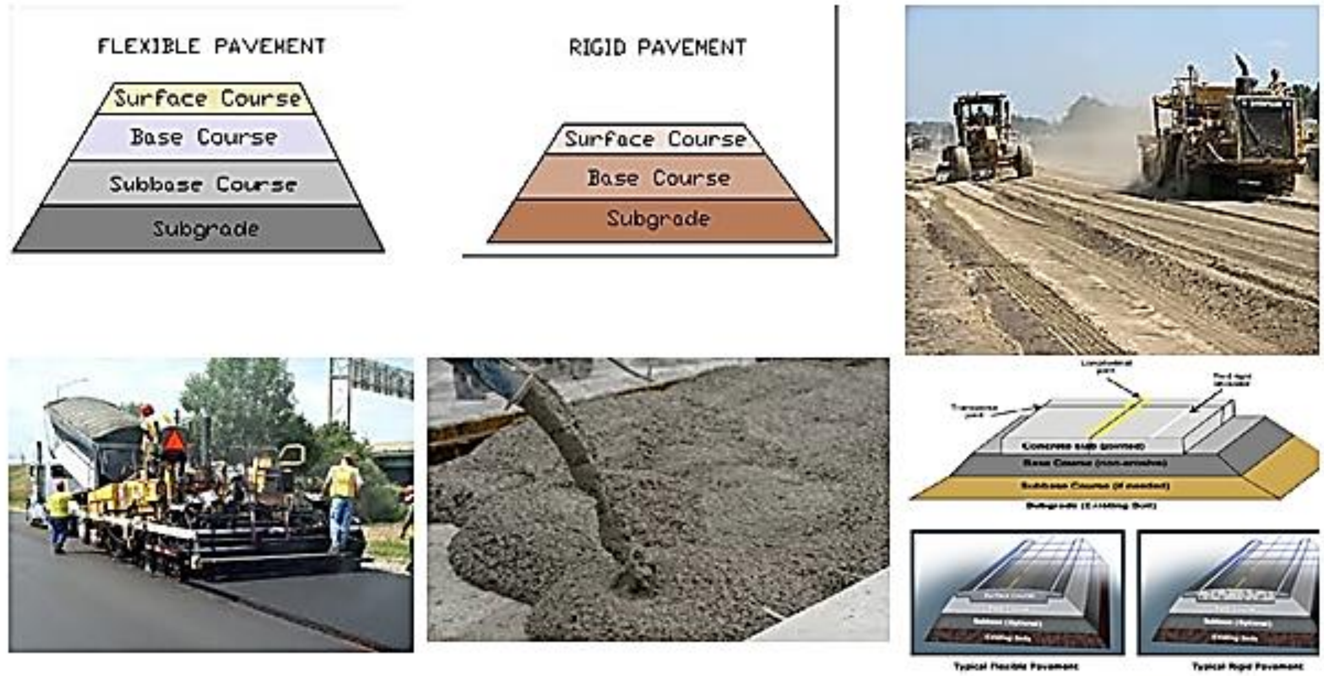
University of Anbar – College of Engineering
Departement of Civil Engineering
Highway Materials
Course No:*CE 4345*



Prepared By:
Dr Talal H. Fadhil
Dr Taher M. Ahmed

B. Aggregates:

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

B.2. Geometrical properties determination:

Aggregate sizes, Particle size distribution – sieving method, Aggregate size, Sieving procedure, 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 pycnometer 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.

B. Aggregates:

B.1. General

There are two main uses of aggregates in civil engineering: as an underlying material for foundations and pavements and as ingredients in portland cement and asphalt concretes.

- Aggregate underlying materials, or base courses, can add stability to a structure, provide a drainage layer, and protect the structure from frost damage. Stability is a function of the interparticle friction between the aggregates and the amount of clay and silt “binder” material in the voids between the aggregate particles. However, increasing the clay and silt content will block the drainage paths between the aggregate particles.
- In portland cement concrete, 60% to 75% of the volume and 79% to 85% of the weight is made up of aggregates. The fine aggregate particles act as a filler to reduce the amount of cement paste needed in the mix.
- In asphalt concrete, aggregates constitute over 80% of the volume and 92% to 96% of the mass. The asphalt cement acts as a binder to hold the aggregates together.

2. Aggregate Sources

- ***Natural* sources** for aggregates include gravel pits, river run deposits, and rock quarries. ***Crushed stones*** are the result of processing rocks from quarries. Usually, gravel deposits must also be crushed to obtain the needed size distribution, shape, and texture.
- **Manufactured aggregates** can use slag waste from steel mills and expanded shale and clays to produce lightweight aggregates.

➢ **Geologists classify** rocks into three basic types: ***igneous, sedimentary, and metamorphic.***

1. **Igneous rocks** are primarily crystalline and are formed by the cooling of molten rock magma as it moves toward or on the surface of the earth. It is classified based on grain size and composition. Coarse grains and fine grains. Based on composition is a function of the silica content, specific gravity and color.

2. Sedimentary rocks are primarily formed either by the deposition of insoluble residue from the disintegration of existing rocks or from deposition of the inorganic remains of marine animals. Classification is based on the predominant mineral present as calcareous (limeston, chalks, etc.), siliceous (chert, sandstone, etc), or argillaceous (shale, etc).

3. Metamorphic rocks form from igneous or sedimentary rocks that are drawn back into the earth's crust and exposed to heat and pressure, re-forming the grain structure. Metamorphic rocks generally have a crystalline structure, with grain sizes ranging from fine to coarse

- **SLAGS:** Slags are by-products that are produced during the production process of metals such as iron and nickel.
- **DEMOLITION MATERIALS:** Demolition materials are used in subbase or base layers after preselection and crushing.
- **ARTIFICIAL AGGREGATES:** Artificial aggregates are mainly produced from the calcination of rocks such as bauxite. Calcined bauxite has good antiskid properties. Other types of aggregates are designated by their low density or specific gravity (unit weight) and are used mainly in producing lightweight concrete.

RECYCLED (PULVERISED) AGGREGATES:

- Pulverised pavement materials are also known as recycled asphalt pavement (RAP). They are produced by crushed and screening old asphalt materials during reconstruction projects. They can be used as an aggregate replacement in new asphalt materials. It is widely used all over the world at the moment in highway construction.

B.2. Geometrical Properties Determination

Aggregate Sizes

Aggregates are divided into coarse aggregates, fine aggregates and fillers.

- **Coarse aggregates** are defined as aggregates whose particles are retained on 4.75 mm sieve (No. 4).
- **Fine aggregate** are defined as aggregates whose particles pass through a 4.75 mm sieve (No. 4) and retained on a 0.075 mm sieve (No. 200).
- **Fillers** are most of which pass through 0.075 mm sieve (No. 200). It is added to construction materials to provide certain properties.

Particle Size Distribution – Sieving Method

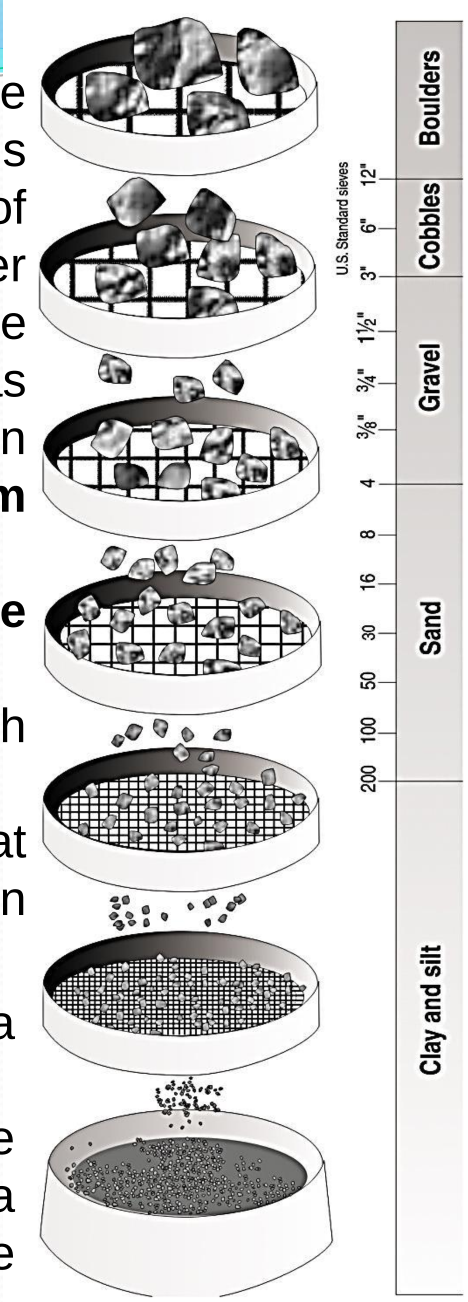
•Gradation describes the particle size distribution of the aggregate which is found by sieving analysis. The particle size distribution is an important property of the aggregates. The surface area of coarse aggregates is lesser than fine aggregate so the binder requiered for coarse aggreagte is less than that for fine aggreagtes. Hence, construction considerations, such as dimensions of construction members, clearance between reinforcing steel, and layer thickness, limit **the maximum aggregate size**.

•Two definitions are used to describe **the maximum aggregate size**:

1.Maximum aggregate size—the smallest sieve size through which 100% of the aggregates sample particles pass.

2.Nominal maximum aggregate size—the largest sieve that retains any of the aggregate particles, but generally not more than 10%.

- Gradation is evaluated by passing the aggregates through a series of sieves, as shown in Figure.
- Gradation results are described by the cumulative percentage of aggregates that either pass through or are retained by a specific sieve size. Then, gradation analysis results are generally plotted on a semilog chart.

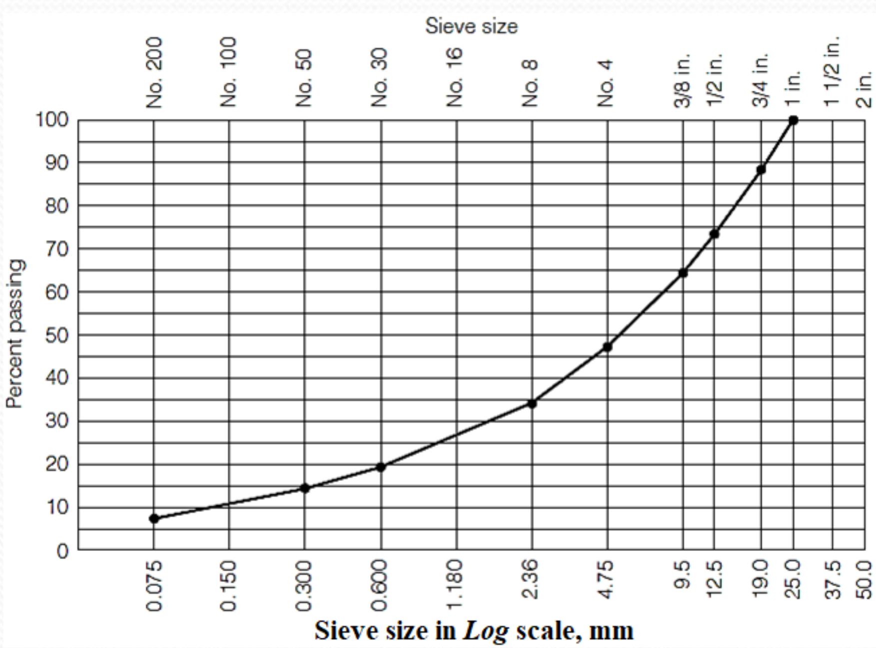


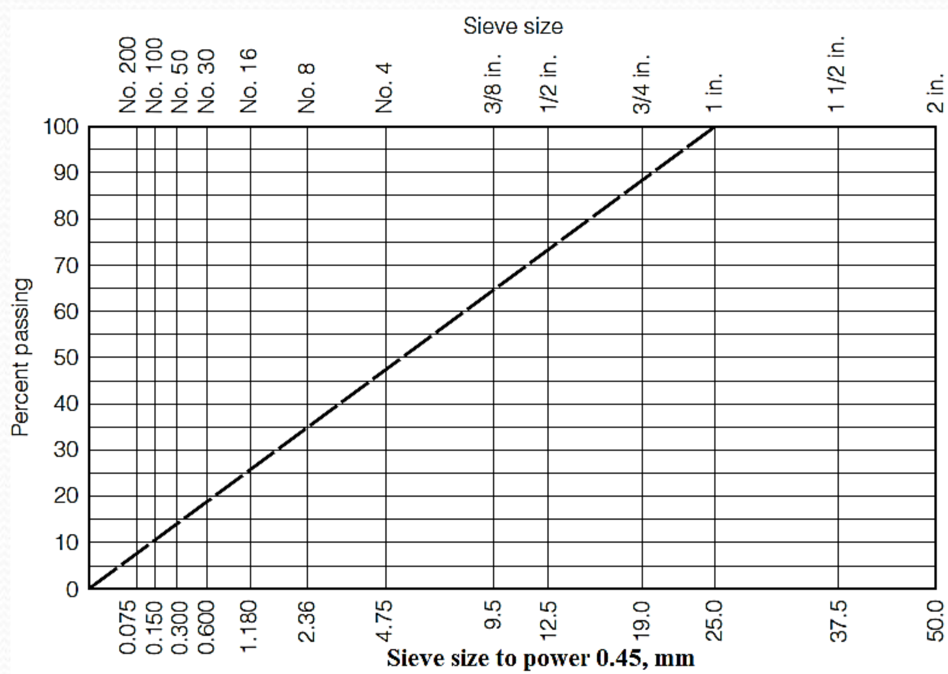
Dense Graded Gradation

- A dense-graded is a well-graded gradation aggregate
- The density of an aggregate mix is a function of the size distribution of the aggregates. The relationship for determining the distribution of aggregates that provides the dense graded or maximum density (minimum amount of voids) is:

$$P_i = 100\left(\frac{d_i}{D}\right)^n$$

Where: $\boldsymbol{P_i}$ is passing a sieve of size $\boldsymbol{d_i}$, $\boldsymbol{D}$ = maximum size of the aggregate.
The value of the exponent **n** recommended by **Fuller** is **0.5.** In the 1960s, the **Federal Highway Administration (FHWA)** recommended a value of **0.45** for **n** and introduced the "**0.45 power**" gradation chart





Example:

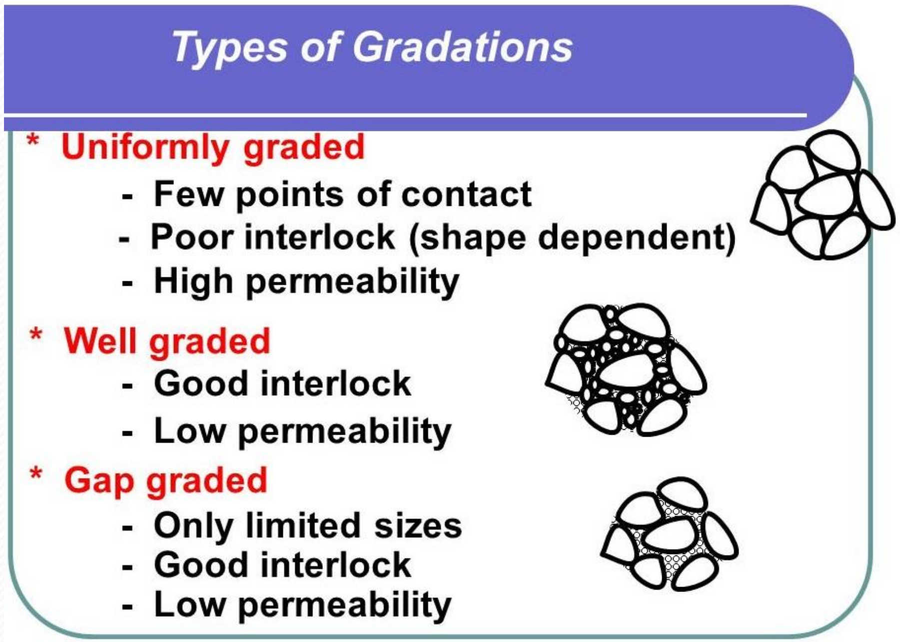
The data in the table below represents set of sieves. Plot the sieve distribution curve by using Fuller and FHWA equations.

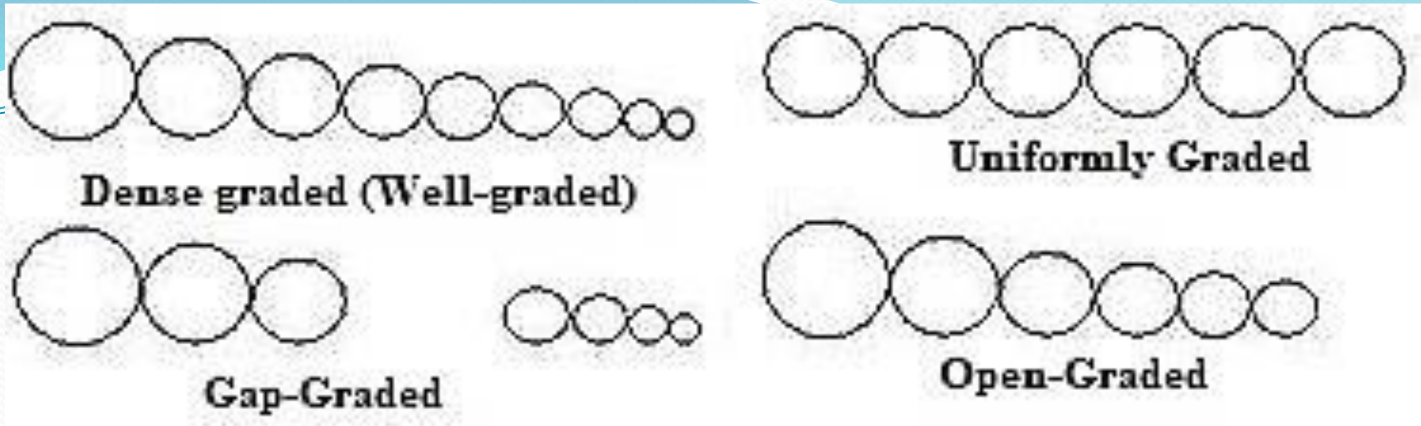
Sieve size (mm)	Passing %	Fuller Eq.	FHWA Eq.
4.75	100		
2.36			
2			
1.18			
0.6			
0.3			
0.15			
0.075			

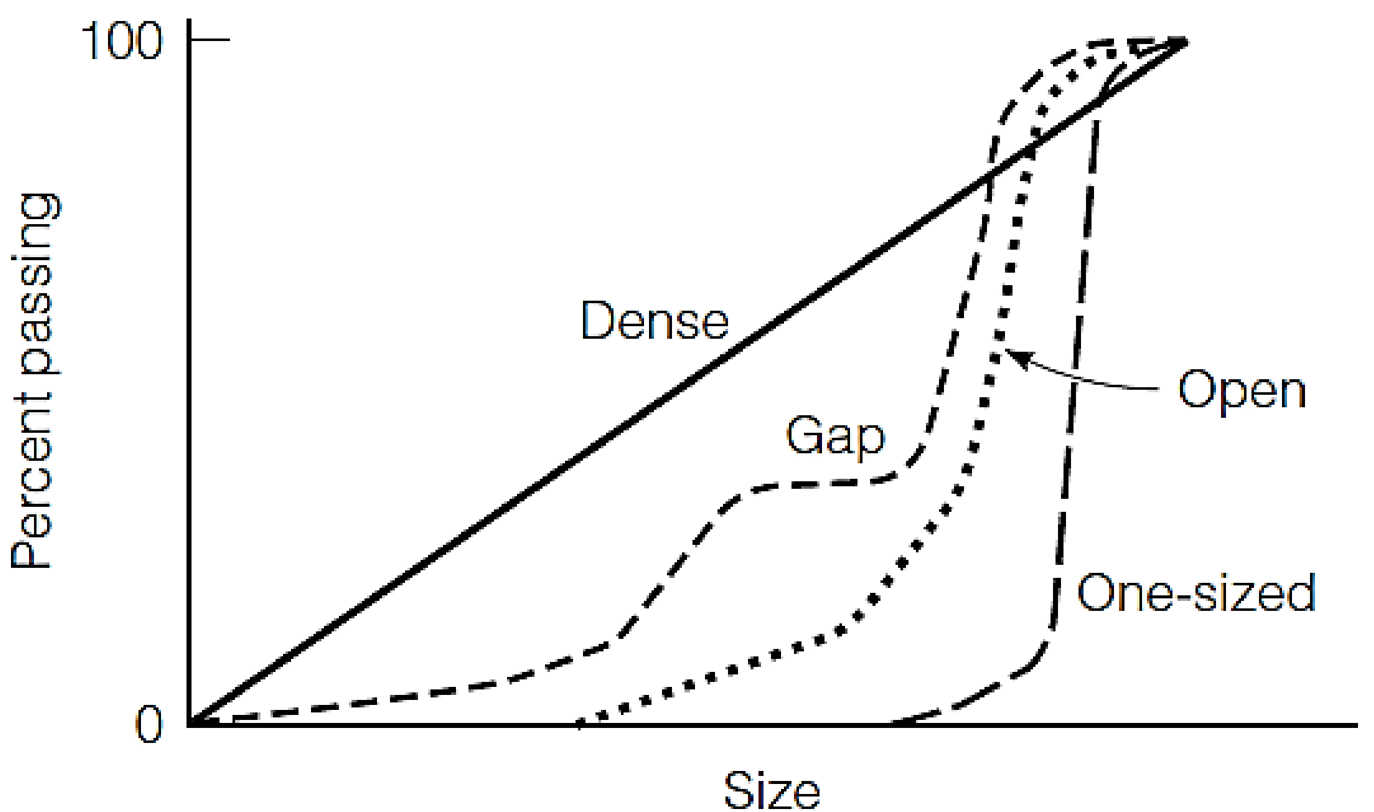
Other Types of Gradation

In addition to the dense graded (well-graded) aggregates, There are other characteristic distributions, as shown in Figure.

- **A uniform graded** is a one-sized distribution, it has the majority of aggregates passing one sieve and being retained on the next smaller sieve. Hence, the majority of the aggregates have essentially the **same diameter**; **their gradation curve is nearly vertical**. One-sized graded aggregates will have **good permeability, but poor stability**, and are used in such applications as chip seals of pavements.
- **Gap-graded** aggregates are missing one or more sizes of material (intermediat sizes) . Their gradation curve has a near horizontal section indicating that nearly the same portions of the aggregates pass two different sieve sizes.
- **Open-graded** aggregates are missing small aggregate sizes (fine) that would block the voids between the larger aggregate. Since there are a lot of voids, the material will be highly permeable, but may not have good stability.




Dense graded (Well-graded)
Uniformly Graded
Gap-Graded
Open-Graded


100
0
Percent passing
Size
Dense
Gap
Open
One-sized

B.3. Basic aggregate tests:

Particle Shape and Surface Texture

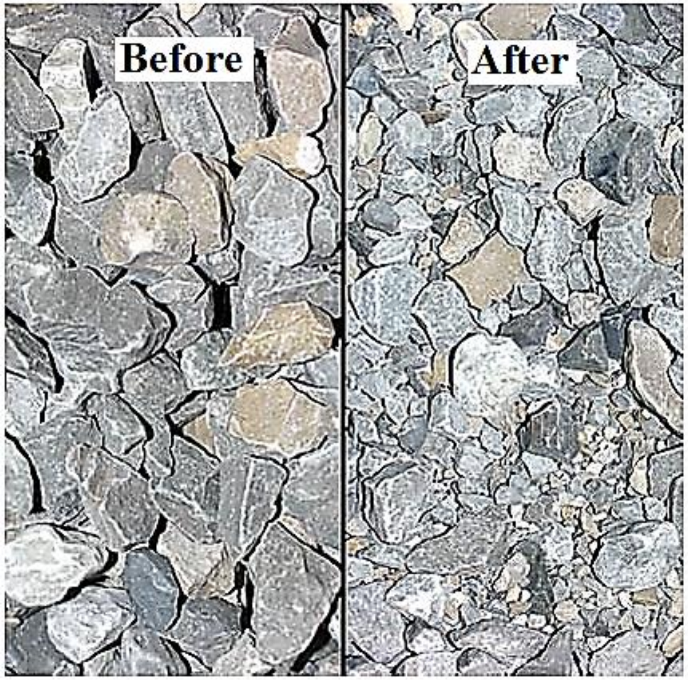
- The shape of the individual aggregate particles, determines how the material will pack into a dense configuration and also determines the mobility of the stones within a mix. There are two considerations in the shape of the material: ***angularity and flakiness***.
- Crushing rocks and gravel produce angular particles with sharp corners. Due to weathering, the corners of the aggregates break down, creating subangular particles. During the moving of the aggregates in water, the corners can become completely rounded.
- Generally, angular aggregates produce bulk materials with higher stability than rounded aggregates. However, the angular aggregates will be more difficult to work into place than rounded aggregates, since their shapes make it difficult for them to slide across each other.
- ***Flakiness*** describes the relationship between the smallest and largest dimensions of the aggregate.

- The **roughness** of the aggregate surface plays an important role in the way the aggregate compacts and bonds with the binder material. Aggregates with a *rough* texture are more difficult to compact into a dense configuration than *smooth* aggregates. Rough texture generally improves bonding and increases interparticle friction. In general, natural gravel and sand have a smooth texture, whereas crushed aggregates have a rough texture.
- For the purpose of preparing portland cement concrete, it is desirable to use rounded and smooth aggregate particles to improve the workability of fresh concrete during mixing. However, angular and rough particles are desirable for asphalt concrete and base courses in order to increase the stability of the materials in the field and to reduce rutting.
- Flaky and elongated aggregates are undesirable for asphalt concrete, since they are difficult to compact during construction and are easy to break.
- A crushed particle exhibits one or more mechanically induced fractured faces and typically has a rough surface texture.
- To evaluate the angularity and surface texture of coarse aggregate, the percentages of particles with one and with two or more crushed faces are counted in a representative sample.
- According to ISSRB for surface and binder courses, the degree of crushing at least is 90% by weight of the materials retained on sieve No. 4 has one of more fractuerd faces. And less tha 10% for flat and elongated pieces with more than 5 to 1 between maximum and minimum dimension.

Resistance to fragmentation by the Los Angeles test: (AASHTO T – 96)

The ability of aggregates to resist to the effect of loads is related to the hardness of the aggregate particles and is described as the toughness or abrasion resistance. The aggregate must resist crushing and degradation when placed, compacted, and exposed to loads.

The mass of tested aggregate sample is 5000 ± 5 g **(W_1).** In this test, aggregates sample is placed in a large steel drum (diameter 70 cm and hieght 50 cm) rotated typically for 500 revolutions (30 – 33 RPM); 11 iron balls, diameter 4.8 cm and weight of each is 445 gm, are put inside the drum with the aggregate.



After completion of the test, the aggregates are sieved on sieve No. 12 (1.7 mm) and the mass of the passed material is (**W_2**).

$$\text{Abrasion } (\%) = \frac{W_2}{W_1} 100, \qquad \text{Los Angeles value (LAV)} = \text{Abrasion}$$

The lower the Los Angeles value, the more durable and resistant the aggregate to fragmentation.

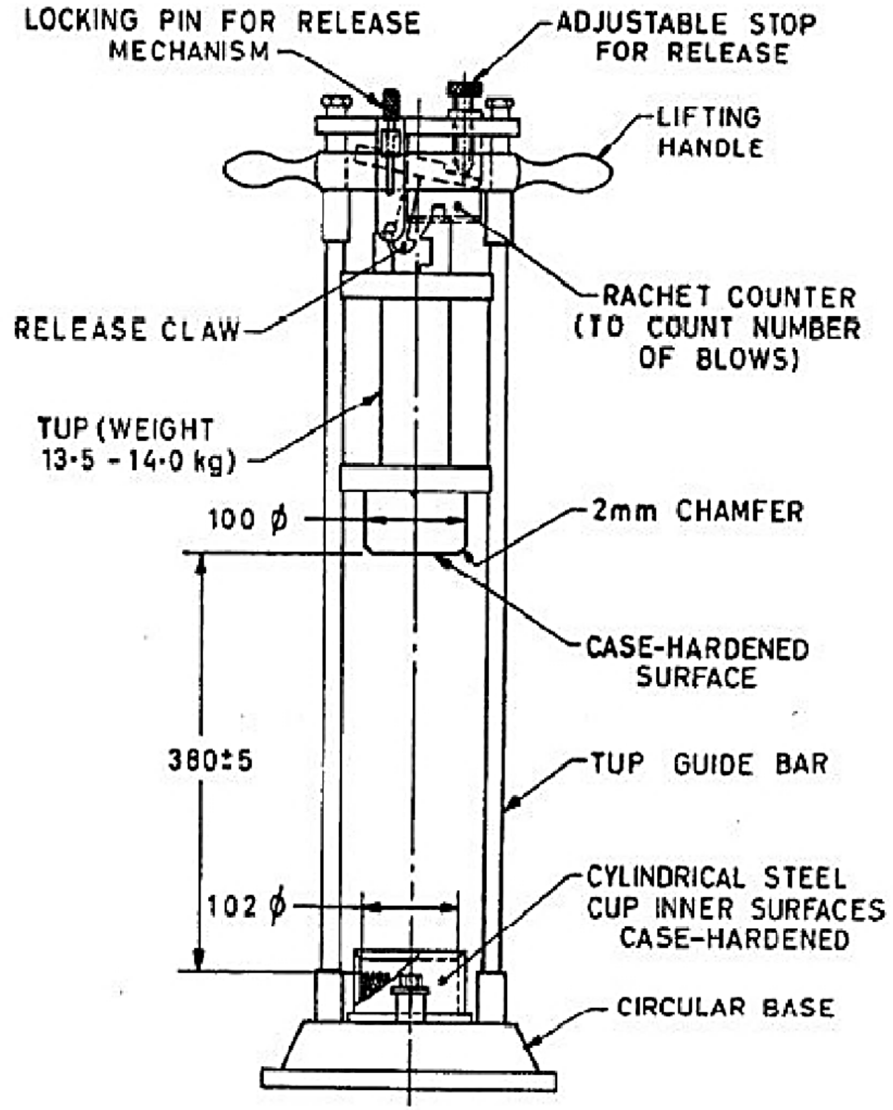
***Note*: according to ISSRB, percent of wear (LAV) for aggregate coarser than 2.36 mm (No. 8) is not more than 30% for surfac course and 35% for binder course and 40% for base course.**

Resistance to impact test:

The resistance impact test is an alternative test to the resistance to fragmentation by the Los Angeles test, a relative measure of the resistance of an aggregate to sudden shock or impact. A sample of a dried aggregate passing sive size 12.5 mm and retaind on sieve 10 mm is taken and is put into a metal mould (diameter 10 mm) with three layers, each layer is compacted by steel rod (d= 10 mm, l= 230 mm) 25 blows.

The wieght of this sample is taken (**W_1**) and then pourd into another steel container of the impact machien. The sample is exposed to 15 blows droped from a height of 370 mm. After crushing, the aggregate is sieved through sieve 2.36 mm (No. 8) and than weighed (**W_2**). The impact crushing value (**I_{CV}**) is:

$$I_{CV} = \frac{W_2}{W_1} \times 100$$



All dimensions in millimetres.

Soundness and Durability

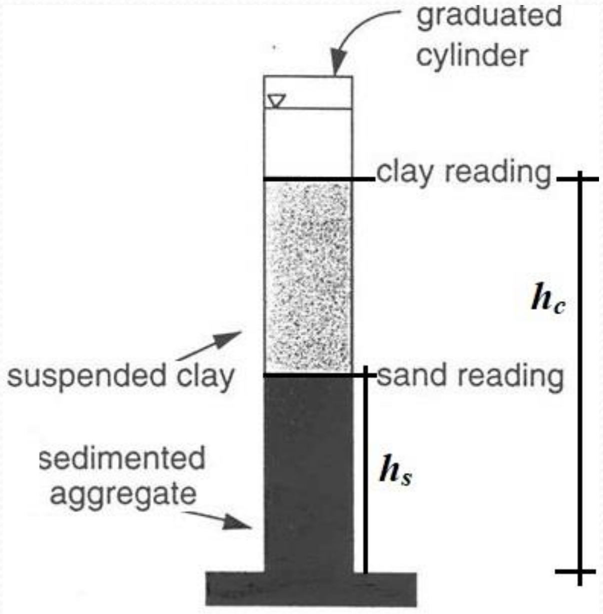
The ability of aggregate to withstand weathering is defined as soundness or durability. Aggregates used in various civil engineering applications must be sound and durable, particularly if the structure is subjected to severe climatic conditions. Water freezing in the voids of aggregates generates stresses that can fracture the stones. The soundness test (ASTM C88) simulates weathering by soaking the aggregates in either a sodium sulfate or a magnesium sulfate solution. These sulfates cause crystals to grow in the aggregates, simulating the effect of freezing. The test starts with an oven-dry sample separated into different sized fractions. The sample is subjected to 5 cycles of soaking in the sulfate for (16 to 18) hours at 21±1 ^{o}C followed by drying. Afterwards, the aggregates are washed by water with barium chloride ($BaCl_2$) (at 43 ± 6°C) through the samples in their containers and dried, each size is weighed, and the weighted average percentage loss for the entire sample is computed.

According to ISSRB the loss due to soundness test for coarse aggreagte is less than 12% when sodium sulfate is used and less tha 18% for magnesium sulfate is used.

Sand Equivalent Test

This test is conducted to determine quickly the relative proportion of the clay-like materials in fine aggregate and granular soils. A low sand equivalent value indicates the presence of clay proportion. This is detrimental to the quality of the aggregate and characterises the aggregates as 'non-clean'.

From a representative sample, a mass of 120 g of dried material is placed into a graduated transparent cylinder. A portion of calcium chloride solution is added to the cylinder until it reaches about 100 mm. The contents of the cylinder are left undisturbed for about 10 min and then, after loosening the material from the bottom and placing a stopper, it is shaken manually (more than 90 times) or in a mechanical shaker for 30 ± 1 s. Then, more calcium chloride solution is added to the cylinder until the cylinder is filled to the 380 ± 0.25 mm graduation mark. The cylinder and its content are then left undisturbed for 20 min. During this period, the material settles out from suspension to form two distinctive layers. The height of the clay suspension (***h_c***) and the height of the sand reading (***h_s***) are taken. The sand equivalent (***SE***) is calculated by the following formula:

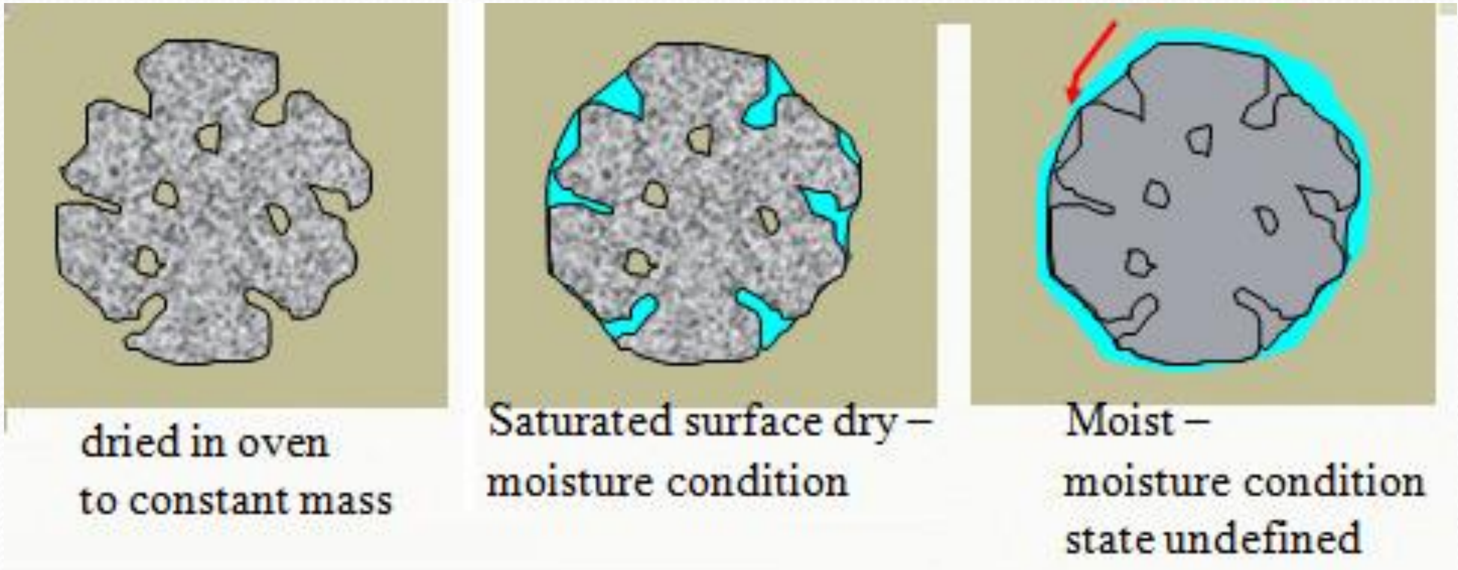


$$SE = h_s/h_c \times 100.$$

$$SE \geq 0.45 \text{ according to ISSRB}$$

Particle Density and Water Absorption tests:

Aggregates can capture water and asphalt binder in surface voids. The amount of absorbed water by aggregates is important in the design of Portland Cement Concrete (PCC) and for Hot Mix Asphalt (HMA). Aggregate's absorption must be evaluated to determine the appropriate amount of water for PCC mix design. Also, absorption is important for asphalt concrete, where, highly absorptive aggregates require greater amounts of asphalt binder, making the HMA more expensive.



Specific Gravity of Coarse Aggregate:

- For coarse aggregate, the AASHTO method (AASHTO T85) requires the sample be immersed for a period of 15–19 h while the ASTM method (ASTM C127) specifies an immersed period of 24 ± 4 h. After the specimen is removed from the water, it is rolled in an absorbent towel until all visible films of water are removed. This is defined as the saturated surface dry (SSD) condition. Three mass measurements are obtained from a sample: (i) the SSD mass, (ii) water submerged mass, and (iii) the oven dry mass from which the value of **Gsb (bulk specific gravity of stone (aggregate))** of an aggregate can be determined.

Coarse Aggregate Specific Gravity (ASTM C127, AASHTO T 85)

$$\text{Bulk Dry Sp. Gr.} = \frac{A}{B - C}$$

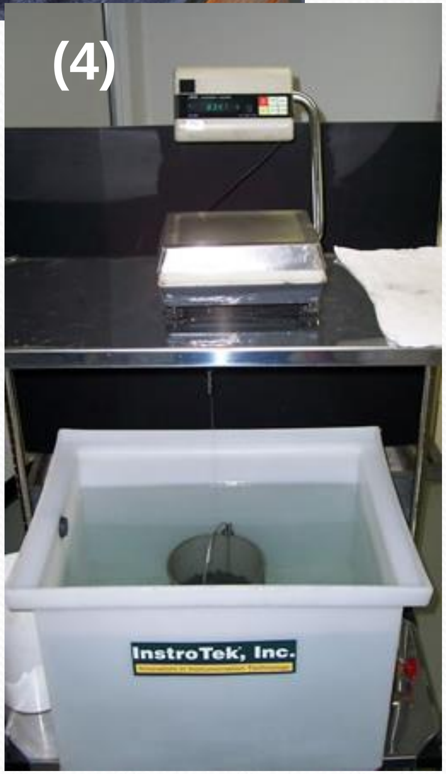
$$\text{Bulk SSD Sp. Gr.} = \frac{B}{B - C}$$

$$\text{Apparent Sp. Gr.} = \frac{A}{A - C}$$

$$\text{Absorption (\%)} = \frac{B - A}{A}(100)$$

where

A = dry weight
B = SSD weight
C = submerged weight

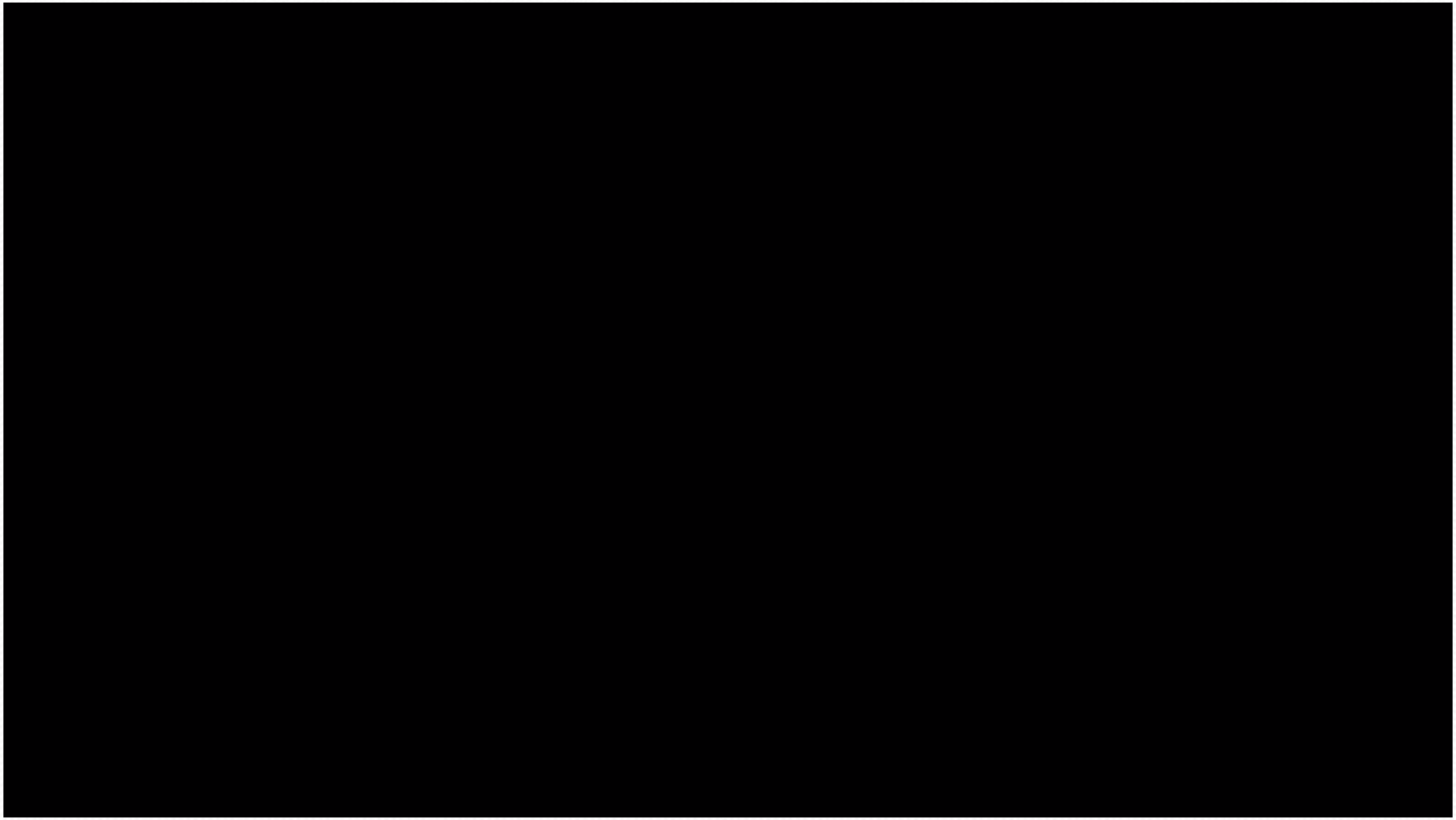


Dry then saturate the aggregates

Dry to SSD condition and weigh

Measure submerged weight

(5) **Measure dry weight**



Specific Gravity of Fine Aggregate:

- For fine aggregate, both methods: AASHTO T84 and ASTM C128 are similar, except for the required period in which a sample of fine aggregate is submersed in water to essentially fill the pores. **The AASHTO procedure requires immersion of fine aggregate in water for 15–19 h,** while **the ASTM method specifies a soaking period of 24 ± 4 h**. In both methods, the soaked sample is then spread on a pan and exposed to a gentle current of warm air until approaching to saturated surface dry condition. The aggregate is lightly tamped into a **cone-shaped (4cm top diameter, 9 cm bottom diameter, and 7 cm height)** mold with 25 light drops of the tamper (340± 15g). If the tamped fine aggregate keep the same shape of the cone when the mold is removed, the fine aggregate is assumed to have excess moisture, and it needs to further drying. When the cone of sand just begins to slump upon removal of the mold, it is assumed to have reached the SSD condition. Three masses are determined from the method using either gravimetric or volumetric methods; (i) SSD, (ii) saturated sample in water, and (iii) oven dry which are used to calculate ***Gsb***.

Fine Aggregate Specific Gravity (ASTM C128 & AASHTO T 84)

$$\text{Bulk Dry Sp. Gr.} = \frac{A}{B + S - C}$$

$$\text{Bulk SSD Sp. Gr.} = \frac{S}{B + S - C}$$

$$\text{Apparent Sp. Gr.} = \frac{A}{B + A - C}$$

$$\text{Absorption (\%)} = \frac{S - A}{A}(100)$$

where

A = dry weight
B = weight of the pycnometer filled with water
C = weight of the pycnometer filled with aggregate and water
S = saturated surface—dry weight of the sample

Filler' Tests:

- Mineral filler : Mineral filler shall consists of limestone or other stone dust. Portland cement, hydrated lime or other inert non-plastic mineral matter from approved sources.
- Mineral fillers shall be thoroughly dried and free from lumps of aggregations of fine particles. It shall confirm to the grading requirements as shown in table below.
- The plasticity index (PI) as determined by AASHTO T90 shall not be greater than 4.

TABLE R9/1

MINERAL FILLER GRADING

U.S. Sieve Size Mm	Percentage Passing by Weight
0.600 (No. 30)	100
0.300 (No. 50)	95-100
0.075 (No. 200)	70-100

Specific Gravity of Fillers:

Depending on the react of filler with water, there are two types which are used in HMA production, react and non-react with water. For example, limestone dust is non-react with water while cement is react, so the procedure for determining the specific gravity (sp.gr) for the filler is as shown below:

- Specific gravity of the filler is the ratio of the mass of a given volume of the filler to that of an equal volume of water at the same condition of temperature.
- The specific gravity of Portland cement is generally about (3.12-3.19). Cement will react with water, so to prevent this reaction kerosene should be used instead of water to be mixed with cement.

Testing procedure

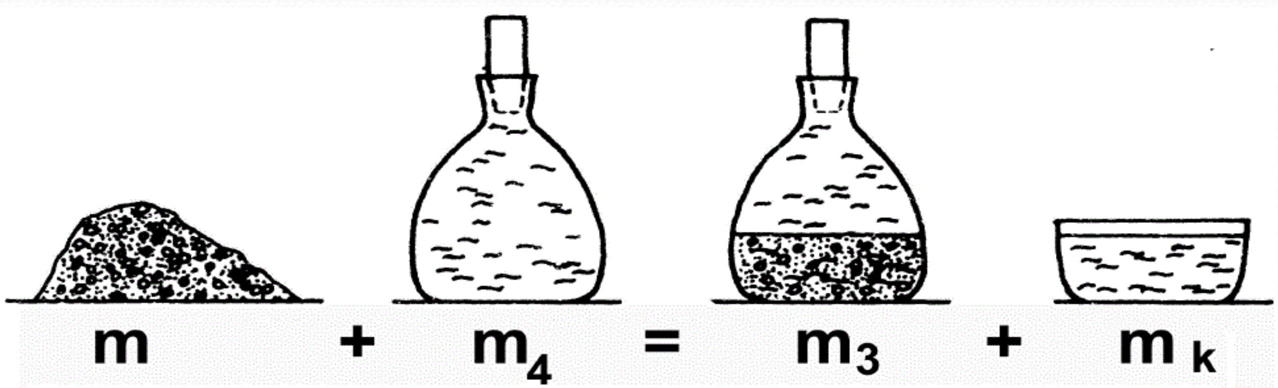
1. Weight mass of the empty pycnometer with stopper = **m1.**
2. Fill the pycnometer with measuring liquid. Replace stopper carefully, allowing excess liquid to escape through the hole in the stopper. Make sure there are no bubbles. Dry outside and weight = **m4.**
3. Fill the dry, empty pycnometer about 1/3 full of the sample. Closed it and weight again = **m2.**
4. Add measuring liquid to the sample. Fill pycnometer about 2/3 full. Mix up with caution and refill with the liquid, closed the pycnometer and weight = **m3.**

5. Calculate the mass of the sample from formula: **m = m2 - m1.**
6. Count the density from the basic formula.

$$\rho = \frac{m \times \rho_k}{m + m_4 - m_3} \quad , \quad \rho^k = \frac{m_4 - m_1}{m_5 - m_1}$$

where m is mass of the sample of the tested material **(m = m2 – m1)**
m_1 mass of dry empty pycnometer including stopper
m_2 mass of dry pycnometer with sample and stopper
m_3 mass of closed pycnometer with sample and measuring liquid
m_4 mass of the closed pycnometer with measuring liquid including stopper.
m_5 mass of the closed pycnometer with water including stopper.
ρ^k density of measuring liquid at tested temperature

Note: Measuring liquid could not be water in case of measuring cement density usually is used kerosene or any liquid non-react with cement.



where m_k is mass of liquid, volume of which was pushed up by volume of the solid material

B.4. Blending Two or More Aggregates:

Introduction

- The blending of aggregates is a process in which two, three, or more of aggregates, which have different types of sources and sizes, are mixed together to give a blend with a specified gradation.

The blending of aggregates is done because:

1- There are **no individual sources, sizes, and types** of aggregates (natural or artificial) that individually can supply aggregate of gradation to meet a specific or desired gradation.

2- It is more **economical** to use some natural sands or rounded aggregates in addition to crushed or manufactured aggregates, and this process (mixing natural and crushed) cannot be held without using a blending operation.

- Regardless of which method will be used, there are two important pieces of information that must be known before finding the proportion values. These are the sieve analysis of each material, and the limits of desired specifications.

Trial-and-error method

Trial-and-error method: Is the most common method of determining the proportions of aggregate which meets specification requirements. The designer, who has high of experience, can estimate the percentage value of each aggregate contributes in the blend. He also can predict the first approximation value by interpreting the sieve analysis of each type and desired gradation. By repeating the trial process several times, the contribution of each one can be estimated.

Mathematical Methods

Mathematical method: depending on the basic formula of this method which is true for any number of aggregates combined.

$$P = A \cdot a + B \cdot b + C \cdot c + \cdots \qquad \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots (1)$$

$$a + b + c + \cdots = 1 \qquad \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots (2)$$

Where

P is the percentage of material passing through a given sieve for the combined aggregates A, B, C which represents the mid point of the specification for a given sieve.

A, B, and C are the percentages of material passing a given sieve for aggregates A, B, C, respectively.

a, b, and c are the proportions of aggregate A, B, and C used in the combination.

❑ For blending two types of aggregate A and B:

$P = A \cdot a + B \cdot b, \qquad a + b = 1.$

$$b = \frac{P - A}{B - A} \qquad (3)$$

$$a = \frac{P - B}{A - B} \qquad (4)$$

❑ For blending three types of aggregate A, B and C:

The following data listed in the table below, the following notes can be drawn

Sieve, in (mm)	3/4 (19)	1/2 (12.5)	3/8 (9.5)	No.4 (4.75)	No. 8 (2.36)	No. 30 (0.6)	No. 50 (0.3)	No. 100 (0.15)	No. 200 (0.075)
Specification (% passing)	100	80-100	70-90	50-70	35-50	18-29	13-23	8-16	4-10
Mid. Point (% passing)	100	90	80	60	42.5	23.5	18	12	7
Agg. A (% passing)	100	90	59	16	3.2	1.1	0	0	0
Agg. B (% passing)	100	100	100	96	82	51	36	21	9.2
Agg. C (% passing)	100	100	100	100	100	100	98	93	82

- As shown from the table, the majority of contribution for aggregate greater than sieve No. 8 is coming from aggregate (A) because the amount of aggregate passing of sieve (No. 8) are 82 % and 100 % for aggregates B and C respectively while from A the % passing is 3.2 (it means that the amount of retaining on sieve NO. 8 are 96.8, 18 and 0 for A, B and C respectively).
- Applying Equation (4) to find the contribution of aggregate A (*a*)

$$a = \frac{42.5-82}{3.2-82} = 0.5$$

- The percentage of sieve No. 200 are to be examined, by applying Equation (1).

$7 = 0 \times 0.5 + 9.2\times b + 82\times c$ (i)

- Now applying Equation (2).

b + c = 1 - 0.5 = 0.5 ⟹ b = 0.5 – c (ii)

Substituting Equation (ii) in (i) yields:
c = 0.03 ⟹ b = 0.5 - 0.03= 0.47

Final Results

Sieve, in (mm)	3/4 (19)	1/2 (12.5)	3/8 (9.5)	No.4 (4.75)	No. 8 (2.36)	No. 30 (0.6)	No. 50 (0.3)	No. 100 (0.15)	No. 200 (0.075)
Specification (% passing)	100	80-100	70-90	50-70	35-50	18-29	13-23	8-16	4-10
Mid. Point (% passing)	100	90	80	60	42.5	23.5	18	12	7
Agg. A (% passing)	100	90	59	16	3.2	1.1	0	0	0
Agg. A × 0.5 (% contribution)	50	45.0	29.5	8.0	1.6	0.6	0	0	0
Agg. B (% passing)	100	100	100	96	82	51	36	21	9.2
Agg. B × 0.47 (% contribution)	47.0	47.0	47.0	45.1	38.5	24.0	16.9	9.9	4.3
Agg. C (% passing)	100	100	100	100	100	100	98	93	82
Agg. C × 0.03 (% contribution)	3.0	3.0	3.0	3.0	3.0	3.0	2.95	2.8	2.5
Total	100	95	79.5	56.1	43.1	27.6	19.85	12.7	6.8

Note: Determination of the percentages *a, b, c, d and so on, is carried out by solving the system* of linear equations. The disadvantage of this method is that more than one solution or combination can be found. To find the optimum or desired solution, successive approximations are needed (different trials are sometimes needed to reach the perfect proportions values).

H.W.: Blend an aggregate mixture consisting of three aggregates A, B and C, such that the gradation of the final mix is within the specified limits. The percentage passing the particular size for each aggregate as well as the specified limits (mid points) is shown in Table below.

Results from sieve analysis and specification limits for aggregate composition

Sieve size (mm)	Aggregate A	Aggregate B	Aggregate C	*Specification limits*	*Limits' mid value*
	Percentage passing (cumulative), by weight				
19.0	100	100	100	100	100
12.5	90.0	100	100	90–100	95
4.75	40.0	100	100	60–75	67.5
2.36	6.5	98.1	100	40–55	47.5
0.600	3.0	20.7	93.2	20–35	27.5
0.300	1.2	12.2	58.7	12–22	17.0
0.075	0.5	3.3	27.4	5–10	7.5

Graphical Methods:

There are different types of graphical methods which can be used to find the proportions of each types of aggregates to obtain the blending of aggregate which are placed inside the zone of specification (upper and lower limits). Two methods are selected and detailed as below using the data listed in table of the Example 1 below:

Example 1 : General gradation of tree types of agg.

Sieve Size mm [inches.]	% Passing				
	A	B	C	Mid. Point	Specification
19 [3/4]	100	100	100	100	100
12.5 [1/2]	63	100	100	78	70 - 85
4.75 [No.4]	19	100	100	48	40 - 55
2.38 [No.8]	8	93	100	36	30 - 42
0.3 [No.50]	5	55	100	25	20 - 30
0.15 [No.100]	3	36	97	17	12 - 22
0.075 [No.200]	0	3	88	8	5 - 11

1. Rothfuch’s Method (Equaled areas):

The following steps are used in this method for finding the blending of aggregates which is approximately the closest to the mid points of the specification.

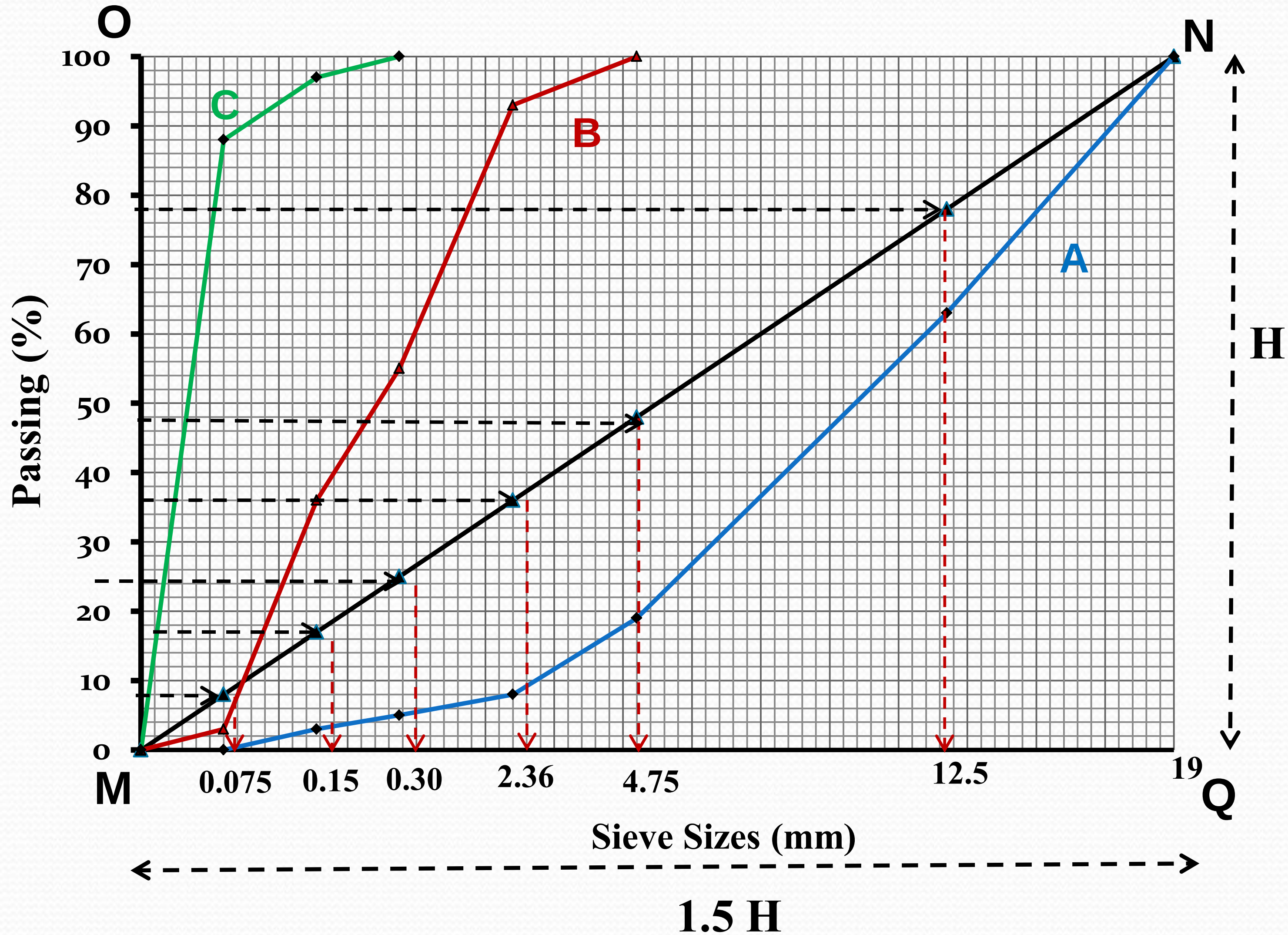
1. Using the graph paper and draw the X-axis’s length 1.5 of the vertical axis (Y-axis) to create a rectangular shape (MQNO).

2. The vertical axis (Y-axis) represents the passing (%) and starts from zero to 100. while, the horizontal axis(X-axis) represents the location of sieve sizes.

3. Draw the diagonal MN of the rectangle.

4. Use the mid point values of the specification on Y-axis (passing %) and project them on the diagonal (MN) and from the intersection points drop dawn vertically to find the locations of the sieve sizes on the X-axis.

5. Plot the gradations of aggregate A, B, and C on the graph.



O
N
M
Q
C
B
A
H
1.5 H
Passing (%)
Sieve Sizes (mm)
100
90
80
70
60
50
40
30
20
10
0
0.075
0.15
0.30
2.36
4.75
12.5
19

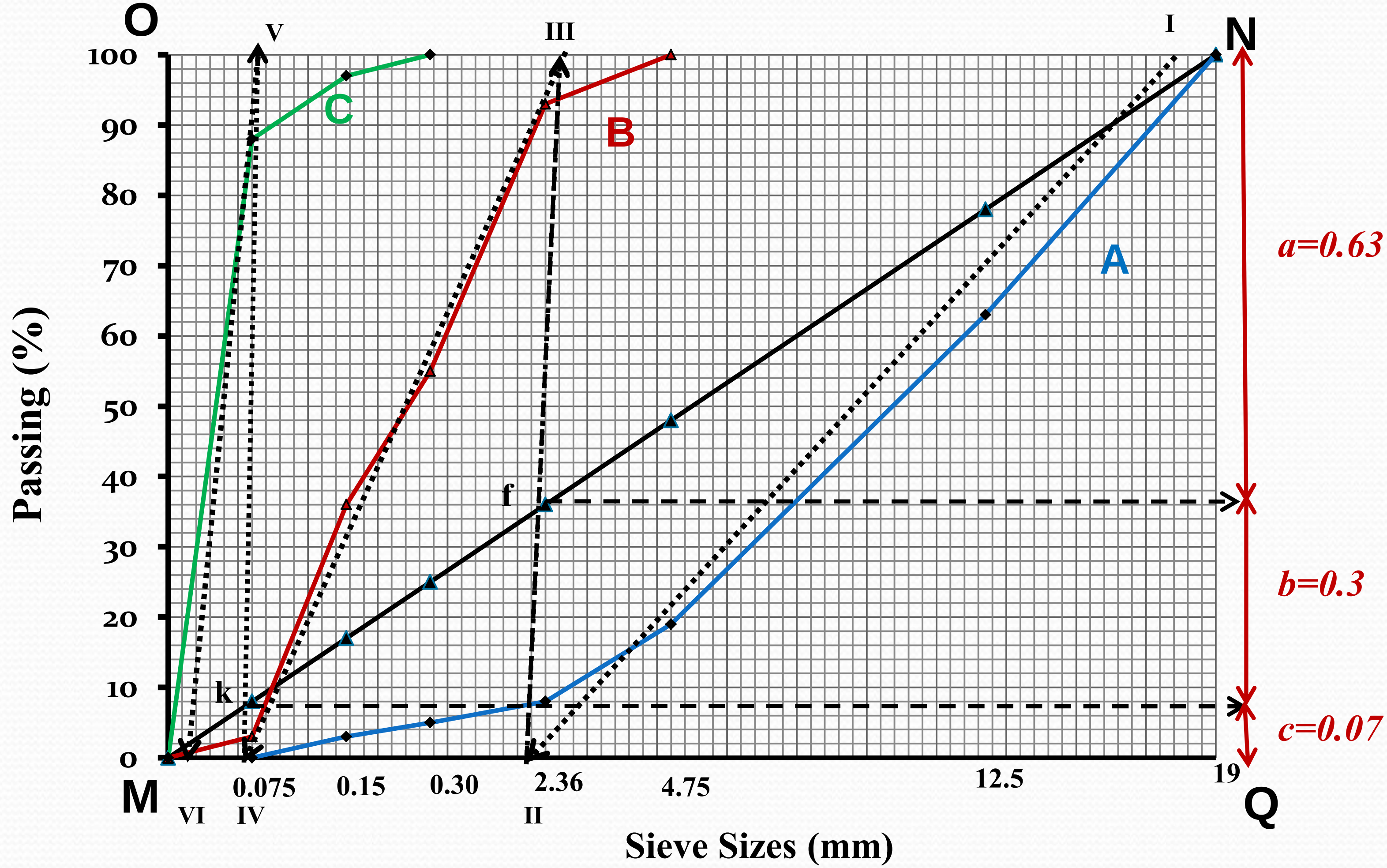
6. Select a line passing through each gradation curve. The selected line must cross the lines ON and MQ. During passing the selected lines through the curve several areas are created above and blow its, the main criteria of choosing the selected line is the above and below areas must be equaled to achieve this condition, the line needs to move in anyways.

7. In the above example the selected lines are**: I-II for Agg. A, III-IV for Agg. B, and V-VI for Agg. C** as shown in figure.

8. Plot lines between points **II** – **III** and **IV** – **V.** These lines cross the diagonal line (MN) in points **f** and **k** .

9. From the points f and k, draw a horizontal lines parallel to x-axis to intersect with Y-axis, the intersection points give the values of the contribution of each types of aggregate.

10. In this example, **a= 0.63, b= 0.3,** and **c=0.07**.


O
N
M
Q
V
III
I
100
90
80
70
60
50
40
30
20
10
0
Passing (%)
C
B
A
f
k
a=0.63
b=0.3
c=0.07
0.075
0.15
0.30
2.36
4.75
12.5
19
VI
IV
II
Sieve Sizes (mm)

2. Equaled Distances Method :

The following steps are used in this method for finding the blending of aggregates which is approximately the closest to the mid points of the specification.

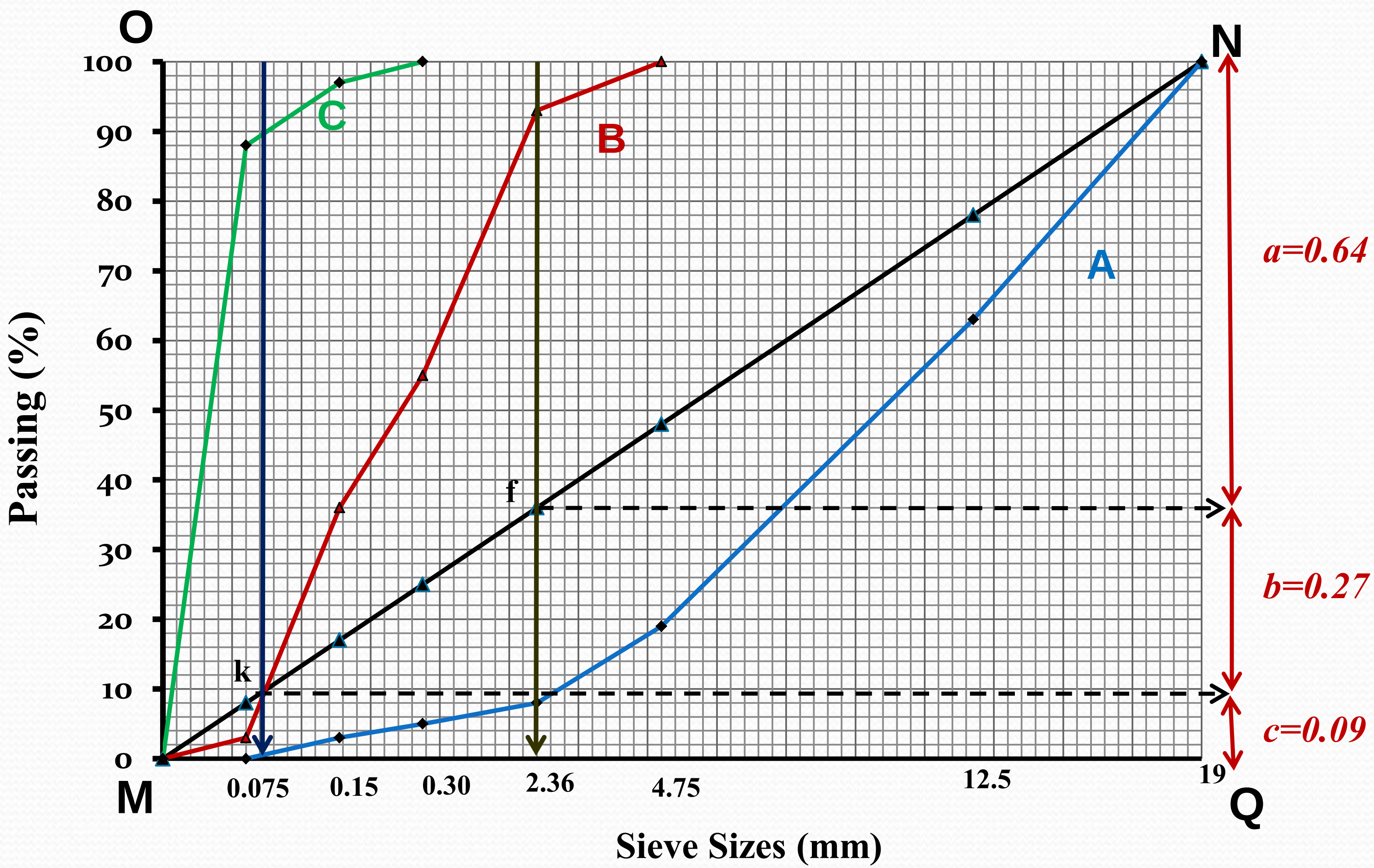
1. Follow the same steps as in Rothfuch's method from step 1 to 5.

2. Use a ruler and move it from left to right until getting a position in which the distance from the curve of **Agg. B** to the line **ON is equal to the distance** from the curve of **Agg. A** to the line **MQ.** This line crosses the diagonal line **(MN)** at point ***f*****.**

3. Repeat the same procedure in step (2) with the curves of **aggregate B and C** to cerate an intersection point on the diagonal line (**MN)** at point **k**.

7. From the points f and k, draw a horizontal lines parallel to x-axis to intersect with Y-axis, the intersection points give the values of the contribution of each types of aggregate.

8. By this method, the contribution values of each type of aggregate are: **a= 0.63, b= 0.3,** and **c=0.07**.


O
N
100
90
80
70
60
50
40
30
20
10
0
Passing (%)
C
B
A
f
k
a=0.64
b=0.27
c=0.09
M
0.075
0.15
0.30
2.36
4.75
12.5
19
Q
Sieve Sizes (mm)