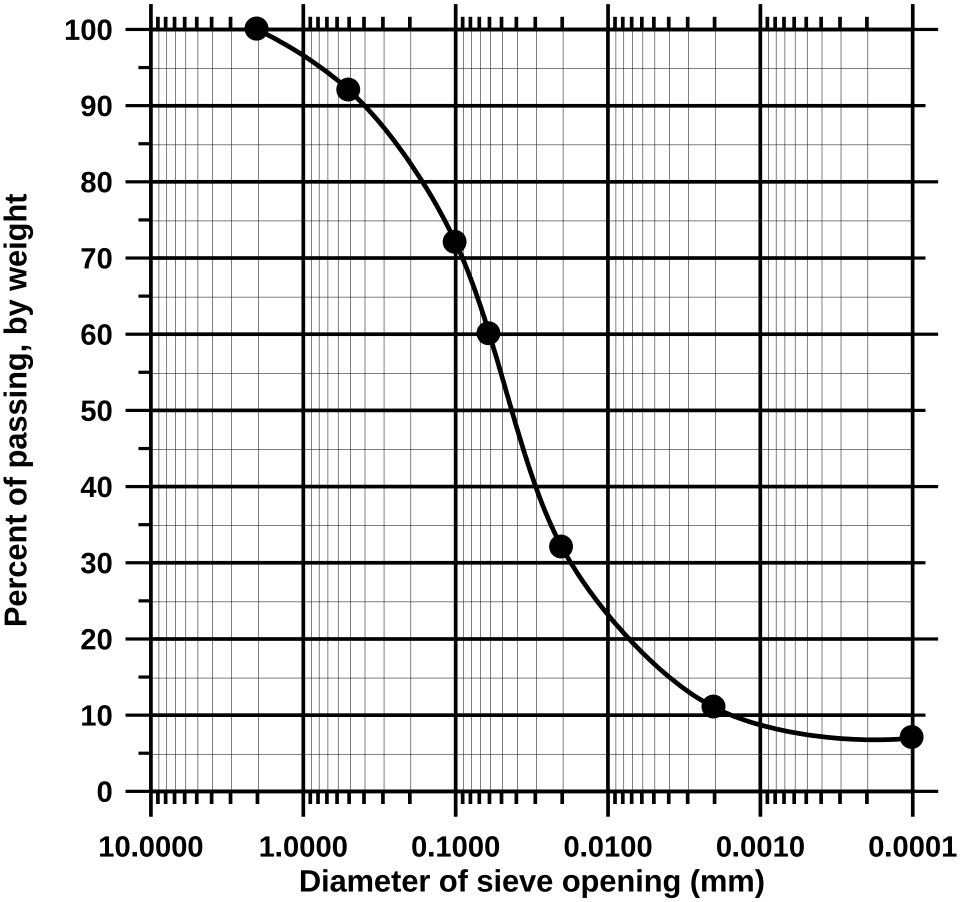
A Well-Graded soil has Cc between 1& 30.

EX: Percentage finer by weight (N) and diameter of grains (D in mm) shown below:-

% of finer	100	92	72	60	32	11	7
Diameter (mm)	2	0.5	0.1	0.06	0.02	0.002	0.0001

Draw the particle size curve and calculate the Coefficient of Uniformity, Cu and classify the sample?

Solution:-



$$Cu=\frac{D_{60}}{D_{10}}=\frac{0.06}{0.0018}=33.3$$

$$C_c=\frac{D_{30}^2}{D_{10}\times D_{60}}=\frac{(0.018)^2}{0.0018\times 0.06}\approx 3 \quad \text{Well-Graded}$$

3-2-B) Wet Mechanical Analysis (Hydrometer test or method of Sedimentation)

- The particle size distribution of a **Fine-Grained Soil** can be determined by the method of sedimentation.
- This method is based on Stokes law which governs the velocity at which spherical particles settle in a suspension.
- The law doses not applied to particles smaller than 0.0002mm.
- The method of Stokes law states that the velocity of spherical particle sinking in a still fluid as:-

$$V=\frac{2}{9}r^2\left(\frac{\gamma_p-\gamma_f}{\eta}\right)$$

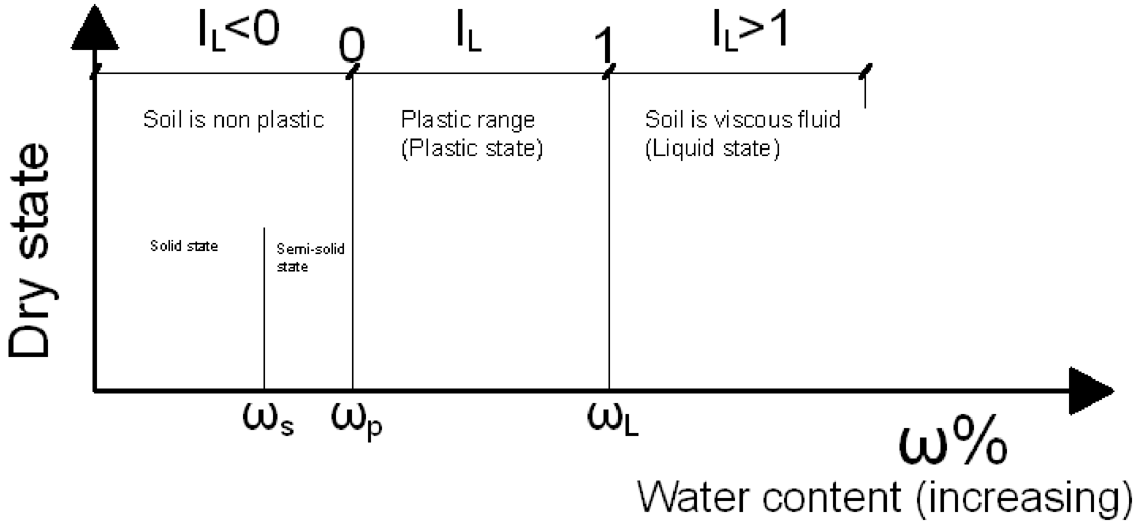
Where: - r=radius of the particle, γ_p, γ_f = the unit weight of the particle and the fluid respectively and η= the viscosity of the fluid. Then,

$$D = \left(\frac{18\eta h}{(\gamma_p - \gamma_f)t} \right)^{1/2}$$

Where: - D=the diameter of particle and h= the distance of filler in time t.

3-3) Atterberg (or consistency) limits

The limits of soil consistency are based on water content and they are shown below:-



- **Liquid limit ω_L:**-is the **ω** at which **25 blows** of the liquid machine close a standard groove cut in the soil pat for a distance of 12.7cm.
- **Plastic limit ω_p:**-is the **ω** at which a thread of the soil, when rolled down to a diameter of 3mm, will just crumble.
- **Shrinkage limit ω_s:**-is the **ω** at which there is no longer shrinkage in volume upon further drying.
- **Liquidity index I_L:**- is the relationship between **ω_L, ω_p** and **ω_n** as below (it varies from zero for soils at the plastic limit to 1 for soils at the liquid limit as in above fig.)

$$I_L = \frac{\omega_n - \omega_p}{\omega_L - \omega_P} = \frac{\omega_n - \omega_p}{I_p}$$

Where I_p is plasticity index and **ω_n** is the natural water content.

Soil type	state	I_p	ω_L
Sand	Non-plastic	0	20
Silt	Low-plastic	<7	25
Silt-Clay	Medium-plastic	7-17	40
Clay	High-plastic	>17	70

4) Soil permeability and flow of water through the soils

4-1) Modes of occurrence of water in soil (Znker)

a. Absorbed water

هي المياه المغلفة للحبيبات الصلبة والتي تمثل حالة من حالات التميؤ الكيميائي وتتواجد كغلاف رقيق جدا لحالة التربة الجافة.

b. Hydroscopic soil moisture

هي الرطوبة التي تمتصها التربة من المياه الجوفية ومن الهواء الجوي الذي يشغل فراغات التربة ولا يمكن فصلها عن الحبيبات آلا بالتجفيف لدرجة حرارة تصل إلى 110^oC حيث تلتصق بالحبيبات بفعل التجاذب الكهرومغناطيسي.

c. Gravitational water

المياه الأرضية المتزنة بفعل الجاذبية وتشمل:-

- **Free water**

المياه التي تسري داخل التربة والتي تسبب ضغط هيدروليكي (uplift pressure) يؤدي إلى خروجها بشكل ينابيع أو أبار ارتوازية.

- **Ground water**

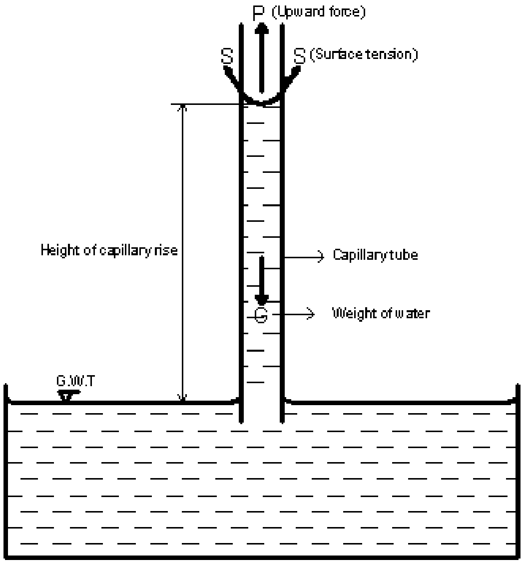
* يكون سريانها محكوم بوزن تلك المياه ذات الميل الهيدروليكي المتمثل بميل مستوى المياه الجوفية وخاصية النفاذية للتربة.

* يعلو منسوب سطح المياه الجوفية (Ground Water Table (G.W.T)) طبقة مشبعة من التربة نتيجة ارتفاع المياه الجوفية داخل الأنابيب الشعرية المتصلة والمكونة من الفراغات التي تحتويها التربة بفعل الخاصية الشعرية(Capillary action).

* يكون ارتفاع المياه الشعرية (Capillary Rise) متناسب مع دقة ونعومة التربة وبالتالي دقة الأنابيب الشعرية المكونة من الفراغات شديدة الدقة.

* تعلو الطبقة المشبعة طبقة غير مشبعة يتواجد فيها الهواء مع الماء الجوفي ويكون مجموع سمك الطبقة المشبعة وغير المشبعة مساوي للارتفاع الشعري ويعلو تلك الطبقة تربة يتراوح محتواها المائي بين الجاف (Dry) عند سطح التربة وبين محتوى مائي يتناسب مع معدل التبخر إلى معدل ارتفاع المياه الشعرية.

* لدراسة اتزان المياه الشعرية المرتفعة يمكن دراسة الأنبوب الشعري الموضح بالشكل.



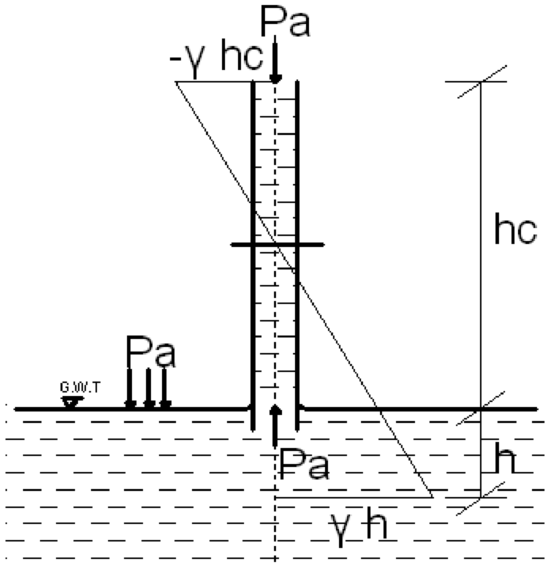
Upward force (P) =S cosα=2π.r.T$_s$.cosα

Downward force (G) =γ.π.r^2.h

Upward force (P) = Downward force (G)

Hence, $h = \frac{2T_s \cos\alpha}{\gamma r}$

T$_s$=surface tension



It is represented the **Stress Diagram for water**, as the drying increase the capillary pressure increase while as the saturation level increase the capillary pressure decrease.

4-2) Factors effecting on permeability

1) Grain size of the particles

The flow (which is represented by the coefficient of permeability (k)) is directly proportional to the square of pore size (which is specified by the shape and size of particles, (D_{10})) as in the following formula:-

$k = 100 D_{10}^{2}$ For sandy soil (D_{10} ranged between 1.1-1.3)

2) The properties of the pore fluid

The water is the fluid will deal with in the soil. This fluid has constant unit weight. The increase of temperature of this fluid will lead to decrease of viscosity and consequently the coefficient of permeability. So, the measurement of coefficient of permeability must be at 20°C.

3) The void ratio of the soil

يتناسب معامل النفاذية طرديا مع $C\frac{e^3}{1+e^2}$ حيث أن C يعتمد على ترتيب الحبيبات وشكلها ولا يؤثر تأثيرا كبيرا بالنسبة للترب غير المتماسكة(الرملية) أما التربة الطينية فأن C يتغير بتغير نسبة الفراغات. يتناسب معامل النفاذية طرديا مع مسامية التربة حيث يؤدي زيادة حجم الفراغات المفردة إلى زيادة المساحة الكلية للجريان.

4) Structure arrangement of the soil الترتيب الهيكلي لحبيبات التربة

أن الحدل (الرص) يؤدي إلى تغير ترتيب وشكل الفراغات في التربة وبالتالي يؤثر على المعامل C والذي بدوره يؤثر على النفاذية. طبيعة التربة في الموقع تظهر نفاذية بالاتجاه الشاقولي اقل مما هو عليه بالاتجاه الأفقي ويعزى ذلك إلى التطبق الإنشائي الأفقي.

5) Organic materials

عند أجراء فحص النفاذية للتربة فيجب إشباع العينة بصورة كلية وذلك لان وجود الهواء المحصور والشوائب العضوية يعرقل الجريان ويقلل النفاذية.

4-3) Permeability of the soil (Definitions and Darcy’s Law)

Compaction

It is the application of mechanical energy on the soil to rearrange the particles and to reduce the void ratio by driving out air. Hence, the purpose of this process is to obtain the smallest possible void ratio because:

1) The maximum shear strength can occur approximately at the minimum void ratio.
2) Large air voids may lead to subsequent compaction under working loads causing settlement of the structure during service.
3) If large air voids are lift in the soil, they may subsequently be filled with water which may reduce the shear strength of the soil. Also, this increase in water content may be accompanied by swelling and loss of strength in some types of clay.

Factors affecting on compaction process

Compaction is measured in terms of the achieved dry density (γ_d) and it to be function for following factors:

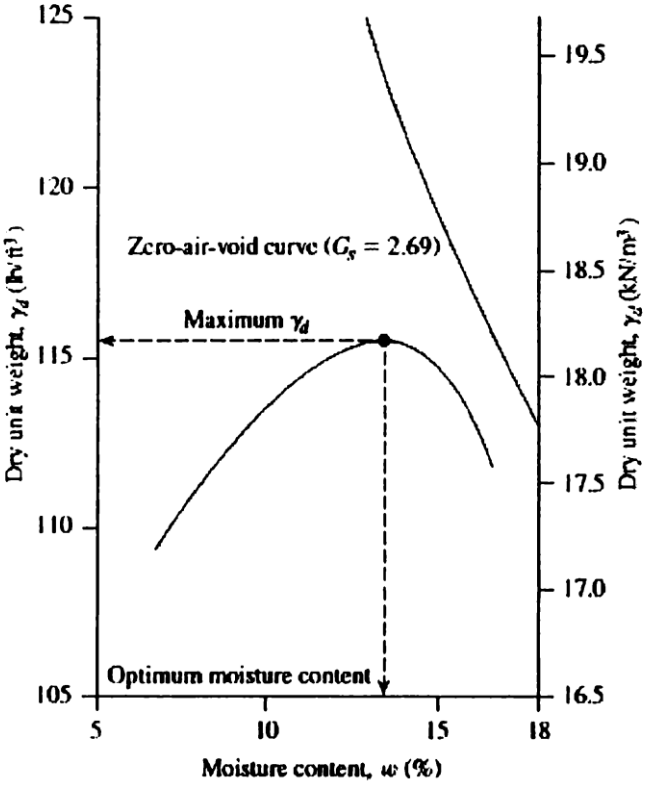
1) Water content (ω); 2) Compactive effort applied to the soil; 3) Nature of the soil.

1) Water content

Adding water to the soil during compaction acts as a softening agent on the soil particles. The soil particles slip over each other and move into a densely packed position.

- Add water gets better compaction.
- A little more water - a little better compaction.
- Even more water – Soil begins to flow.

The values of determined γ_d can be plotted against the corresponding moisture contents to obtain the maximum dry unit weight and the optimum moisture content for the soil.

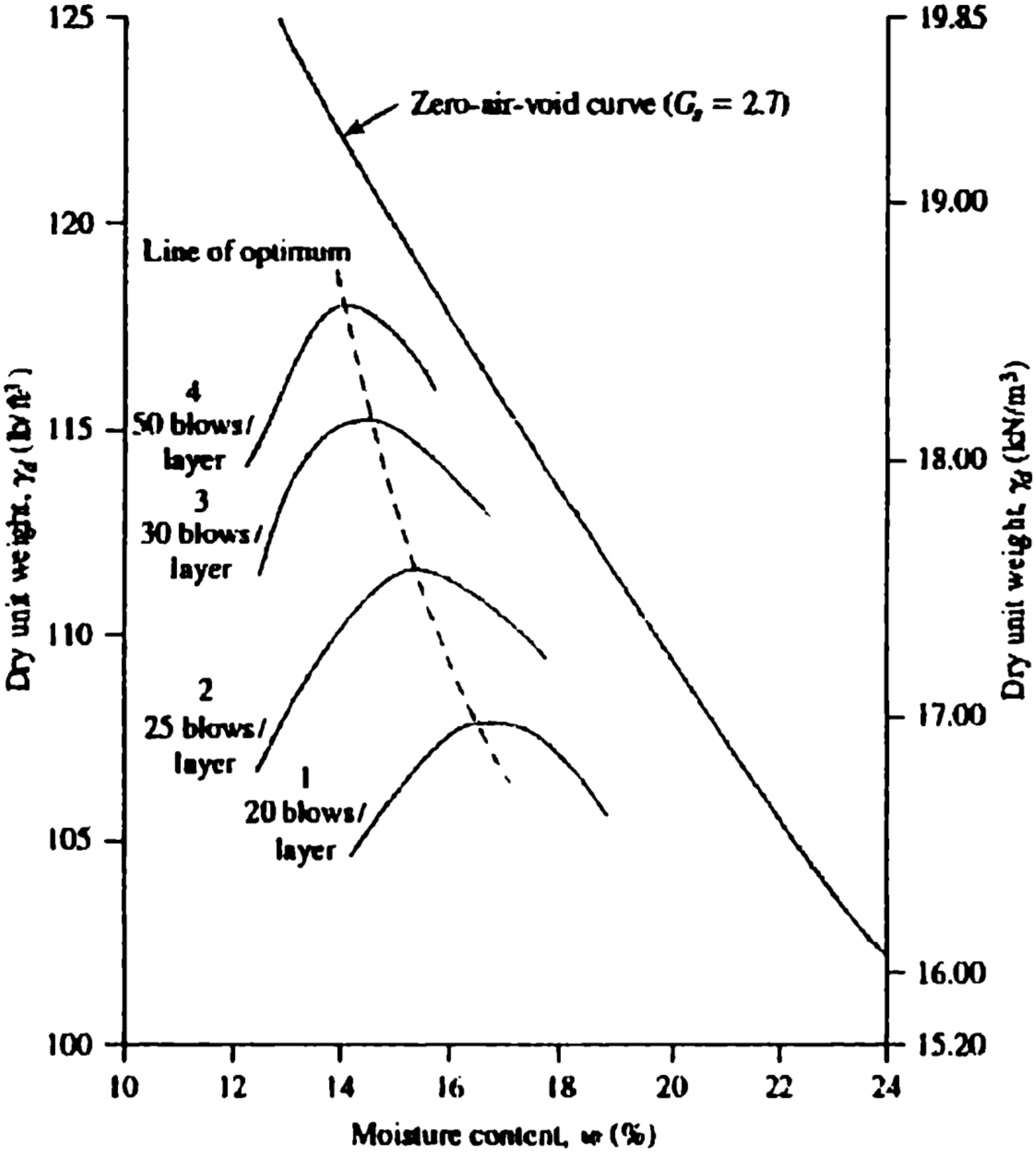


2) Compactive effort applied to the soil

The compaction effort can be calculated as follows:

$$CE = \frac{(\#\ blows/layer)(\#layers)(weight\ of\ hammer)(height\ of\ drops)}{volume\ of\ mold}$$

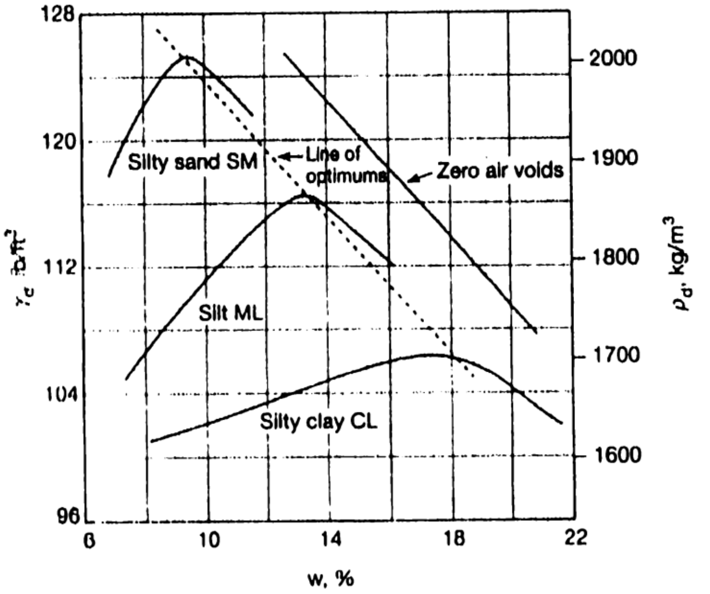
As the compaction effort increased, $\gamma_{d(max)}$ is increased and the optimum moisture content decreased to some extent.



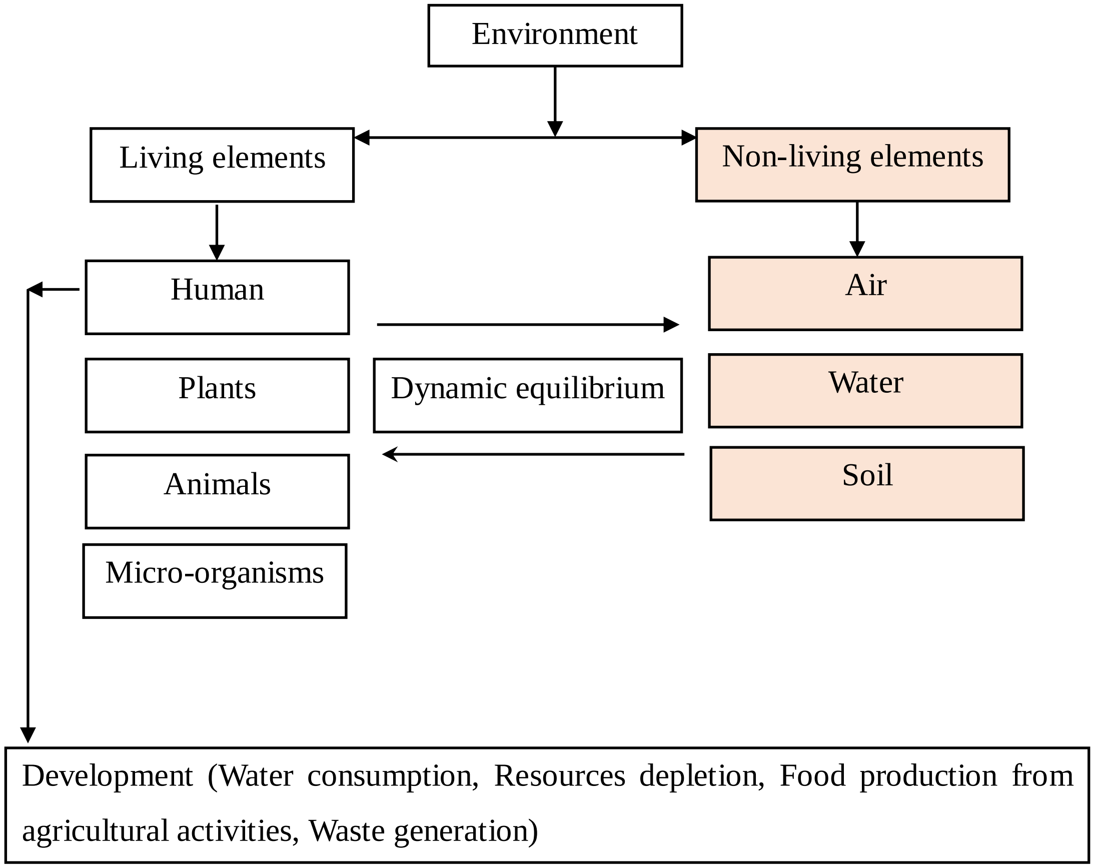
3) Nature (type) of the soil

The type of soil (grain-size distribution, shape of grains, Gs and amount and type of clay minerals) has a great influence on $\gamma_{d(max)}$ and w_{opt}.

- fine grain soil needs more water to reach w_{opt}; and
- coarse grain soil needs less water to reach w_{opt}.



Soil pollution



Waste materials are a part of the high standard of living to which we have become accustomed in an industrialized society. The manufacture of products that we use in everyday life results in the generation of wastes, some of which may be persistent, toxic, flammable, corrosive, or explosive. The soil pollution can be produced by: -

1. Soil spreading: waste liquids especially lubricating oils and other petroleum residues were commonly spread on soil and unpaved roads.

These liquids are aromatic hydrocarbons which are one of the hazardous compounds.

2. Underground storage tanks (USTs): through the twentieth century, approximately 5 million USTs were installed to hold gasoline, jet fuel, solvents and other industrial compounds. Unfortunately, soil is corrosive environment and after a relatively short period of time the tanks rust, corrode and leak. According to the Environmental Protection Agency (EPA) records, there are 1.8 million underground storage tanks were and still in use in the United States. EPA estimates are that 280000 tanks are leaking and discharging their contents directly into the soil and groundwater.
3. Pesticide rinse and formulation areas: agricultural chemicals have been used widely throughout the world. Pesticides have been received by farmers in concentrated form and then diluted onsite for application. Because of the remote nature of these sites and the lack of regulatory control, spillage and improper disposal of the rinsate (water, containing low concentrations of contaminants, resulting from the cleaning of containers etc) have become common issue; so, these areas were contaminated.
4. Sanitary landfills: every sanitary landfill that was designed to accept newspapers, cans, bottles and other household wastes also received waste petroleum products, solvents, pesticides and other products. If these sanitary landfills are unlined so the wastes have often migrated to the groundwater and reached to surface water.

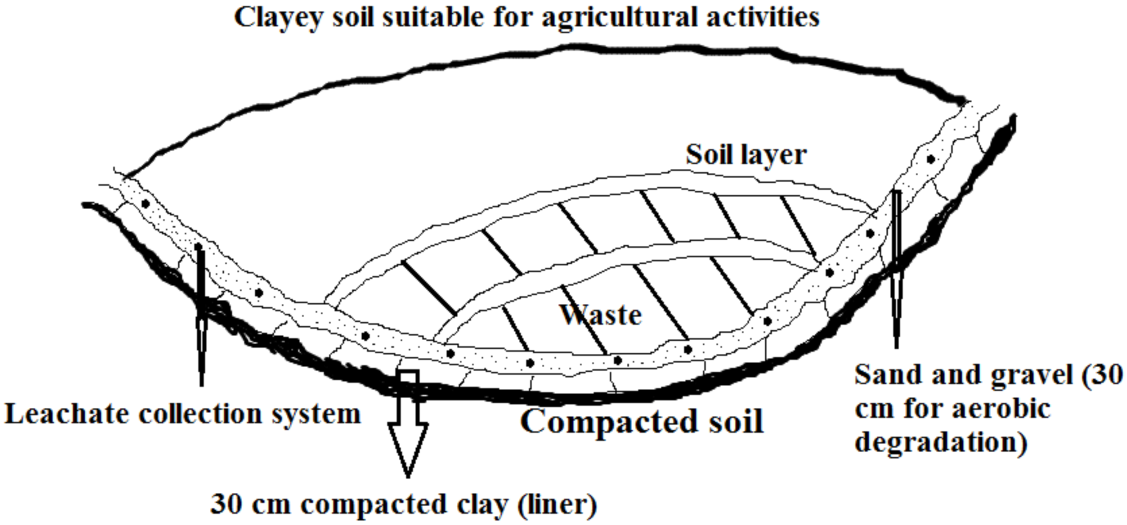


Figure explained the components of Ideal Sanitary Landfill

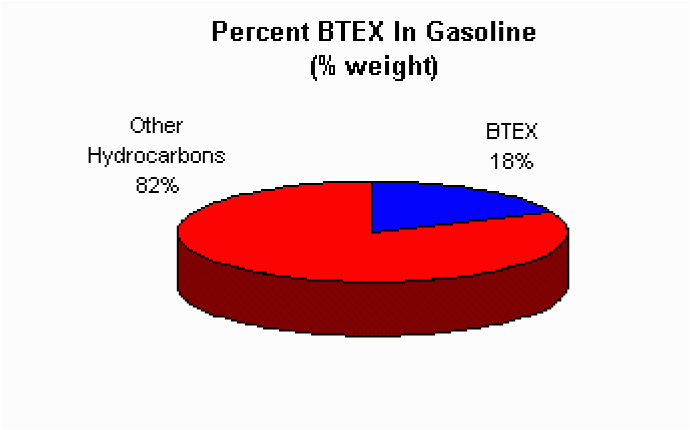
Organic contaminants

Non-Aqueous Phase Liquids (NAPLs) are organic fluids that are only slightly miscible with water. As a comprehensive term they may be referred to as “oil”. These organic fluids form a serious threat to groundwater resources, for example one liter of oil can significantly affect the quality of 100000 liters of water and consequently this water cannot be used.

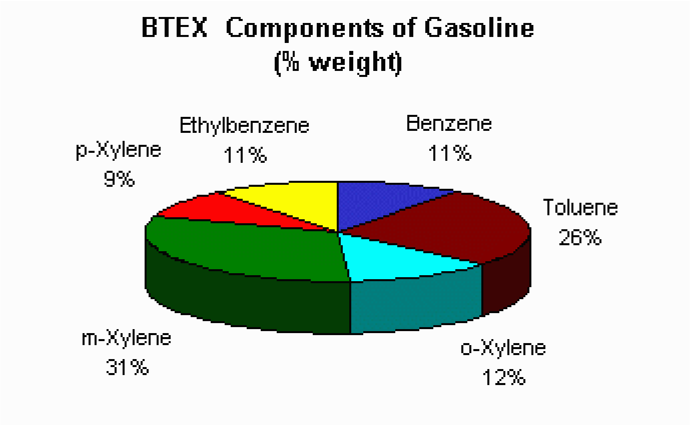
Two types of oil (or NAPLs) can be distinguished: - oil that is lighter than water, such as kerosene, benzene and jet fuel, so that it may accumulate on the groundwater level. This type of oil is called LNAPL, where the “L” stands for “lighter” than water. The other type of oil is denser than water, such as Trichloroethylene (TCE), so that it may percolate much deeper into the soil layers through the groundwater. This type of oil is called DNAPL, where the “D” stands for “denser” than water.

When the oil leaks above an unconfined aquifer, the oil migrates through the unsaturated zone as a separate phase under the dominant influence of gravity and capillary forces towards the groundwater. Hence, the unsaturated or vadose zone is represented the first line of defense in protecting the groundwater aquifer system. Consequently, the ability to estimate the time of travel through the vadose zone can help ensure that enough time is available to respond to and hopefully alleviate the oil entering the aquifer. In the subsurface, much of the oil (or NAPL or contaminant) represents: - (1) the immobile phase, which is the contaminant portion retained in the pore spaces and, (2) the mobile phase, which is the contaminant portion mostly spreading in the body of water for DNAPL or spreading over the water table for LNAPL. Once oil introduced in the groundwater system, estimates of contaminant plume migration over time is necessary in order to design an efficient and effective remediation program. Groundwater modeling serves as a quick and efficient tool in setting up the appropriate remediation program.

The reason why the BTEX, entering soil and groundwater system, are considered such a serious problem is that they all have some acute and long-term toxic effects. In addition to the toxicity, benzene is known to be a carcinogen.



(a)



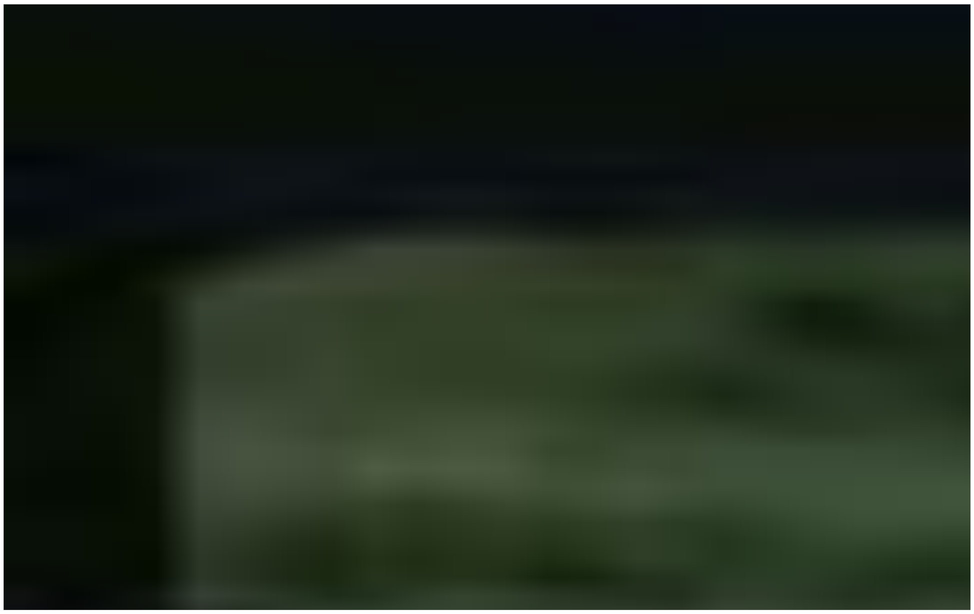
(b)

Fig: Composition of gasoline.

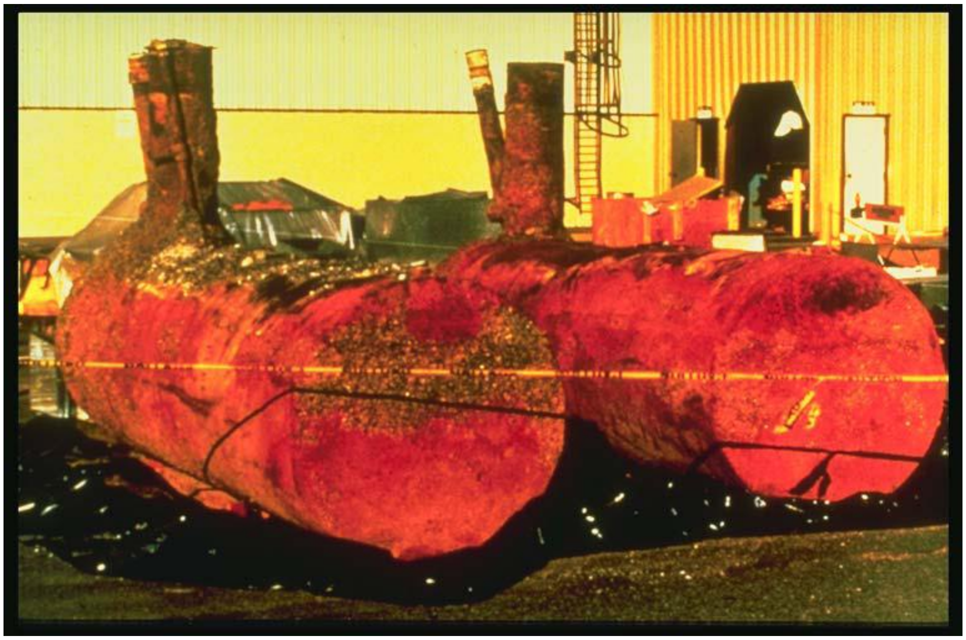
Above ground storage tanks and pipelines in oil refinery.

Oil spillage in gasoline stations.

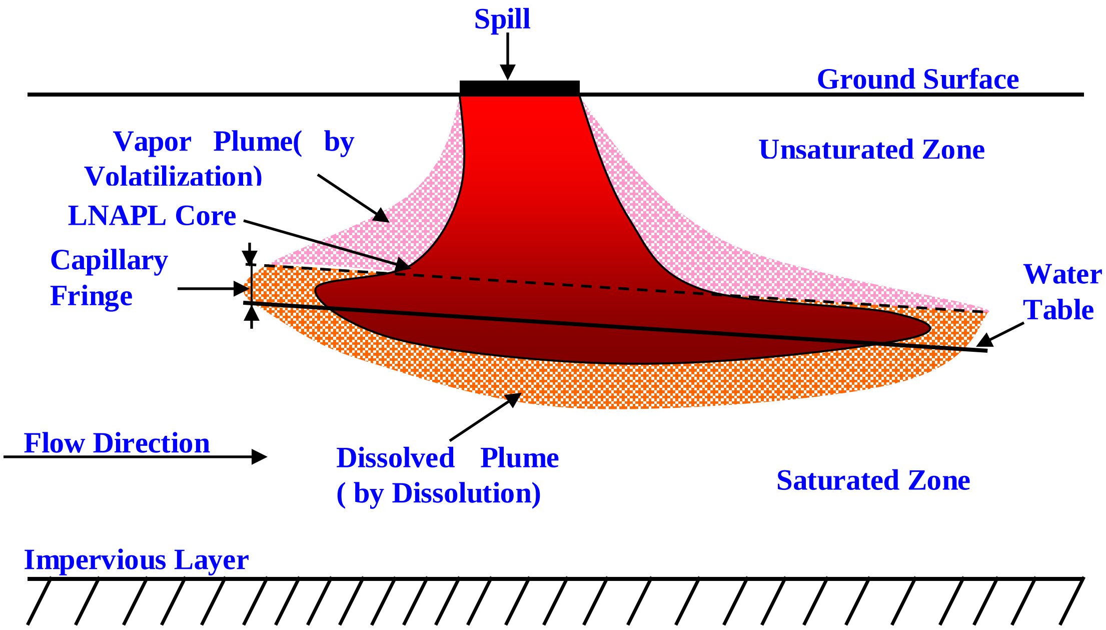
Oil spillage caused by fracture of pipelines.



Oil spillage from joints of pipelines.



Accidental spill.


Spill
Ground Surface
Unsaturated Zone
Vapor Plume(by Volatilization)
LNAPL Core
Capillary Fringe
Water Table
Flow Direction
Dissolved Plume (by Dissolution)
Saturated Zone
Impervious Layer

(a)


Spill
Ground Surface

Governing Equation for Mass Transport

This section develops a general differential equation, describing the transport of a dissolved constituent, subject to physical and chemical transport processes. Consider the elemental control volume shown in Figure 1. The mass conservation equation for this volume may be expressed as**:**

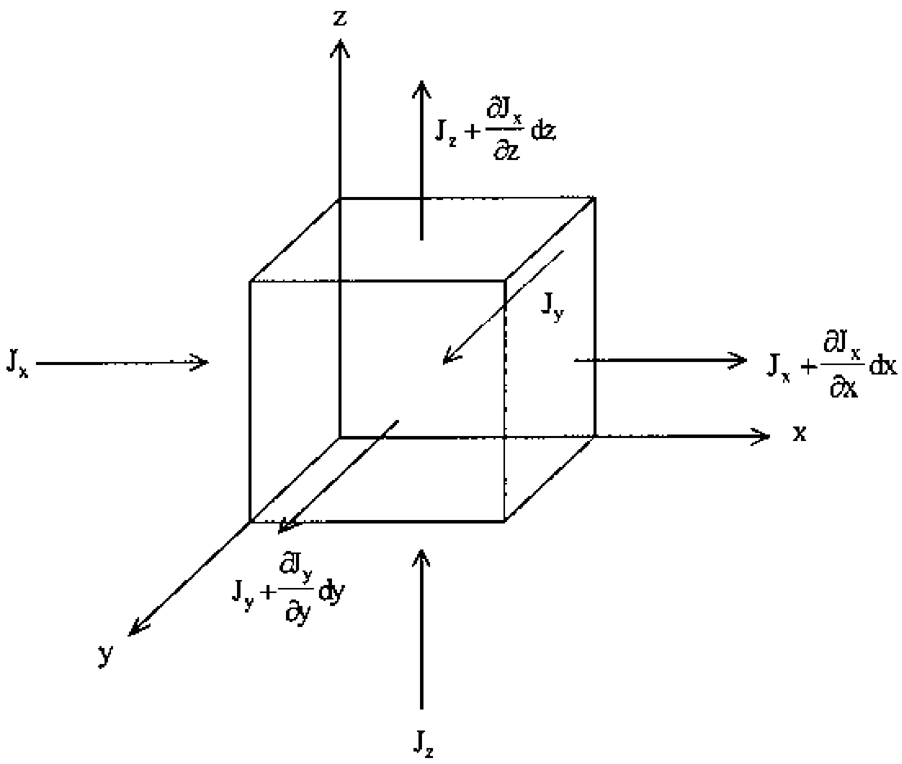


Figure 1: Elemental control volume for mass flux (Reddi and Inyang, 2000).

(Rate of mass input) - (rate of mass output) ± (rate of mass production or consumption) = rate of mass accumulation (1)

This equation can be written mathematically as:

$$-\left[\frac{\partial J_x}{\partial x} + \frac{\partial J_y}{\partial y} + \frac{\partial J_z}{\partial z}\right] \pm r = \frac{\partial (nc)}{\partial t} \qquad (2)$$

where *J* is the mass flux of solute per unit cross-sectional area transported in the direction indicated by the subscript *x*, *y*, or *z*; *r* is the rate of mass production/consumption given by the kinetic model of reaction, *n* is the porosity of the medium, and *c* is the solute concentration expressed as mass of solute per unit volume of solution.

The two mass transport processes of advection and dispersion govern *J* in Eq.2. The transport of dissolved contaminants follows that of water via advection and is therefore related to the velocity of water flow. The direction of hydraulic gradients specifies the extent of the dissolved contaminant transport. If advection is the only mechanism of transport, the pore velocity (Darcy velocity divided by porosity) is an indicator of the transport of dissolved contaminants. In reality, however, there are other mechanisms incorporating with advection. The saturated soil possesses concentration gradients in addition to hydraulic gradients because of the localized presence of the dissolved chemical. These concentration gradients provide an additional mechanism of transport namely, diffusion. The effect of diffusion is represented by spread out of contaminant in all directions in response to concentration gradients. The relative contributions of advection and diffusion are therefore dependent on the magnitudes of velocity and the concentration gradients. The diffusion of chemicals in soils is typically grouped with another important transport mechanism known as mechanical dispersion. The mechanical dispersion is the effect of advective velocities which, when sufficiently high, cause a mixing of the chemical in the porous medium. Accordingly, the mass flux (*J*) due to advection and dispersion in the x direction may be expressed as (Reddi and Inyang, 2000):

$$J_{advection} = V_x nc \quad \& \quad J_{dispersion} = -nD_x \frac{\partial c}{\partial x} \qquad (3)$$

Where V_x is pore velocity in the x direction. Note that D_x includes the two components of molecular diffusion and mechanical dispersion. Summing up the contributions from advection and dispersion, the mass fluxes are substituted into the Eq.2 and the resultant will be:

$$-\left[\frac{\partial}{\partial x}\left(V_x nc - nD_x\frac{\partial c}{\partial x}\right)\right] - \left[\frac{\partial}{\partial y}\left(V_y nc - nD_y\frac{\partial c}{\partial y}\right)\right] - \left[\frac{\partial}{\partial z}\left(V_z nc - nD_z\frac{\partial c}{\partial z}\right)\right] \pm r = \frac{\partial(nc)}{\partial t} \qquad (4)$$

By assuming that the velocities are steady and uniform and that the dispersion coefficients do not vary in space. It is also assumed that the porosity of the medium is constant in time and space. One dimensional mass transport of solute in the saturated zone of the soil which well-known advection-dispersion equation (ADE) can be established as follows:

$$D_z\frac{\partial^2 c}{\partial z^2} - V_z\frac{\partial c}{\partial z} \pm \frac{r}{n} = \frac{\partial c}{\partial t} \qquad (5)$$

The exact form of the ADE depends on the mass transfer processes accounted for in the term *r*. One of the dominant mass transfer mechanisms occurring during mass transport is sorption which represents the fundamental mechanism for the operation of the reactive permeable barriers. Incorporating sorption can be achieved by using Linear, Langmuir, or Freundlich isotherm. However, the simplest way for incorporation is the linear sorption isotherm as below:

$$S = K_d c \qquad (6)$$

Where S is the quantity of mass sorbed on the surface of solids and K_d is the distribution coefficient. The rate expression r is equal to the product of time derivative of S and dry mass density, ρ_b. Thus,

$$r = \rho_b\frac{\partial S}{\partial t} = K_d\rho_b\frac{\partial c}{\partial t} \qquad (7)$$

Substituting Eq.7 in the Eq.5 and rearrangement of terms yields:

$$D_z\frac{\partial^2 c}{\partial z^2} - V_z\frac{\partial c}{\partial z} = R\frac{\partial c}{\partial t} \qquad (8)$$

Where R ($=1+\rho_b K_d/n$) is known as the retardation factor since it has the effect of retarding the transport of adsorbed species relative to the advection front.

For inert medium like sand, the retardation factor (R) equal 1 and Eq.8 will be as follows:

$$\frac{\partial c}{\partial t} = D_z\frac{\partial^2 c}{\partial z^2} - V_z\frac{\partial c}{\partial z} \qquad (9)$$

Analytical solution of this equation will be as follows:

$$C(z,t) = \frac{C_o}{2}\left[erfc\left(\frac{z-V_z t}{2\sqrt{D_z t}}\right) + exp\left(\frac{V_z z}{D_z}\right) erfc\left(\frac{z+V_z t}{2\sqrt{D_z t}}\right)\right] \qquad (10)$$

$$C(z,t) = \frac{C_o}{2}\left[erfc\left(\frac{z-V_z t}{2\sqrt{D_z t}}\right)\right]$$ (11) because the second term is very small

EXAMPLE// Large wooden vats are contained a brine. One of these vats has been leaking directly to into the water table. The concentration of chloride in the brine is 1575mg/L. The flow in the aquifer that receives the brine is essentially one-dimensional and has the following characteristics; hydraulic conductivity=2.93×10^{-4}m/sec, hydraulic gradient =0.00678 and effective porosity (n_e)=0.259. The estimated effective diffusion coefficient for chloride is 2×10^{-9} m^2/sec. Calculate the concentration of chloride above any background value at distance 125m from leaking vat 0.5years after the leak began.

Solution:

1) We must apply the Eq.11, $C(z,t) = \frac{C_o}{2}\left[erfc\left(\frac{z-V_z t}{2\sqrt{D_z t}}\right)\right]$
2) Now, we must calculate the parameters of Eq.11 as follows:

a) Calculate V_z

$$V_z = \frac{K}{n_e} i = \frac{2.93\times10^{-4}}{0.259}\times 0.00678 = 7.67\times10^{-6} m/s$$

b) Calculate D_z

$$D_z = \alpha_z V_z + D^*$$

$$\alpha_z = 0.83(log z)^{2.414}$$ (z must be in m)

$\alpha_z = 0.83(log125)^{2.414}$

$\alpha_z = 4.96m$

$D_z = 4.96m \times 7.67 \times 10^{-6} m/s + 2 \times 10^{-9} m^2/s$

$D_z = 3.8 \times 10^{-5} m^2/s + 2 \times 10^{-9} m^2/s$ the second term can neglect because it is very small

$D_z = 3.8 \times 10^{-5} m^2/s$

3) $C(125m, 0.5year) = \frac{1575}{2}\left[erfc\left(\frac{125-7.67\times10^{-6}\times0.5\times365\times24\times3600}{2\sqrt{3.8\times10^{-5}\times0.5\times365\times24\times3600}}\right)\right]$

$$C(125m, 0.5year) = \frac{1575}{2}[erfc(0.0816)]$$

$$C(125m, 0.5year) = 715\ mg/L$$

Values of the Error Function and Complementary Error Function

x	erf *x*	erfc *x*	*x*	erf *x*	erfc *x*
0	0	1.0	1.0	0.842701	0.157299
0.05	0.056372	0.943628	1.1	0.880205	0.119795
0.1	0.112643	0.887537	1.2	0.910314	0.089686
0.15	0.167996	0.823004	1.3	0.934008	0.065992
0.2	0.222703	0.777297	1.4	0.952285	0.047715
0.25	0.276326	0.723674	1.5	0.996105	0.033895
0.3	0.328627	0.671373	1.6	0.976348	0.023652
0.35	0.379382	0.620618	1.7	0.983790	0.016210
0.4	0.428392	0.571608	1.8	0.989091	0.010909
0.45	0.475482	0.524518	1.9	0.992790	0.007210
0.5	0.520500	0.479500	2.0	0.995322	0.004678
0.55	0.563323	0.436677	2.1	0.997021	0.002979
0.6	0.603856	0.396144	2.2	0.998137	0.001863
0.65	0.642029	0.357971	2.3	0.998857	0.001143
0.7	0.677801	0.322199	2.4	0.999311	0.000689
0.75	0.711156	0.288844	2.5	0.999593	0.000407
0.8	0.742101	0.257899	2.6	0.999764	0.000236
0.85	0.770668	0.229332	2.7	0.999866	0.000134
0.9	0.796908	0.203092	2.8	0.999925	0.000075
0.95	0.820891	0.179109	2.9	0.999959	0.000041
			3.0	0.999978	0.000022

$$erf\,x = \left(\frac{4}{\pi}\right)^{1/2} \int_0^x \exp\left(-z\right)^2 dz$$

$$erf\ (0) = 0; \quad erf\ (\infty) = 1; \quad erf\ (-x) = -erf\ (x); \quad 1 - erf\ (x) = cerf\ (x)$$