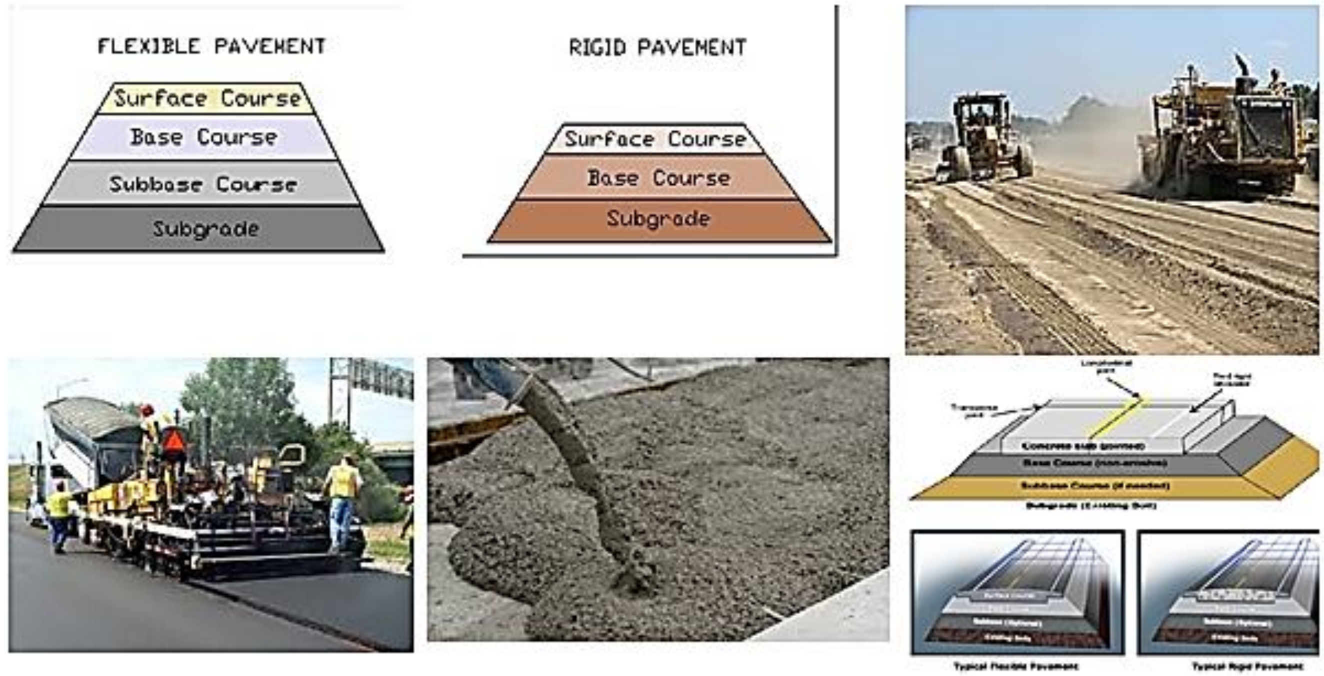
University of Anbar – College of Engineering
Departement of Civil Engineering
Highway Materials
Course No:*CE 4345*



Prepared By:
Dr Talal H. Fadhil
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A. Soil

A.1. Physical properties of soils:

General, Moisture content, Void ratio, Porosity, Percentage of air voids,, Degree of saturation, Density and specific gravity of soil particles, Density and unit weight of soil in place (in situ), Density of saturated soil, Other useful relationships, and Laboratory maximum density of soils.

A.2. Basic soil tests:

Particle size analysis, Particle size distribution by sieving,, The usefulness of aggregate gradation, Liquid limit, plastic limit and plasticity index, Moisture–laboratory density relationship, and Proctor compaction test (standard & modified).

A.3. Soil classification:

AASHTO soil classification system, Group index of soils, and Unified soil classification system (USCS).

A.4. Soil bearing capacity tests:

CBR laboratory test :CBR test procedure, Plate bearing test – modulus of reaction (k), Correlation between CBR and k value, Elastic modulus and resilient modulus of soils, Repeated triaxial test – resilient modulus test, and Correlation between resilient modulus and CBR.

B. Aggregates:

B.1. *General, Crushed aggregates, Natural aggregate, Slags, Mine waste, Demolition materials, Artificial aggregates, Recycled (pulverised) aggregates,.*

B.2. Geometrical properties determination:

Aggregate sizes, Particle size distribution – sieving method, Aggregate size, Sieving procedure and aggregate, and gradation curve determination.

B.3. Basic aggregate tests:

Resistance to fragmentation by the Los Angeles test, Resistance to impact test, Particle density and water absorption tests, Determination of density of coarse aggregate particles by wire-basket method, Determination of density of fine aggregate particles, Determination of density of aggregate particles less than 0.063 by pyknometer method, Magnesium sulfate test, Flat particles, elongated particles or flat and elongated particles test, Crushed and broken surfaces test, and Sand equivalent test.

B.4. Blending two or more aggregates:

Trial-and-error method, Mathematical methods, and Graphical method.

C. Bitumen, bituminous binders:

C.1. *General, Natural asphalt, Rock asphalt, Tar, Asphalt cement, Cut-back asphalts, Emulsified asphalt, Modified bitumens and Special bitumens , Bitumen modifiers, methods of modification and main changes to the properties of the bitumen .*

C.2. Rational and Superpave Laboratory tests and properties of bitumen:

General, Penetration test, Softening point test, Penetration index, Ductility test, Viscosity test viscometers, (Superpave Tests) Viscosity tests by rotational viscometers, Dynamic shear rheometer, Rolling thin oven test (RTOT), Thin film oven test (TFOT), Flash and fire point – cleveland open cup, Accelerated ageing by PAV, Bending beam rheometer test for flexural creep stiffness, and Direct tension test for fracture properties.

D. Flexible Pavement Layers:

General

D.1. Subgrade

Bearing capacity of subgrade and influencing factors, Estimation of subgrade CBR, Capping layer (Top Subgrade layer), Materials for capping layer, Soil stabilisation, Compaction of capping layer, Use of geotextiles and geotextile-related products.

D.2. Sub-base course

Sub-base course material and it's requirements and tests.

D.3. Base course

Materials for base course, Requirements of aggregates for unbound mixtures, Strength and stiffness of unbound materials and unbound layers, Hydraulically bound materials for bases and sub-bases.

E. Asphalt concrete (AC):

General AC (including global components of AC), Job Mix Formula (JMF).

E.1. Standard Marshall mix design *(Volumatric analyses, stability + flow).*

Tolerances from target mix, Volumetric properties of compacted bituminous mixture, Test method for determination of the theoretical maximum specific gravity and density, Test method for determination of bulk specific gravity and density of compacted bituminous mixture.

E.2. Modified Marshall mix design *(maximum aggregate size >25 mm).*

E.3. Superpave mix design

E.4. Stone Matrix Asphalt (SMA).

E.5. Warm Mix Asphalts (WMA)

WMA technologies, Performance of WMA, Specifications of WMA and Mix design practices for WMA.

E.6.Cold Asphat Mix (CAM)

General, Characteristic types of cold asphalts, Production of cold asphalt mixtures.

F. Asphalt layers:

Asphalt base, Binder course, Surface layer, Type of asphalt mixtuers for each layer.

G. Fundamental mechanical properties of asphalts and laboratory tests:

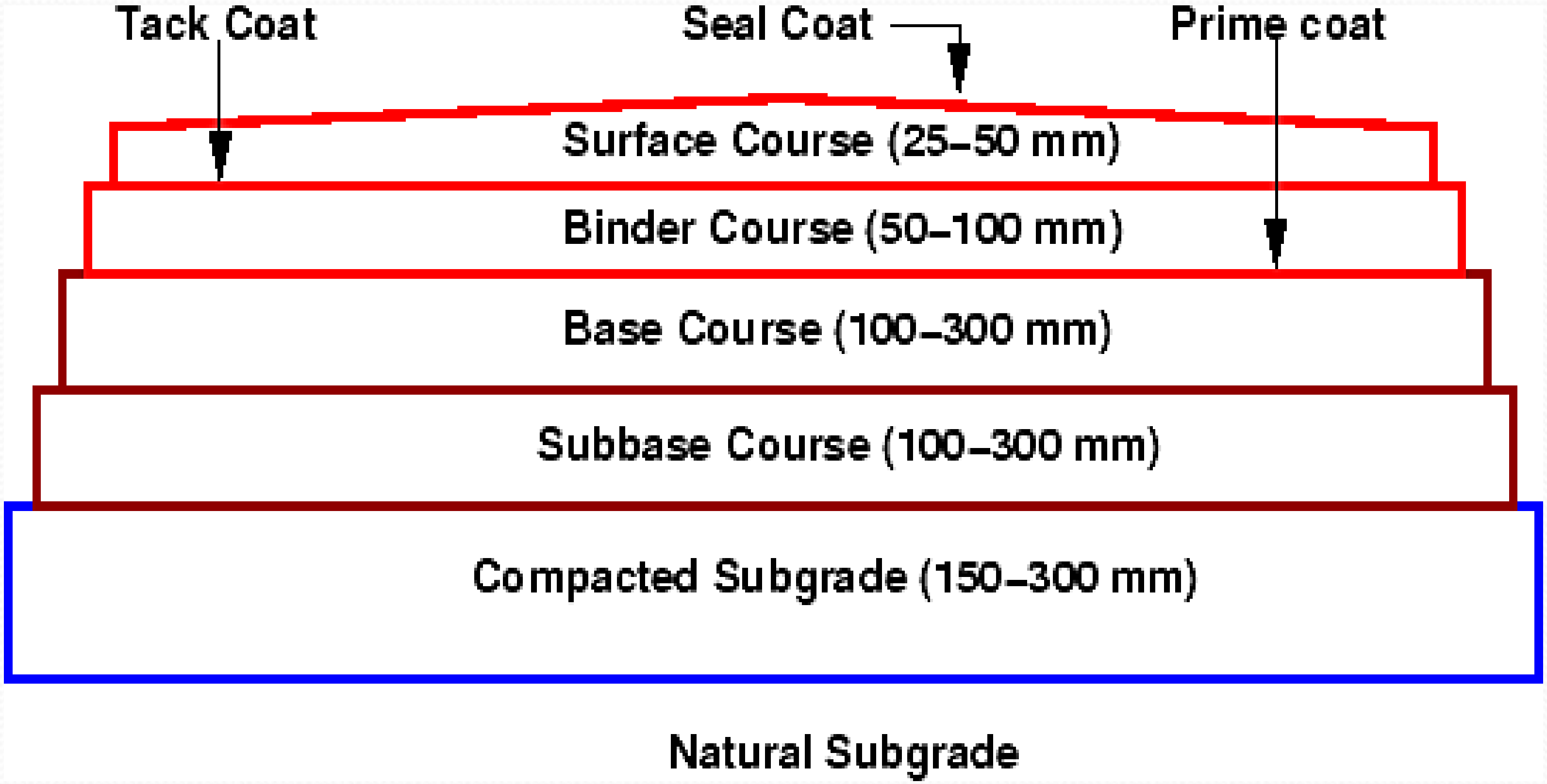
General, Stiffness modulus of asphalts, Indirect tensile test on cylindrical specimens, Permanent deformation of asphalts (dynamic and static modes test), and Fatigue of asphalts.

Text book: ((**Highway Engineering Pavements, Materials and Control of Quality**))

By: ***Athanassios Nikolaides***

CRC Press is an imprint of Taylor & Francis Group, an Informa business

Conventional Flexible Pavements Components



A. Soil

A.1. Physical properties of soils:

General

- The basic fractions of soils are boulders, cobbles, gravels, sand, silt and clay.
- The representative size of the particles for the above fractions are based on the region and specifications.

Soil fractions

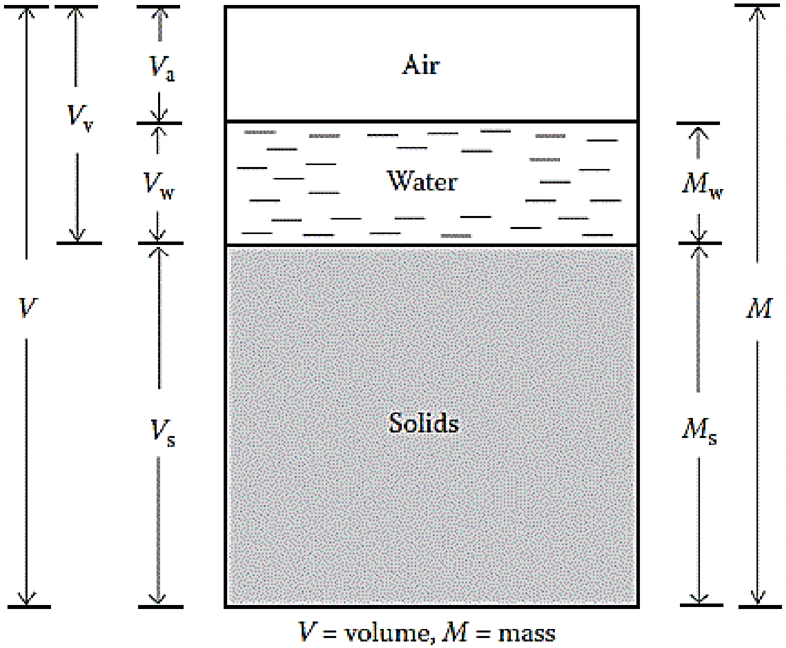
	CEN EN ISO 14688-1 (2013)	AASHTO M 146 (2012)	ASTM D 2487 (2011)
Groups		*Particle size (mm)*	
Boulders		>300	>300
Large boulder (LBo)	>630	—	—
Boulder (Bo)	>200–630	—	—
Cobble (Co)	>63–200	>75–300	>75–300
Gravel (Gr)	>2.0–63	>2.0–75	>4.75–75
Coarse (CGr)	*>20–63*	*>25–75*	*>19–75*
Medium (MGr)	*>6.3–20*	*>9.5–25*	—
Fine (FGr)	*>2.0–6.3*	*>2.0–9.5*	*>4.75–4.75*
Sand (Sa)	>0.063–2	>0.075–2.0	>0.075–4.75
Coarse (CSa)	*>0.63–2.0*	*>0.425–2.0*	*>2.0–4.75*
Medium (MSa)	*>0.2–0.63*	—	*>0.475–2.0*
Fine (FSa)	*>0.063–0.2*	*>0.075–0.425*	*>0.075–0.475*
Silt (Si)	>0.002–0.063	0.075–0.002	<0.075–PI <4
Coarse silt (CSi)	*>0.02–0.063*	—	—
Medium silt (MSi)	*>0.0063–0.02*	—	—
Fine silt (FSi)	*>0.002–0.0063*	—	—
Clay	≤0.002	<0.002	<0.075–PI >4
Peat		Organic soil	

Notes:

- *Boulders and cobbles, gravels and sands* are granular soils (not cohesive ,high permeability and good stability). The natural has a spherical shape and other praperd by crushing has at least one broken and crushed surface
- Silt is soil consisting of very fine spherical particles (0.002 to 0.063 mm (0.075 mm)), (cohesive, powder (larger than clay but smaller than sand particles).
- Clay is the finest soil material (less than 0.002 mm) has a flattened and elongated particle shapes. In water is a colloid in suspension case.
- Characteristically, it is reported that in 1 g of clay, there are approximately 90 billion particles, whereas in 1 g of silt and coarse sand (0.5–1.0 mm), there are 5.5 million particles and 700 particles, respectively.

PHYSICAL PROPERTIES OF SOILS:

Natural soil combined of three phases {(solid, liquid and air) (solid particles, voids or pores with or without water)}, as shown in figure. These phases give the soil its basic properties, which affect its mechanical behaviour.



Phases' Diagram.

1. Moistuer Content

Moisture (water) content of soil (w) is defined as the ratio of the water mass contained in the soil (M_w) to the mass of solids (M_s) and is expressed as a percentage by mass of solids. The moisture of the soil is a crucial factor for the highway engineer, where it effects on the bearing capacity of the pavement's foundation layer.

$$w = \left({}^{M_w}/_{M_s} \right) \times 100(\%)$$

2. Void ratio

Void ratio (**e**) is defined as the ratio of the volume of air voids (*V*a) and water voids (V_w) to the volume of solids (V_s):

$$e = (V_a + V_w)/V_s$$

3. Porosity

Porosity (***n***) is defined as the ratio of the volume of all voids (V_v) (air voids and voids filled with water) to the total volume (*V*) **OR** can also be calculated from the void ratio (***e***). The void ratio and the porosity are parameters that characterise the soil whether it is loose or dense.

$$n = (V_v/V) \times 100\% \ (or) = \ [e/(1+e)] \times 100\%$$

4. Percentage of air voids

The percentage of air voids (n_a) is defined as the ratio of air voids (V_a) to the total volume (*V*).

$$n_a = (V_a/V) \times 100(\%)$$

5. Degree of saturation:

The degree of saturation (*S*) is defined as the ratio of the volume of the water to the volume of all voids (V_v) (volume of air voids and voids filled with water).

$$S = (V_w / V_v) \times 100 (\%)$$

6. Density and specific gravity of soil particles

The density of soil particles (ρ_s) is defined as the ratio of the mass of soil particles solids (M_s) to the corresponding volume of soil particles (V_s).

$$\rho_s = M_s / V_s \quad (\text{kg/m}^3).$$

The specific gravity of a soil (g or γ) is the ratio of the weight in air of a given volume of soil particles at a stated temperature to the weight in air of an equal volume of distilled water at the stated temperature

7. Density and unit weight of soil in place (in situ)

The soil density (ρ) in situ is defined as the ratio of the mass of solids (Ms) and the mass of water (Mw) to the total volume (V) of the soil.

$$\rho = (M_s + M_w)/V \ (\text{kg/m}^3).$$

In some cases, the soil density can also be called ‘apparent soil density’ or ‘wet density of soil’. The density of the undisturbed or compacted soil in situ is determined by the sand-cone method or the rubber balloon method or nuclear methods. *((https://www.youtube.com/watch?v=IlF3m4OLFwc))*.

8. Other useful relationships

where *w* is the moisture content (%), *e* is the void ratio, ρ is the soil density in situ (kg/m^3), *S* is the degree of saturation (%), ρ_d is the dry density (kg/m^3), ρ_s is the density of soil particles (kg/m^3), ρ_w is the density of water (kg/m^3).

$$w = (\rho - \rho_d)/\rho_d \quad \text{or} \quad \rho_d = \rho/(1 + w)$$

$$e = (\rho_s - \rho_d)/\rho_d \quad \text{or} \quad \rho_d = \rho_s/(1 + e)$$

$$\rho = (\rho_s + S \times e \times \rho_w)/(1 + e)$$

9. Laboratory maximum density of soils

- It is corresponding to moisture content, which is defined by the Proctor method.
- To achieve sufficiently compacted soil material so that settlement does not occur.
- Sufficient compaction is achieved when the density of the soil material, after compaction, is greater than or equal to a certain required percentage of the laboratory optimum density determined (92% to 98%).

A.2. BASIC SOIL TESTS:

Particle size analysis

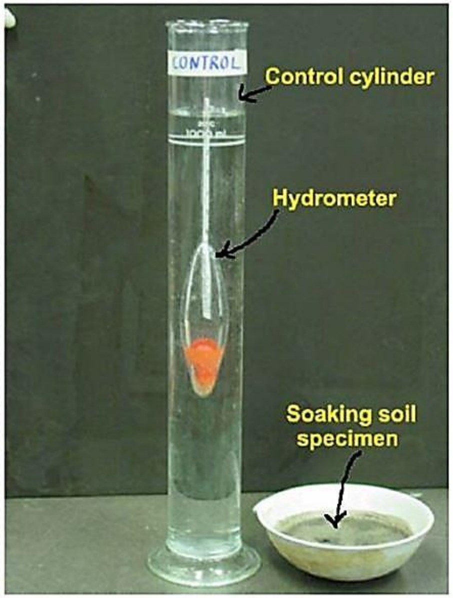
- Particle size analysis is the determination of the particle size distribution of a soil sample. Where , physical characteristics, classification of soils, many geotechnical and geohydrological properties of soil are related to the particle size distribution.
- Determination of the particle size distribution either by sieving or sedimentation method. Where, sieving methode used when fine soils materials (passing through 0.063 or 0.075 mm sieves) are less than 10% and while sedimentation method for fine soils materials more trhan 10%.

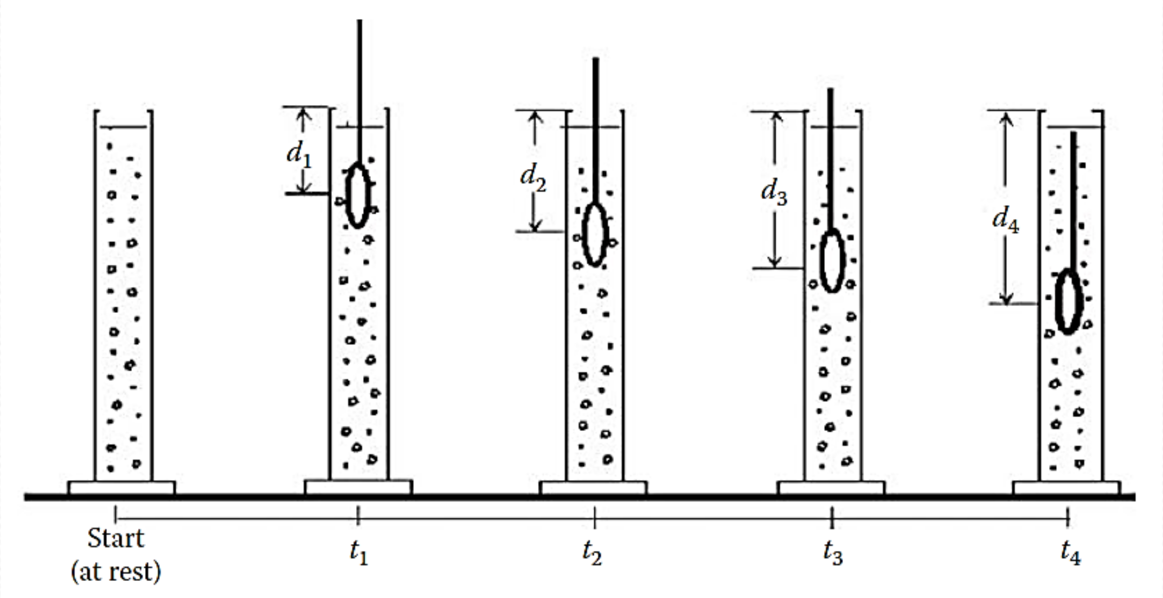
1. Particle size distribution by sieving

Sieving is carried out using appropriate diameter and size sieves. The procedure is detailed as in ASTM D 422 or AASHTO T 88.

2. Particle size distribution by sedimentation

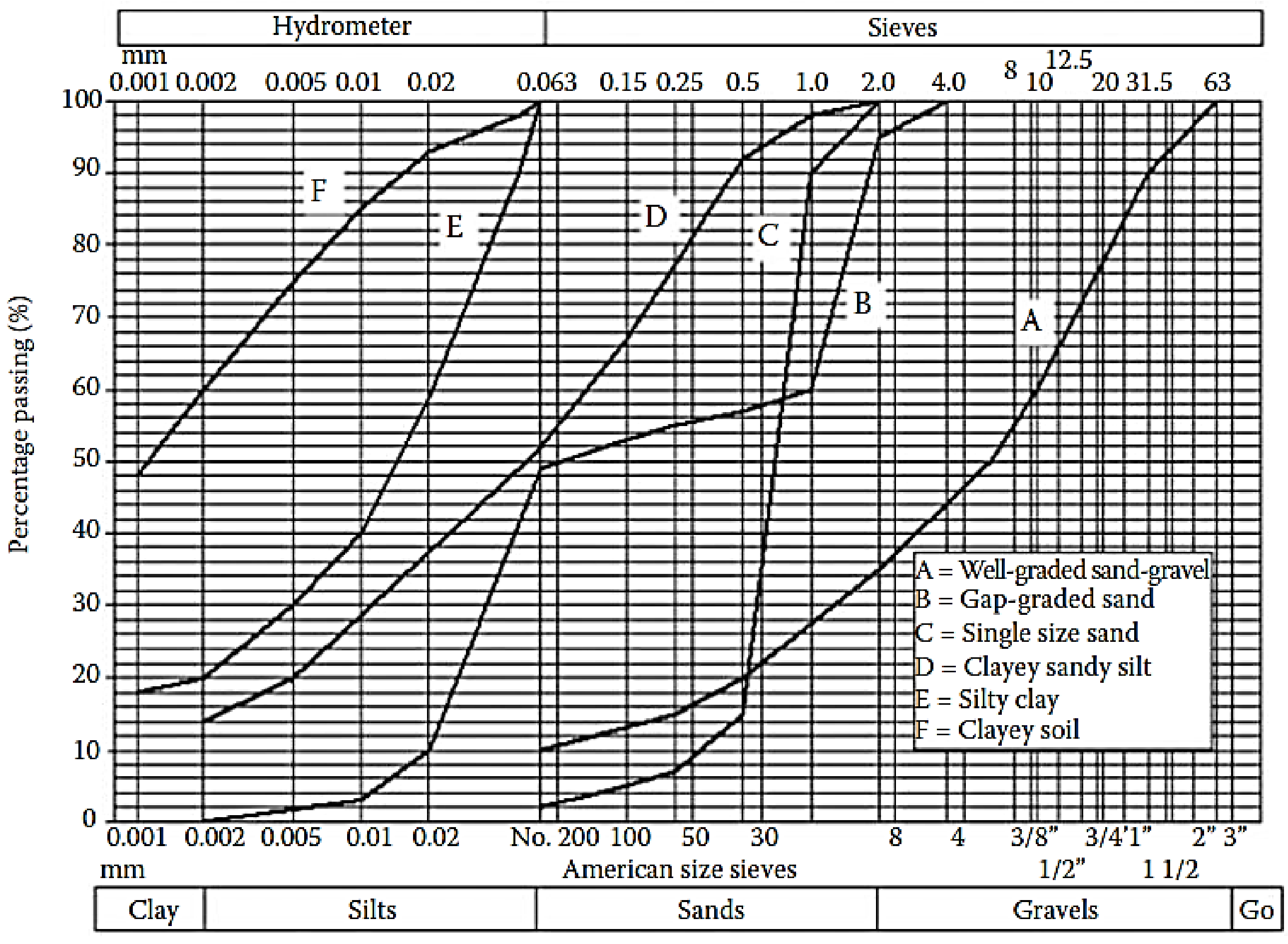
According to ASTM D 422 or (AASHTO T 88), materials passing through a 2.0 mm sieve are separated. A mass of test portion of approximately **100 g, if sandy soil is used**, or **50 g, if clay and silt size**, is placed in a 250 ml beaker. The sample is covered with 125 ml of stock solution (sodium hexametaphosphate solution, 40 g/L), stirred until is thoroughly wetted and allowed to soak for at least 12 or 16 h.





The usefulness of aggregate gradation

- The position, the shape and the slope of the gradation curve provide useful information for the soil material. Where the position of gradation curve is used in soil classification groups, while the shape and slope determine the distribution of the particles and the deficiency or sufficiency of certain size particles.



- The particle size of the soil material affects its mechanical behaviour. Coarse soil materials have a better mechanical behaviour than fine ones in terms of strength and resistance to loading. Additionally, the particle size determines the ability or possibility of water retention or absorption, as well as the possibility of frost damage or swelling. **Very fine soils** (particularly silt and clay) absorb and retain water. As a result, **they swell and they are also susceptible to frost damage**. **Coarse materials do not have any of the abovementioned deficiencies; hence, they are preferable and more suitable as foundation layer materials**.
- The relatively moderate slope of curves A, [illegible], E and F indicates a uniform particle distribution and consequently the existence of all sizes particles. The almost vertical 'S'-shaped curve (curve [illegible]) indicates a material with almost single-size particles. The double 'S'-shaped curve (curve B) indicates a material in which certain particle sizes are absent. This type of curve is known as a gap graded curve.
- The uniformity of the soil material, desirable in most cases, is quantified by reference to the uniformity coefficient and the coefficient of curvature. The uniformity coefficient (C_U) and the coefficient of gradation (C_C) are determined by the following equations:

$$C_U = D60/D10$$

$$C_C = (D30)^2/(D10 \times D60)$$

where D10, D30 and D60 are the particle sizes corresponding to the ordinates 60% 30% and 10% by mass of the percentage passing.

Grain Size Distribution (Cont.)

- Describe the shape

Example: well graded

$$D_{10} = 0.02\,\text{mm (effective size)}$$
$$D_{30} = 0.6\,\text{mm}$$
$$D_{60} = 9\,\text{mm}$$

Coefficient of uniformity

$$C_u = \frac{D_{60}}{D_{10}} = \frac{9}{0.02} = 450$$

Coefficient of curvature

$$C_c = \frac{(D_{30})^2}{(D_{10})(D_{60})} = \frac{(0.6)^2}{(0.02)(9)} = 2$$

- Criteria

Well – graded soil

$1 < C_c < 3$ and $C_u \geq 4$

(for gravels)

$1 < C_c < 3$ and $C_u \geq 6$

(for sands)

- Question

What is the C_u for a soil with only one grain size?

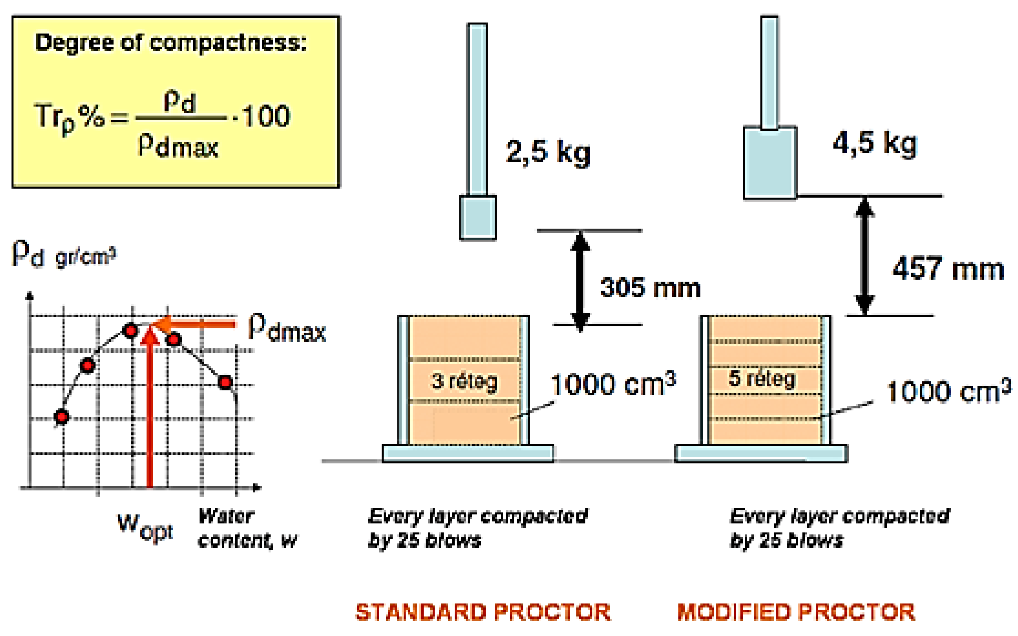
Liquid limit, plastic limit and plasticity index

- The liquid and plastic limits are known as Atterberg limits (ASTM D 4318 or AASHTO T 89).
- The liquid limit (**LL**) of a material is the water content at which the soil passes from the liquid to plastic condition and is determined by the liquid limit test.
- The plastic limit (**PL**) of a material is the water content at which the soil becomes too dry to be in a plastic condition and is determined by the plastic limit test. The thread is further rolled so its diameter reaches 3.2 mm within 2 min. Then, break the thread into several pieces.
- The plasticity index (**PI**) is the numerical deference between the liquid limit and the plastic limit **PI = LL − PL**
- The plasticity index (PI) is the most commonly used parameter in pavement engineering. Soil materials with a high plasticity index value are unsuitable for pavement foundation. Examples of such materials include all clayey, silty and sand-silt materials.
- According to Iraqi specification the suitable soils are with LL less than 55% and PI less than 30%.

Proctor compaction test (Standard and modified)

The proctor compaction test (standard and modified) defines the relationship between soil density and moisture content with the aim of determining the maximum density at a certain moisture content, known as the optimum moisture content. The modified proctor compaction test is performed according to ASTM D 1557 or AASHTO T 180.

The soil sample should have particles all passing through the 19.0 mm sieve. In case the soil contains particles retained on the 19.0 mm sieve and its percentage is 10% to 30%, the corresponding percentage retained shall be replaced by an equivalent mass of material passing through the 19.0 mm sieve and retained on the 4.75 mm sieve.



A.3. Soil classification:

The soil fractions as described by natural properties (such as origin, colour, shape, etc.) did not help engineers to easily recognise the soil's suitability for roadworks. Several classification systems have been developed for this purpose, such as:AASHTO, USCS (ASTM), European and UK.

AASHTO soil classification system (AASHTO M 145)

- The AASHTO soil classification system considers coarse soil materials (boulders, cobbles, gravels and sands) as those in which ≥65% of their mass is retained on a 0.0075 mm sieve. Fine soil materials (silts and clays) are those in which >35% of their mass passes through a 0.075 mm sieve.
- The coarse soil material is divided into three major groups (A-1, A-2 and A-3) and seven subgroups (A-1-a, A-1-b, A-3, A-2-4, A-2-5, A-2-6 and A-2-7), depending on the retained percentage in certain sieves, the liquid limit and the plasticity index. The A-1 group is considered to be the coarsest, whereas the A-3 group is the least coarse. Fine soil material is divided into four major groups (A-4, A-5, A-6 and A-7) and only A-7 is further divided into two subgroups (A-7-5 and A-7-6). The A-4 and A-5 groups refer to silts, while the A-6 and A-7 groups refer to clays.

Table 1.7 AASHTO soil classification system

General classification	*Coarse soil material, percentage passing through the 0.075 mm sieve <35%*							*Fine soil material (silt–clayey), percentage passing through the 0.075 mm sieve >35%*				
Classification group	*A-1*			*A-2*							*A-7*	
Subgroup	*A-1-a*	*A-1-b*	*A-3*	*A-2-4*	*A-2-5*	*A-2-6*	*A-2-7*	*A-4*	*A-5*	*A-6*	*A-7-5*	*A-7-6*
% Passing from sieve												
2.00 mm	50 max	—	—	—	—	—	—	—	—	—	—	—
0.425 mm	30 max	50 max	51 min	—	—	—	—	—	—	—	—	—
0.075 mm	15 max	25 max	10 max	35 max	35 max	35 max	35 max	36 min	36 min	36 min	36 min	36 min
Characteristics (passing through the 0.425 mm sieve)												
Liquid limit	—		—	40 max	41 min	40 max	41 min	40 max	41 min	40 max	41 min	41 min
Plasticity index	6 max		N.P.	10 max	10 max	11 min	11 min	10 max	10 max	11 min	11 min[a]	11 min[b]
Typical types of soils	Gravels, sand and sand gravels		Fine sand	Silty or clayey sand gravels				Silty soils		Clayey soils		
Suitability as subgrade	Excellent to good							Fair to poor				

Source: AASHTO M 145, *Classification of Soils and Soil-Aggregate Mixtures for Highway Construction Purposes*, Washington, DC: AASHTO, 2012. With permission.

[a] The plasticity index of the materials in subgroup A-7-5 is equal to or less than (LL − 30), where LL is the liquid limit.
[b] The plasticity index of the materials in subgroup A-7-6 is greater than (LL − 30), where LL is the liquid limit.

Group Index

- The group index of soils (GI) indirectly expresses the bearing capacity of soil material. The values obtained are higher than zero (0). Low values from 0 to 4 indicate a soil material with good bearing capacity, whereas values >8 indicate a soil material with bearing capacity varying from low to bad.
- The group index of a soil material depends on the liquid limit, plasticity index and the percentage passing through the 0.075 mm sieve. The relationship used to calculate the GI is as follows:

$$GI = (F - 35) \times [0.2 + 0.005 \times (LL - 40)] + 0.01 \times (F - 15) \times (PI - 10)$$

where F is the percentage passing through the 0.075 mm sieve (No. 200) (expressed as an integer), LL is the liquid limit and PI is the plasticity index.

The value of group index is expressed as an integer; if negative values are obtained, GI is zero.

Example:

- A sample of soil was tested in the laboratory, and results of the laboratory tests were as follows:
  1. Liquid limit = 42.3%
  2. Plastic Limit = 15.8%
  3. The following sieve analysis data:

U.S. Sieve Size	Percentage Passing
No. 4	100.0
No. 10	93.2
No. 40	81.0
No. 200	60.2

- Classify the soil sample by the AASHOTO classification system

Solution:

- PI = LL – PL = 42.3% - 15.8% = 26.5%
- LL – 30 = 12.3% (< PI = 26.5%)

A-7-6

No. 200 Sieve Passing = 60.2%

Liquid Limit = 42.3%

PI = 26.5%

TABLE 2–4
Classification of Soils and Soil-Aggregate Mixtures by AASHTO Classification System [5]

General Classification	Granular Materials (35% or less passing 0.075 mm)							Silt–Clay Materials (more than 35% passing 0.075 mm)			
	A-1			A-2							A-7
Group Classification	*A-1-a*	*A-1-b*	*A-3*	*A-2-4*	*A-2-5*	*A-2-6*	*A-2-7*	*A-4*	*A-5*	*A-6*	*A-7-5, A-7-6*
Sieve analysis: Percent passing:											
2.00 mm (No. 10)	50 max.	—	—	—	—	—	—	—	—	—	—
0.425 mm (No. 40)	30 max.	50 max.	51 min.	—	—	—	—	—	—	—	—
0.075 mm (No. 200)	15 max.	25 max.	10 max.	35 max.	35 max.	35 max.	35 max.	36 min.	36 min.	36 min.	36 min.
Characteristics of fraction passing 0.425 mm (No. 40):											
Liquid limit				[illegible]0 max.	41 min.	40 max.	41 min.	40 max.	41 min.	40 max.	41 min.
Plasticity index				[illegible] max.	10 max.	11 min.	11 min.	10 max.	10 max.	11 min.	11 min.[1]
Usual types of significant constituent materials	Stone fragments, gravel, and sand		Fine sand	Silty or clayey gravel and sand				Silty soils		Clayey soils	
General ratings as subgrade	Excellent to good							Fair to poor			

[1]Plasticity index of A-7-5 subgroup is equal to or less than *LL* minus 30. Plasticity index of A-7-6 subgroup is greater than *LL* minus 30.

Unified soil classification system (ASTM system (ASTM D 2417))

- In this system, the soils are divided into groups: (a) coarse soils, (b) fine soils (silts and clay) and (c) highly organic soils (peat). As mentioned, coarse soils are those in which a mass of >50% is retained on a 0.075 mm sieve and fines are those in which ≥50% of its mass passes through a 0.075 mm sieve.

- Soils
  - Coarse-grained
  - Fine-grained
  - Highly organic soils
- Group Symbols:

G: Gravel	S: Sand	M: Silt	C: Clay
O: Organic	PT: Peat		
W: Well graded	P: Poorly graded		

- E.g. SW: Well graded sand

Required parameters for classification

•Grain-size distribution
•Liquid Limit
•Plasticity Index

Coarse-grained material

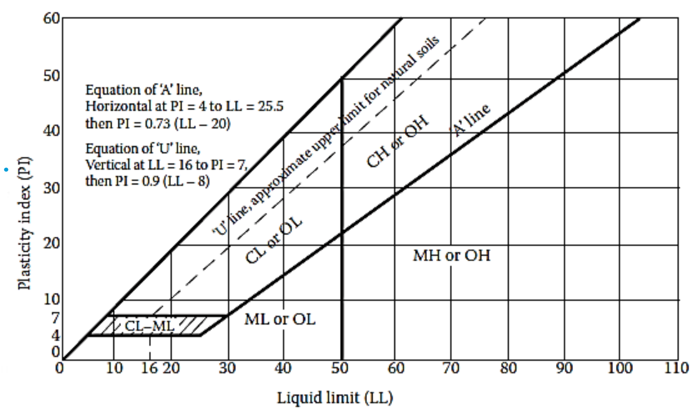
Grain size distribution

COARSE More than 50% retained sieve #200	Gravel: more than 50% coarse fraction retained on sieve #4	Less than 5% fines	$C_u > 4,\ 1 \leq C_c \leq 3$	→ GW
			Not satisfying GW	→ GP
		More than 12% fines	Below 'A' line	→ GM
			Above 'A' line	→ GC
	Sand: less than 50% coarse fraction retained on sieve #4	Less than 5% fines	$C_u > 6,\ 1 \leq C_c \leq 3$	→ SW
			Not satisfying SW	→ SP
		More than 12% fines	Below 'A' line	→ SM
			Above 'A' line	→ SC

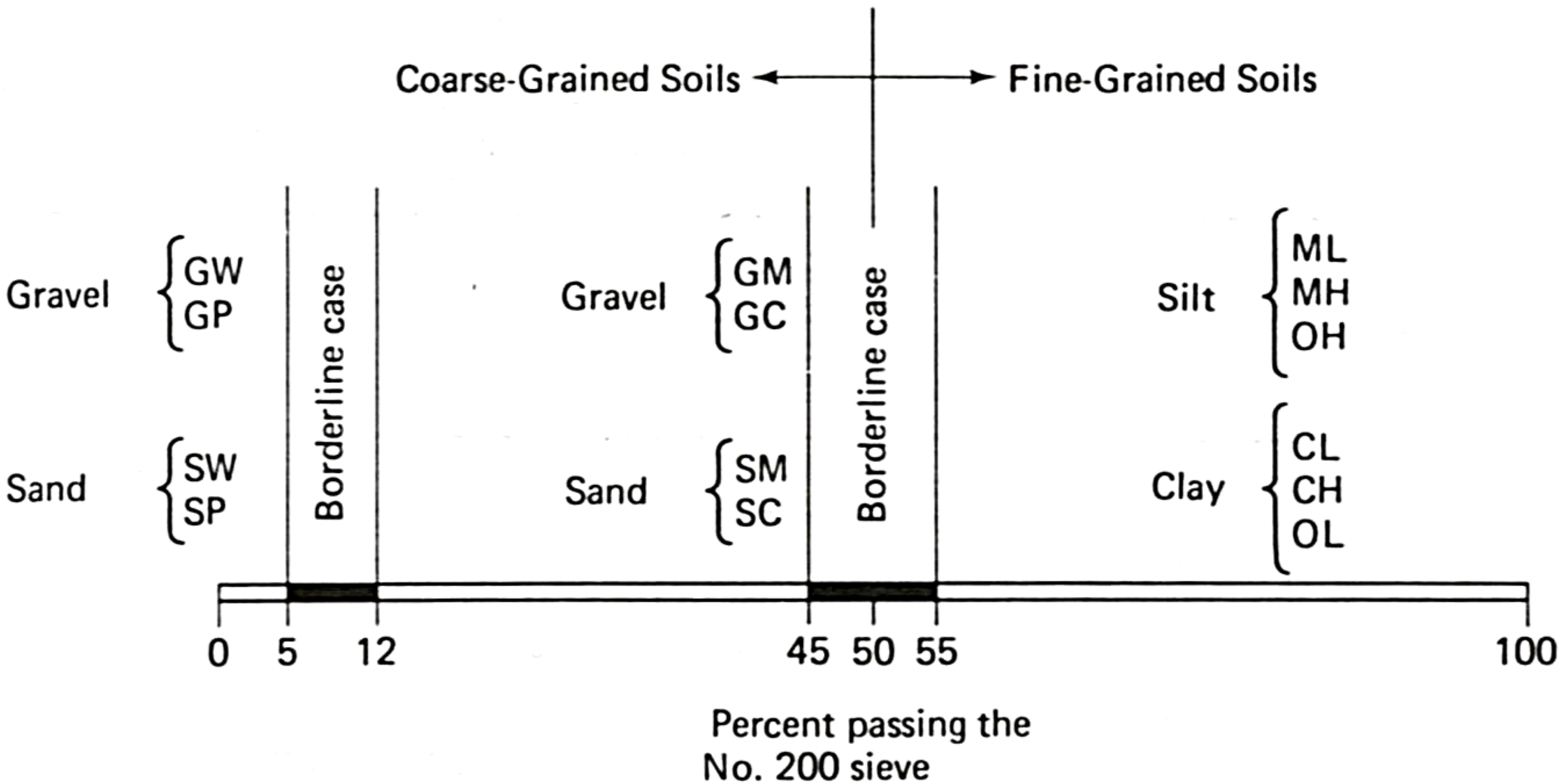
Fine-grained material

LL, PI

FINE Less than 50% retained sieve #200	$LL < 50$	(see plasticity chart)	ML CL OL
	$LL > 50$		MH CH OH
ORGANIC SOILS			→ Pt



UNIFIED SOIL CLASSIFICATION SYSTEM
(Borderline Classifications)



Note: Only two group symbols may be used to describe a soil.
Borderline classifications can exist within each of the above groups.

Example

Classify Soils A and B as given in Example 9–1 and obtain the group symbols and group names. Assume Soil B to be inorganic.

Soil A:

Percent passing No. 4 sieve	=	98
Percent passing No. 10 sieve	=	90
Percent passing No. 40 sieve	=	76
Percent passing No. 200 sieve	=	34
Liquid limit	=	38
Plastic limit	=	26

Soil B:

Percent passing No. 4 sieve	=	100
Percent passing No. 10 sieve	=	98
Percent passing No. 40 sieve	=	86
Percent passing No. 200 sieve	=	58
Liquid limit	=	49
Plastic limit	=	28

Solution:

Solution

Soil A:

Step 1. $F_{200} = 34\%$

Step 2. $R_{200} = 100 - F_{200} = 100 - 34 = 66\%$

Step 3. $R_{200} = 66\% > 50\%$. So it is a coarse-grained soil.

Skip Step 4.

Step 5. $R_4 = 100 - F_4 = 2\%$

$R_4 < 0.5R_{200} = 33\%$

So it is a sandy soil (Step 5b). $F_{200} > 12\%$. Thus C_u and C_c values are not needed.

$PI = LL - PL = 38 - 26 = 12$

$PI = 12 < 0.73(LL - 20) = 0.73(38 - 20) = 13.14$

From Table 9–6, the *group symbol* is **SM**.

$GF = R_4 = 2\%$ (which is $< 15\%$)

From Table 9–6, the *group name* is **silty sand**.

Soil B:

Step 1. $F_{200} = 58\%$

Step 2. $R_{200} = 100 - F_{200} = 100 - 58 = 42\%$

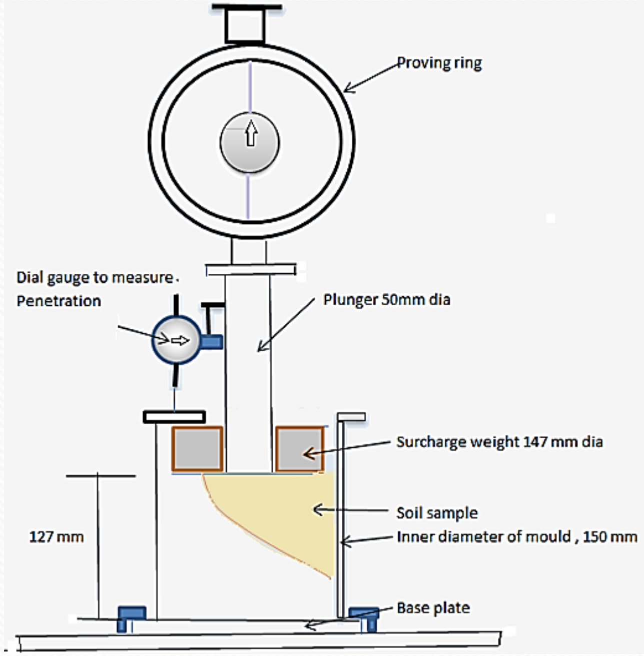
Step 3. $R_{200} = 42\% < 50\%$. So it is a fine-grained soil.

A.4. Soil bearing capacity tests:

Bearing capacity is the capacity of soil to support the loads applied to the ground. In pavement engineering is expressed by reference either to the California bearing ratio (CBR) or to the modulus of subgrade reaction, *k*. These parameters are very useful since they are utilised by many pavement design methodologies.

CBR laboratory test : ASTM D 1883, AASHTO T 193

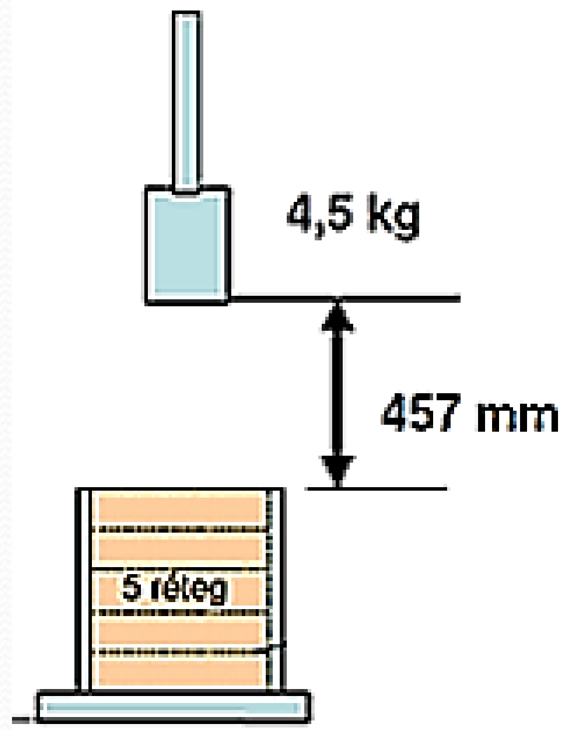
- The test determines the soil's bearing capacity from laboratory-compacted specimen, expressed as CBR.
- CBR is defined as the ratio of the load required to cause a certain penetration of the plunger into the soil material to the load required to obtain the same penetration on a specimen of standard material.



CBR test procedure:

1.Compaction of specimen

1.Preparing soil samples and check the need to replacement by amount of soil passing sieve 19 mm retained on sieve No. 4.
2. A sufficient amount of moist soil material (at least 35 kg) is prepared at the at the optimum moisture content.
3.A cylindrical metal moulds (D= 152.4 mm (6 in) and H= 177.8 mm) (7 in) is used to compact the soil or subbase using a rammer weighs 4.54 kg; diameter, 50.8 mm; height of drop, 457 mm).



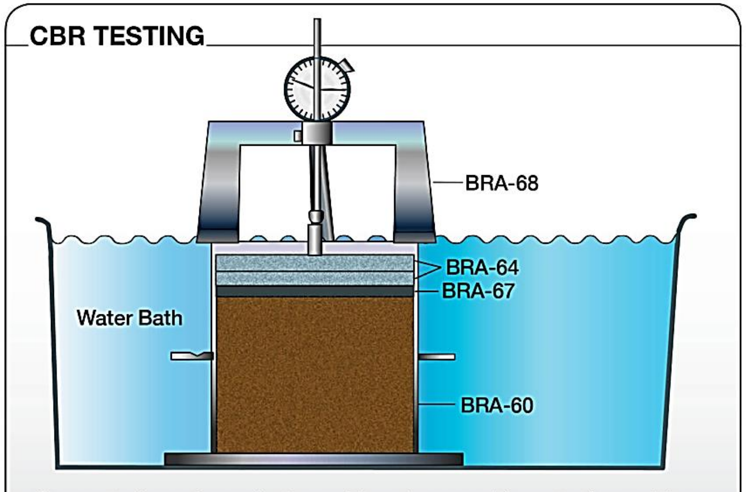
Each layer compacted by 56 blows

Compacted CBR sample

4. The compaction of specimen is carried out in five approximately equal layers. And each layer receives 56 blows.
5. little lower or a little higher than the maximum density, determined by the proctor method. In most cases 20, 30 and 65 blows are used for three different CBR determinations.

2. Specimen saturation

- Soil material, mould and surcharge weights are immersed in water bath for 96 h, a dial indicator is placed over the mould and its initial indication is recorded after the whole system is removed from water and the surcharge weights is left the final dial's read is recorded to estimate the swelling. This step is as a simulation to the conditions of road structuer layers when are exposed to fload for more than three days submer, and this condition is adopted by Iraqi Standard Specifications for Roads and Bridges (ISSRB).



Compacted specimens in the mold are immersed in water for soaking. Surcharge weights are placed on top and the molded specimen is monitored to determine swell.

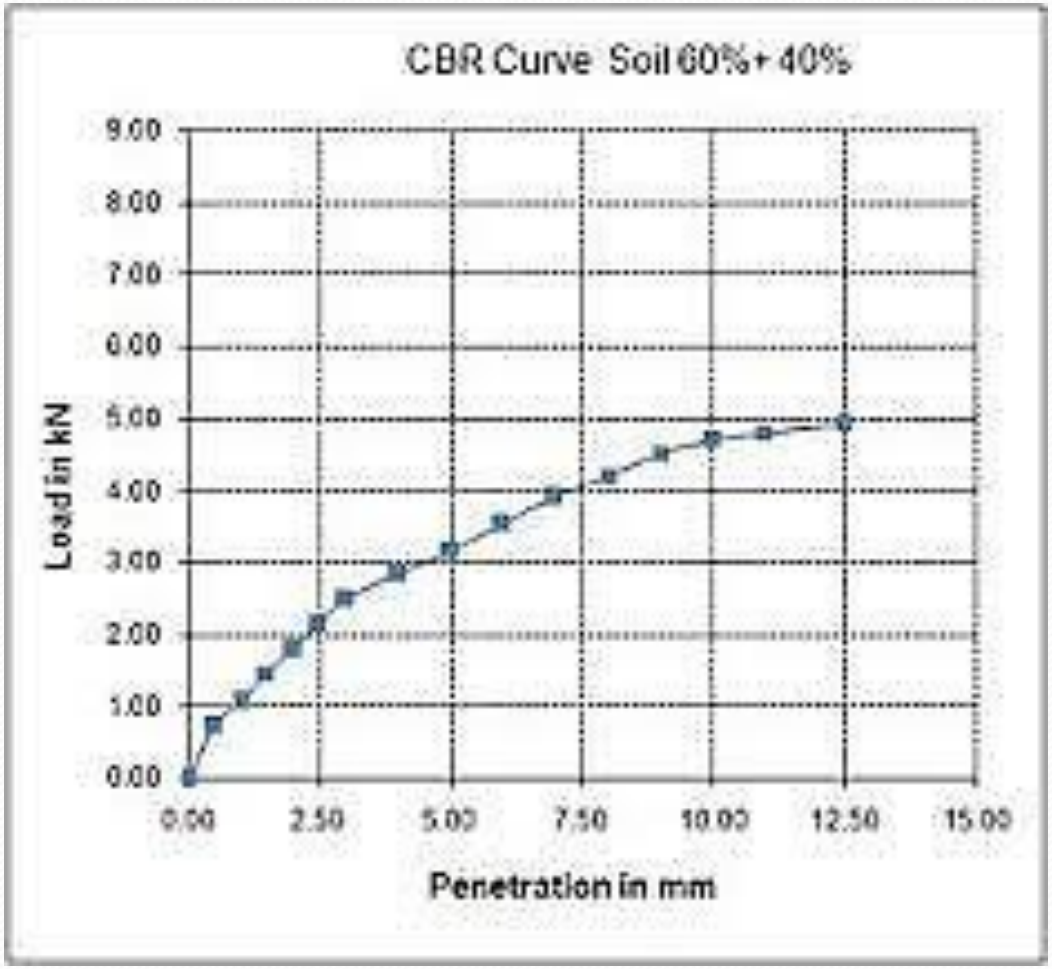
3. Loading–penetration Relationship

- Placing the three annular surcharge weights (2.26 kg each) on the top surface of compacted soil where the plunger's diameter (50 mm) is less than diameter of the annular surcharge weights.
- The compacted and wet specimen is placed on the CBR apparatus and set the device on zero when the plunger touch the top surface of soil.
- The device applies a steadily increased load through the cylindrical loading plunger with a penetration rate of 1.3 mm/min (0.05 in/min).
- Load indications are marked at regular intervals of depth of penetration. Once a penetration of approximately 8.0 mm is achieved, the loading stops.
- The load vs penetration relationship is ploted and then the load values cooresponding to penetrations of 2.5 mm and 5.0 mm are located.
- The CBR is calculated using the following relationship:

$$CBR_{(at\ 2.5\ mm)} = \frac{Load\ at\ penetration\ (2.5)mm}{Load\ of\ \ standard\ crushed\ roak\ (1000)psi\ (6.9\ MPa)}$$

$$CBR\ (_{at\ 5\ mm)} = \frac{Load\ at\ penetration\ (5)mm}{Load\ of\ \ standard\ crushed\ roak\ (1500)psi\ (10.3\ MPa)}$$

- The CBR value that corresponds to a penetration of 2.5 mm must be higher than CBR value that is related to penetration of 5 mm. If not, the test is repeated. If the repeated test gives the same outcome, then the value corresponding to a penetration of 5.0 mm is taken as the CBR of the material tested.



4. Determination of design CBR

- Design CBR is usually defined by the relationship between CBR and the dry density of compacted soil material. The results of the three specimens compacted at different compaction efforts (number of blows), and thus having different densities.
- The design CBR is the value obtained for density equal to 95% of the maximum density according to the (modified) proctor method. As shown in figure below.
- **According to ISSRB the CBR value for subgrade soil greater than 4%; and for sub-base types B & C are 35 and 30 % respectively.**

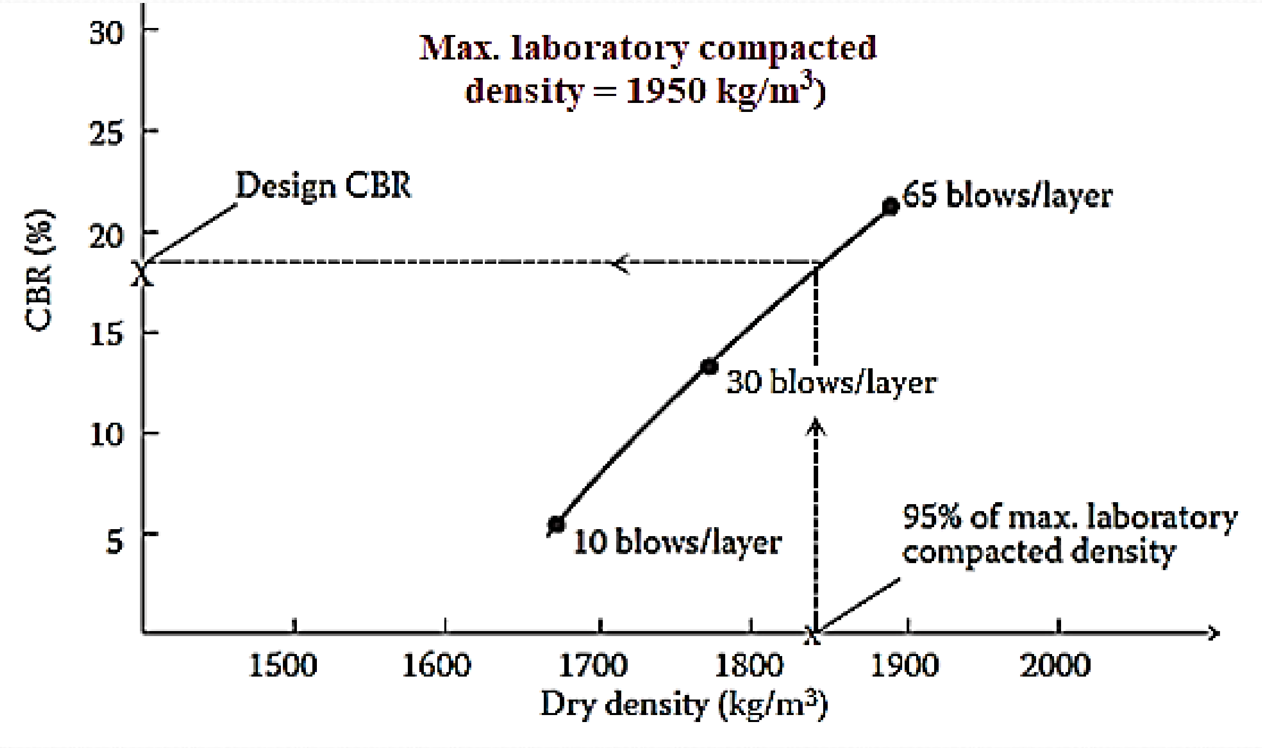
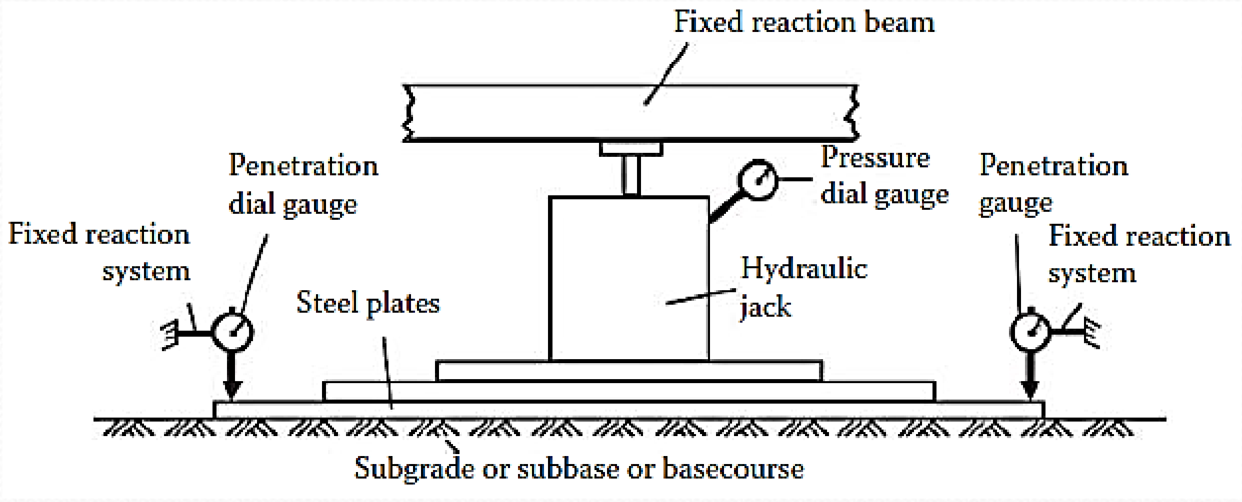


Plate Bearing Test – Modulus of Subgrade Reaction Test (*k*)

The plate bearing test is used for the determination of soil bearing capacity with respect to the modulus of surface reaction (***k*** value). The subgrade bearing capacity in terms of ***k*** value is used, mainly, in rigid pavement design. The constant of proportionality between the applied pressure (***P***) and the respective deflection (**Δ**) is defined as the modulus of subgrade reaction (***k***):

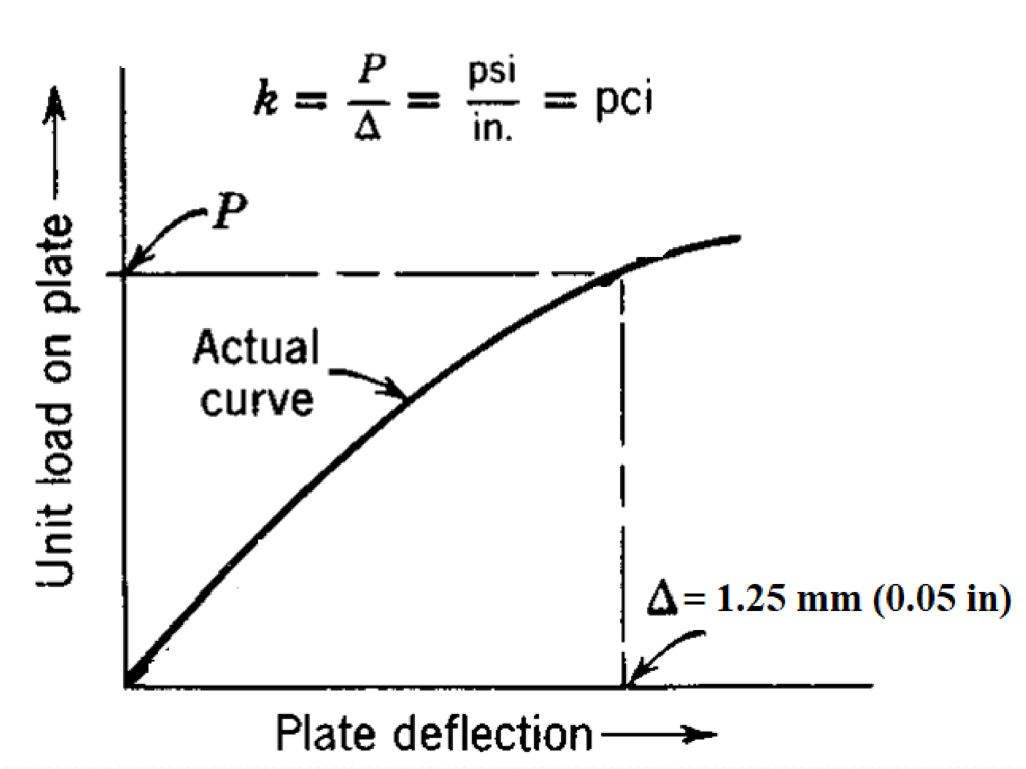
$$P = k \times \Delta$$

The test is carried out on compacted material with certain moisture, using a steel circular plate and a load application system. The steel plate can be of various diameters, but the plate normally used has a 762 mm diameter. For increasing plate's rigidity, two additional circular plates of smaller diameter (approximately 650 and 550 mm) are placed on top of it. Load application is usually carried out with hydraulic jack assembly. Plate bearing test arrangement is shown in Figure below.



- When the load is applied, the pressure induced on the layer's surface results in a corresponding deflection, which is measured by two, three gages. The average value of deflection measured at different magnitudes of pressure determines the pressure versus deflection curve.

As a result, the *k* value is determined from a point of the curve as defined by the test procedure adopted. In most cases, the pressure corresponding to 1.25 mm deflection using a 762 mm diameter plate, is used. Thus, the modulus of reaction (*k* value) is calculated using the formula below:



$$k = P/1.25$$

Where: P is a pressure in (kPa) and Δ is the deflection in (mm).

Correlation between CBR and *k* value

- It has been found that the following relationship between CBR and *k* is:

$$\mathbf{CBR = 6.1 \times 10^{-8} \times (\mathit{k}_{762})1.733(\%)}$$

where $\boldsymbol{k_{762}}$ is the modulus of reaction measured with a **762 mm** diameter plate for plate penetration, which is usually **1.25 mm**.

In case of using a smaller plate, $\boldsymbol{k_{762}}$ can be calculated with the following relationship:

$$\boldsymbol{k_{762} = F \times k_{mm}}$$

where ***F*** is the coefficient calculated from the following relationship:

$$\boldsymbol{F = 0.00124D + 0.0848}$$

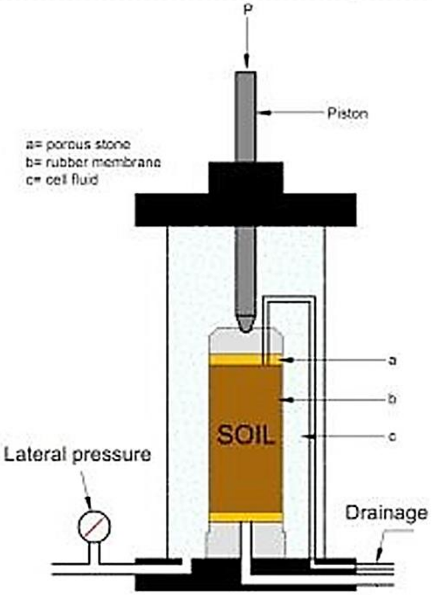
where ***D*** is the diameter of loading plate (mm), and $\boldsymbol{k_{mm}}$ is the modulus of reaction determined by the plate bearing test, using a certain millimeter diameter plate.

- The above relationships are used in estimating the CBR value of soil layer, **which contains a high percentage of coarse soils.**

Resilient Modulus (M_r) (AASHTO T307)

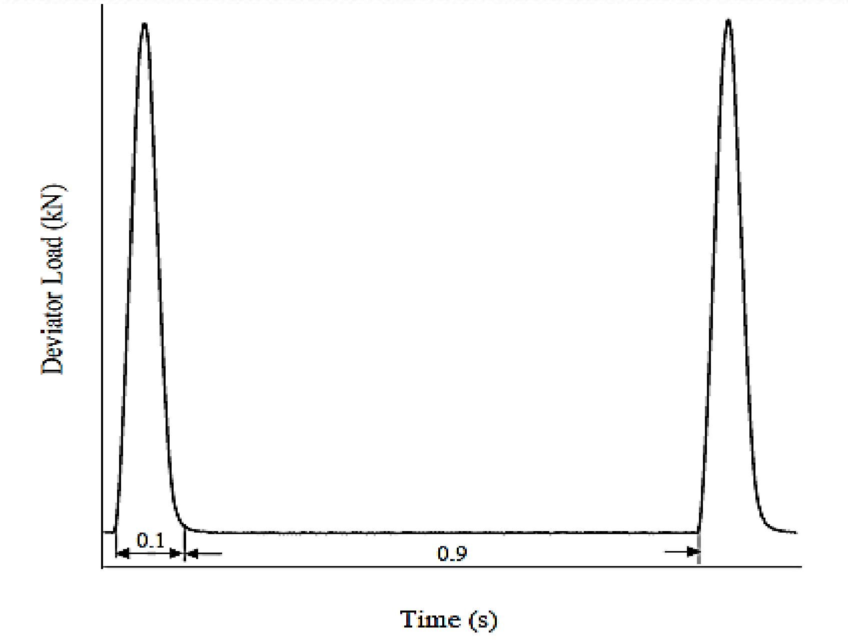
M_r is defined as the ratio of the repeated axial deviator stress (σ_d) to the recoverable or resilient axial strain (ε_r):

$$M_r = \frac{\sigma_d}{\varepsilon_r}$$



M_r Test Proceduer:

AASHTO T 307 requires a haversine-shaped loading waveform as shown in Figure below. The load cycle duration, when using a hydraulic loading device, **is 1 second that includes a 0.1 second load duration and a 0.9 second rest period**. The repeated axial load is applied on top of a cylindrical specimen under confining pressure. The total recoverable axial deformation response of the specimen is measured and used to calculate the resilient modulus. AASHTO T 307 requires the use of a load cell and deformation devices mounted outside the triaxial chamber. Air is specified as the confining fluid, and the specimen size is required to have a minimum diameter to length ratio of 1:2.



(a) Molds of different sizes

(b) Lubricating the mold

(c) Filling mold with one soil layer

(d) Placing compaction piston

(e) Applying static force

(f) Extracting compacted specimen

Note:

After compaction, the specimen is covered with a plastic membrane and is placed in the triaxial apparatus (chamber), **where it is subjected to loadings of 200 repetitions. In each loading cycle of 200 repetitions**, a different deviator stress is used by increasing or decreasing the radial stress, σ_3. At the end of each loading cycle of 200 repetitions, the recovered deformation is measured, from which both the recovered strain and the corresponding resilient modulus (*M*r) are calculated using the equation below.

$$M_r = \frac{\sigma_d}{\varepsilon_r}$$

Correlation between resilient modulus and CBR

The most widely used equations for estimating stiffness modulus (E or M_r) are as follows:

$M_r = 17.6 \times CBR^{0.64}$	(MPa)	**for materials with CBR>10%**
$M_r = 2555(CBR)^{0.64}$	**(psi)**	
$M_r = 10.3 \times CBR$	(MPa)	**for materials with (2%<CBR≤10%)**
$M_r = 1500 \times CBR$	**(psi)**	

Note: 1 psi = 0.006895 MPa.