COTM 4203: Road & Bridge Construction II

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Chapter 1: Introduction to Pavement Materials

Content

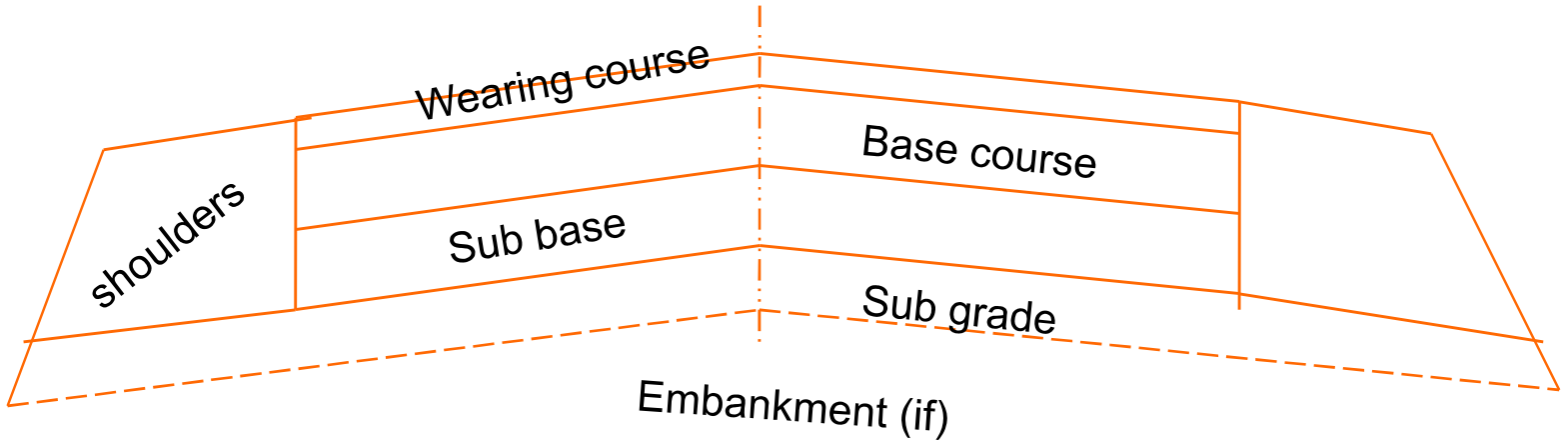
1. Introduction of Pavement materials
    1.1 Introduction
    1.2 Unbound granular materials
    1.3 Stabilized materials
    1.4 Bituminous materials

Introduction to Pavement Materials

- Objective:
  - after completing this lesson the student is expected to
    1. Understand and identify the basic pavement construction materials
    2. Understand the properties of different pavement materials
    3. Identify the type of test and procedure followed to characterize d/t pavement materials

Introduction to Pavement Materials

- 1. Introduction
- The cross-section of any road pavement shows d/t layers constructed out of d/t materials ranging from Naturally existing soil to Crushed stone and from Bitumen to Concrete



Introduction to Pavement Materials

- The main construction materials for Road pavement includes;
  1. ***Soil*** [for sub grades and embankments, e.t.c]
  2. ***Rock boulders*** [for rock fill and capping layers]
  3. ***Natural gravel*** [for fill, sub grade e.t.c]
  4. ***Crushed Weathered Rock*** [Sub base, Base, gravel wearing course]
  5. ***Crushed Rocks/ Aggregated*** [Base course, wearing course, concrete, e.t.c]
  6. ***Bitumen ; cut backs, emulsion, penetration grade***
  7. ***Bituminous mixture*** [base course, wearing course]
  8. ***Concrete*** [for rigid pavement, structures, e.t.c]
  9. ***Stabilized materials***
  10. ***Reclaimed/ recycled materials***

1.1.1 Unbound Granular Materials

- According to different manuals and literatures, materials like Natural gravel, crushed weathered rock, mechanically stabilized, crushed rock/ aggregate, sand e.t.c are classified as ***Unbound Granular Materials.***
- Unbound Granular materials are those used for the construction of mainly for Sub-base, Base, capping layers and gravel wearing course.

Introduction to Pavement Materials

- We use the term "unbound" to identify them from Bituminous bounded and stabilized materials.
- Unbound granular materials, both natural and crushed, should be free from any admixture and stabilizers.
- According to ERA, 2002 Pavement design manual I; unbound granular materials are classified as;

INTRODUCTION TO PAVEMENT MATERIALS

Code	Description	Summary of Specification
GB1	Fresh, crushed rock	Dense graded, unweathered crushed stone,non-plastic parent fines
GB2	Crushed weathered rock, gravel or boulders	Dense grading, PI < 6, soil or parent fines
GB3	Natural coarsely graded granular material, including processed and modified gravels	Dense grading, PI < 6 CBR after soaking > 80
GS	Natural gravel	CBR after soaking > 30
GC	Gravel or gravel-soil	Dense graded; CBR after soaking > 15

Notes: 1. These specifications are sometimes modified according to site conditions, material type and principal use (see text).
2. GB = Granular base course, GS = Granular sub-base, GC = Granular capping layer.

Introduction to Pavement Materials



Introduction to Pavement Materials



Crushed Stone Base Course , Addis Ambo Road Project

Introduction to Pavement Materials

Crushed Gravel Base course, GB2



Introduction to Pavement Materials

Natural Gravel, GS/GC



1.1.1.1 ***Crushed Stone/ Aggregate***

- **Sources of Aggregate**
  - The main source of Aggregates for highway pavement construction is Natural Rock, which outcrop at or near the surface of the earth.
  - Natural Bed rocks are classified based on their mode of geological formation as
    - **Igneous rock**
    - **Sedimentary rocks**
    - **Metamorphic rocks**

INTRODUCTION TO PAVEMENT MATERIALS

1. ***Igneous Rock***

are primarily crystalline and formed by the cooling of molten rock magma as it moves upward or on the surface.

they are classified as acidic and Basic based on their chemical composition. Some of the distinct properties are

Property	Acidic	Basic
Silica (%)	>66	<55
Specific Gravity	<2.75	>2.75
Color	light	Dark
Presence of free quartz	yes	No

2. ***Sedimentary Rocks***

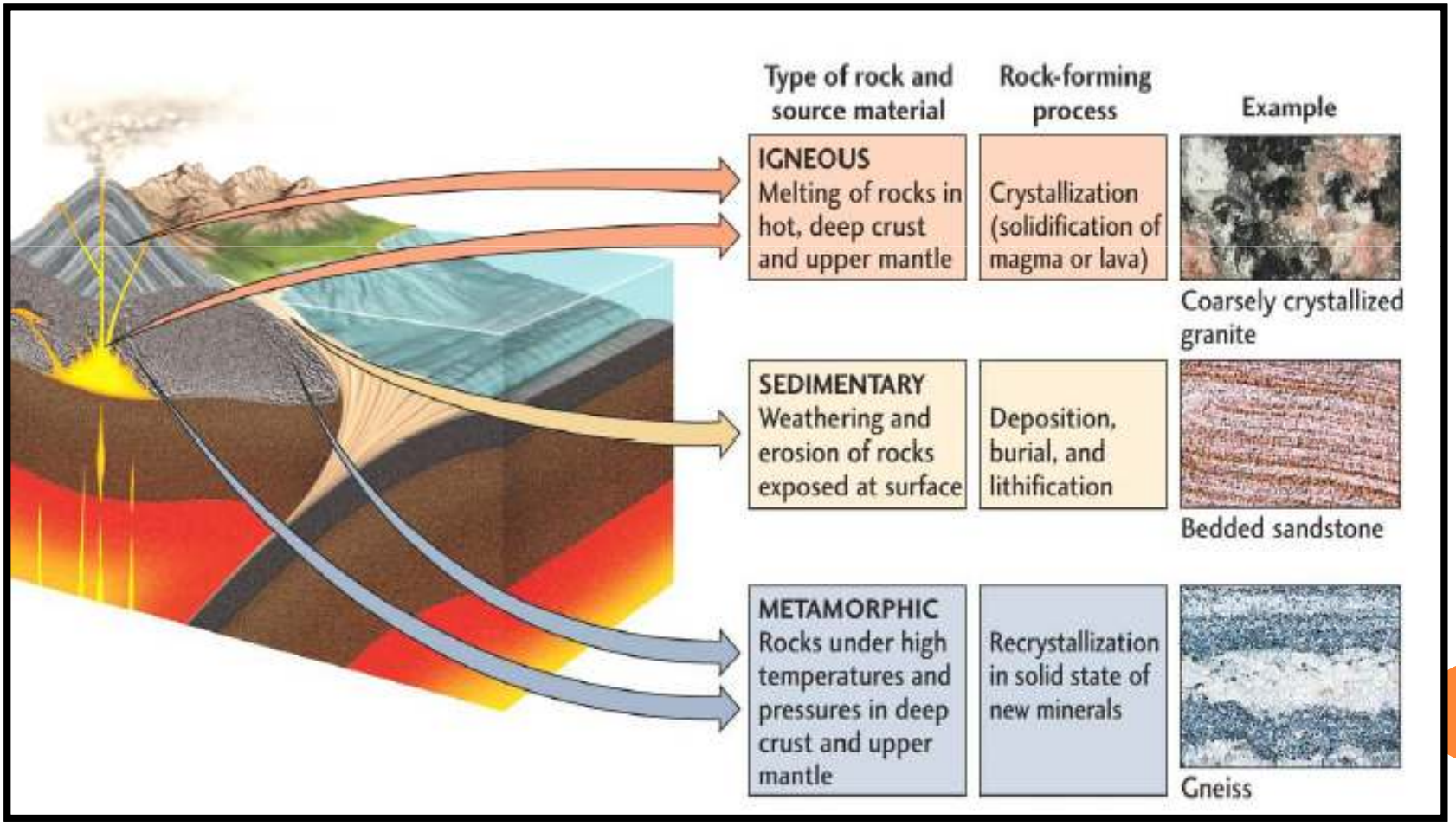
are primarily formed either by deposition of insoluble residue from disintegration of existing rocks or from deposition of the inorganic remain of marine animals

classification is made based on the predominant mineral in the rock as

I. Calcareous (e.g. **Lime stone**, chalks, e.t.c)
II. Siliceous (e.g. chert, **Sand stone**, e.t.c)
III. Argillaceous (e.g. shale, e.t.c.)

3. ***Metamorphic Rocks***

are formed from igneous or sedimentary rocks that have been subjected to heat and pressure by the process of re-crystallization.



Introduction to Pavement Materials

- In general terms, Aggregates need to strong and sound to fit for purpose. As the property of crushed aggregate is depend on the type of the rock, a general conclusion on the quality of the aggregate and its source rock can be deduced .
  - Igneous and metamorphic rocks are usually hard and form excellent aggregates.
  - Sedimentary rocks like lime stone and dolomite [softer than lime stone] are still used as an aggregate for most purpose.
  - However, shale is very weak and easily breakable , so it produce a weak aggregate.
- As any material aggregates have different physical and chemical properties.
- However, their physical properties are much more critical and helpful in determining the performance of aggregates than chemical properties.

Introduction to Pavement Materials

A. *Production of Aggregates*

I. Before starting crushing of rock, the first step is identification or selection of potential quarry (in terms of quantity, quality, location, e.t.c)

II. Clearing site and removing overburdens

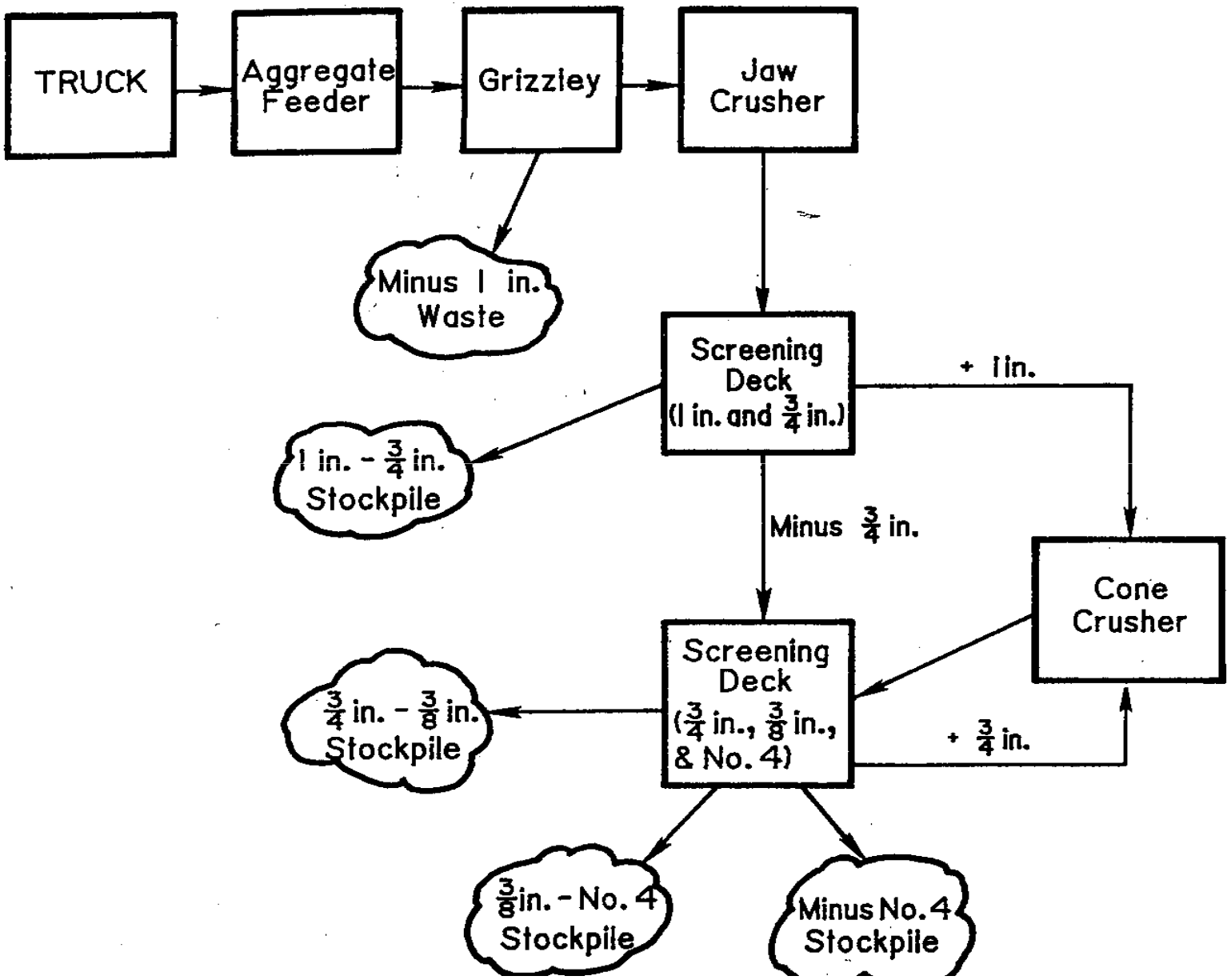
III. Blasting of the rock (NB, professionals should do this for safety and other issues)

IV. Excavating/ dozing and transporting quality materials to the crusher

Introduction to Pavement Materials

- The crushing of aggregate is the process of reducing the size of the natural rock in to the required particle sizes using series of crushers, pulverizes and screening units.
- Most crushers, not all, uses sets of crushing units "Jaw Crusher" as primary crushing unit and "Cone crusher" as secondary units.
- Basically, there are four mechanisms of mechanical reductions applied in crushing operations. i.e
    1. Impact
    2. Attrition
    3. Shearing
    4. Compression

SCHEMATIC ARRANGEMENT OF CONVENTIONAL CRUSHING PLANT



CRUSHER TYPES AND REDUCTION METHODS

Crusher Type	Reduction Method			
	Impact	Attrition	Shearing	Compression
Impactor	x			
Vertical Impact Pulverizes	x			
Bradford Breakers	x			
Ring type Granulator	x		x	x
Hamer mills	x	x	x	
Single role crusher	x		x	x
Gyratory	x	x		x
Jaw Crushers	x			x
Cone Crushers		x	x	x

INTRODUCTION TO PAVEMENT MATERIALS

B. ***Physical Properties and Tests of Aggregates***

- Aggregates generally classified as

According to ASTM

1. ***Course Aggregates : > 4.75mm***
2. ***Fine Aggregates : < 4.75mm and >0.075mm***
3. ***Fillers : <0.075mm or at least 70% passes sieve 0.075mm***

- Aggregates are used in Base course, HMA, Concrete e.t.c. for each purpose Aggregates should meet some performance requirements.
- Some of the characteristics of Aggregates to be evaluated includes;

Introduction to Pavement Materials

1. Size and Gradation
2. Cleanliness
3. Toughness/ hardness
4. Durability/Soundness
5. Surface texture
6. Particle Shape/ flakiness
7. Absorption [water, asphalt]
8. Affinity for Asphalt
9. Specific Gravity

I. ***Toughness and Abrasion Resistant***

- Aggregates must be hard & tough to resist crushing due to Stock pilling, HMA Production, Compaction and Traffic Loading.
- Hence Los Angles Abrasion (LAA) and Aggregate Crushing Value (ACV) are used to evaluate these properties.

A. ***Los Angeles Abrasion (LAA)***

- Test method : ASTM C131 and ASTM C535

- Test Procedure
  i. Take 5 or 10 kg sample for ASTM 131[less than 38mm] or ASTM 535 [76mm-19mm]
  ii. Put six to twelve metal balls each with 51mm dia. And 400gm weight
  iii. Tremble the mix inside a steel drum for 500 to 1000 revolution at 30-33rvp.
  iv. After trembling, the fine that pass sieve #12 [1.68mm] are weight
  v. Calculate the percentage loss by weight of original sample as LAA.

  N:B: Initially no material would pass No. 12 sieve

- Example: A 5.1 kg sample of crushed aggregate is taken to conduct LAA test the weight of sieve No. 12 was found to be 1.98 kg. what is the LAA value of the Aggregate?

  - Solution

    M = 5.1 kg

    m = 1.98 kg

LAA = [m * 100%]/M = [1.98 *100%]/ 5.1

= 38.82 %

  - N:B: typical value of LAA 10% for hard Rock and 60% for soft Rock like lime stone

II. Durability and Soundness

- pavement in general subjected to freezing and thawing temperature.
- Hence, the aggregates to be used must withstand the effect of freezing and thawing.
- An empirical test called "Soundness test" is used to evaluate the durability of aggregates

- During freezing and thawing, water particles in side the aggregates pore freezes and cause to disintegrate the aggregate.
- This effect is modeled by immersing the aggregate in to a solution of Sodium/ Magnesium sulphate. During the test the crystalline grow in the aggregates pore to cause aggregate particle to disintegrates.

A. ***Soundness Test***

Test Method: ASTM C88 and AASHTO T 103

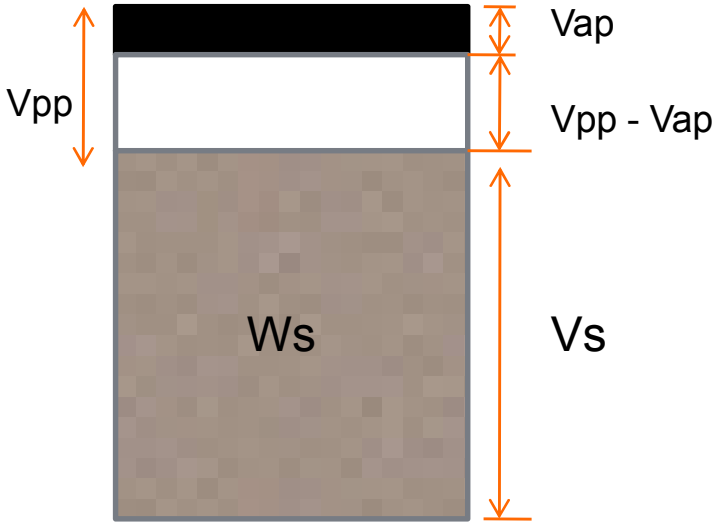
Test Procedure :

1. Prepare an oven dry sample. Separate the sample in to different sieve sizes
2. Immerse the sample in sodium/ magnesium sulphate for 18 hrs.
3. Remove from the solution and dry it at 110 $\pm$ 5 oC and cool it.
4. Repeat the process five times
5. Wash the sample to remove the salt
6. Calculate the weight loss for each sieve fraction
7. Take an weight average percentage of weight loss as soundness.

III. Specific Gravity

- By definition it is the ratio of the weight of unit volume of the material to the weight of an equal volume of water at 23oC.
- Specific Gravity = $\frac{\text{Density of material}}{\text{Density of water @23oc}}$
- It is very important parameter in weight-volume calculations. Basically, we have different specific gravities used in HMA mixture design. These are:
  1) Apparent Specific Gravity
  2) Bulk Specific Gravity
  3) Effective specific gravity
  4) Bulk impregnated specific gravity

- In order to understand the different specific gravities; let us take a sample of HMA schematic volumetric diagram as follow.



Where:
Ws = *oven dry weight of sample*
Vs = *volume of solid*
Vpp = *volume of water permeable pore*
Vap = *volume of asphalt absorbing pore*
γ_w = *unit weight of water*

Apparent Specific Gravity = G_{sa}= Ws/ Vsγ_w

Bulk Specific Gravity = G_{sb} = Ws /[Vs +Vpp]γ_w

Effective Specific gravity = G_{se} = Ws/[Vs+Vpp –Vap] γ_w

A. ***Specific gravity determination*** [for course aggregates]

- Test method ; ASTM C127 and AASHTO T 85
- Test procedure;
  i. Sample 5kg aggregate thoroughly washed and retained on No.4 [4.75mm] sieve. Dry it in an oven.
  ii. Immerse the dried sample in water for 24 hrs.
  iii. After soaking, drain the aggregate and surface dry it until all films of water removed.
  iv. Take the weight of the surface dry sample as [W2]
  v. Place the SSD sample in wire basket and submerge it in water and record the submerged weight as [W3]
  vi. Take out the sample and dry it in an oven. Record the weight as [W1]
  vii. Calculate the specific gravity and absorption as follows ;

$$\textbf{Apparent Specific Gravity} = G_{sa} = \frac{W1}{W1-W3}$$

$$\textbf{Bulk Specific Gravity} = G_{sb} = \frac{W1}{W2-W3}$$

$$\textbf{Absorption (\%)} = \frac{[W2 - W1] * 100\%}{W1}$$

Where

W1 = oven dry weight of Aggregate

W2 = SSD weight of aggregate

W3 = Submerged unit weight of aggregates

B. ***Specific gravity Determination*** [fine aggregates]

- Test methods ; AASHTO T84 and ASTM C128
- Test Procedure
  1. Fill a flask [pycnometer] with water and record the weight as [W2]
  2. Take approximately 1kg of fine aggregate and oven dry it to a constant weight
  3. Immerse the oven dry sample for 24 hrs in water
  4. Spread the aggregate in a flat surface and expose it to a gently moving current of warm air until it become SSD
  5. Conduct a cone test to assure SSD condition
  6. Take approximately 500gm SSD material and place it in the flask. Fill the water until measuring mark and record the weight of fine aggregate, flask and water as [W3] and weight of SSD sample as [W4].
  7. Calculate the specific gravity and absorption as follow

Apparent Specific Gravity = G_{sa} =

$$\frac{W1}{[W2 + W1] - W3}$$

Bulk Specific Gravity = G_{sb} =

$$\frac{W1}{[W2 + W4] - W3}$$

Absorption (%) =

$$\frac{[W4 - W1] * 100\%}{[W1]}$$

Where

W1 = oven dry weight of Aggregate

W2 = weight of flask filled with water

W3 = weight of flask, water and aggregate

W4 = SSD sample weight

- When we have sample, tested in separate size fraction, the average specific gravity is calculated as :

$$G = \frac{[P1 + P2 + P3 + \ldots\ldots\ldots Pn]}{[P1/G1] + [P2/G2] + P3/G3] + \ldots\ldots[Pn/Gn]}$$

Where:
G = average specific gravity
P1, P2, P3, ……Pn = weight percentage fraction of each
G1, G2, G3, ….Gn = specific gravity of each fraction

Example 2: the apparent specific gravity of an aggregate is 2.750 and the water absorption is 2%. Determine the bulk specific gravity?

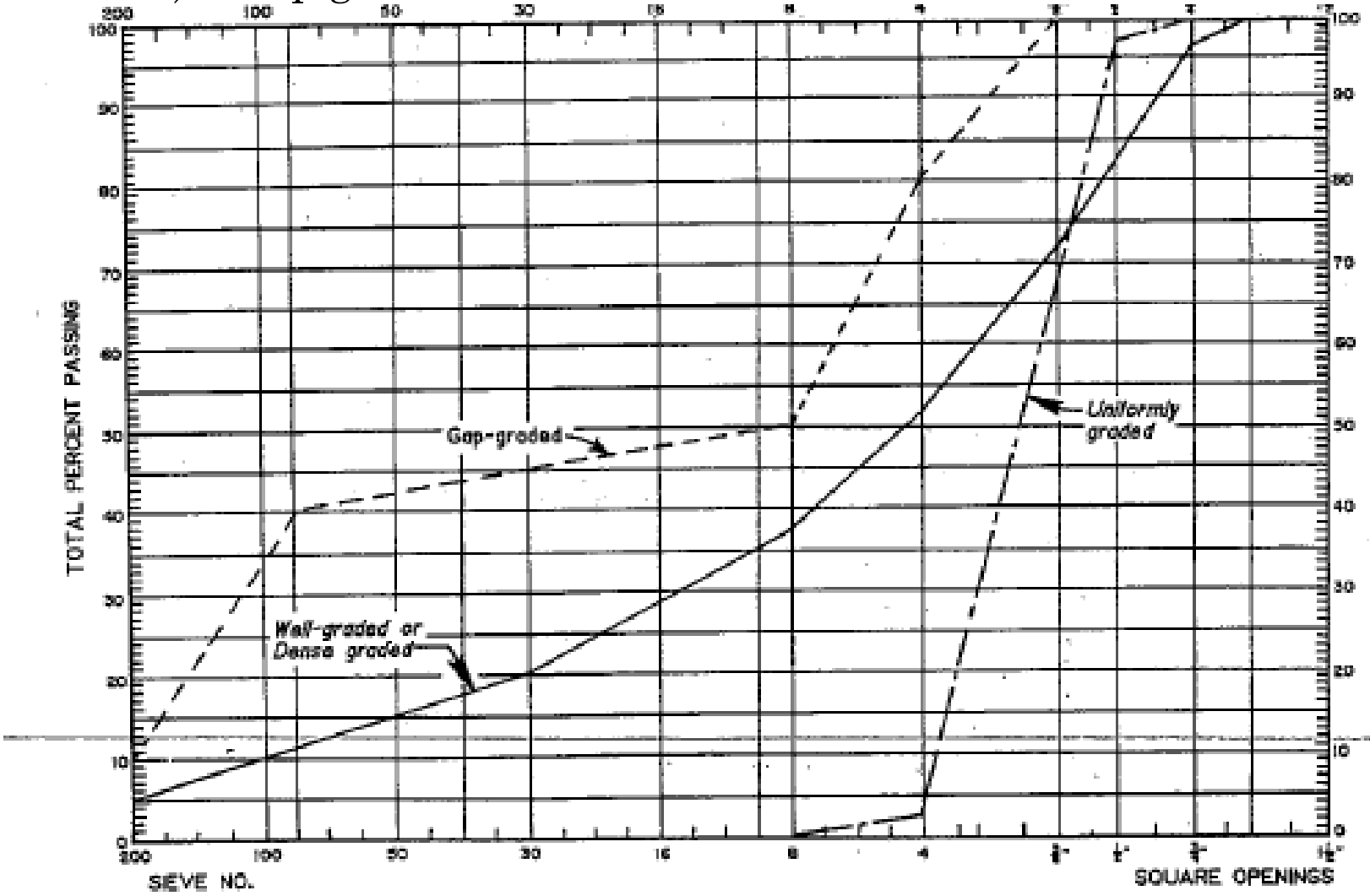
Example 3: Three aggregates are blended together with the proportion of 50%, 30% and 20%. The specific gravity of each aggregate is 2.750, 2.641 and 2.70 respectively. Determine, the specific gravity of the blend.

IV. Particle Size Distribution /Gradation

- **Gradation**: is the distribution of particle sizes expressed as a percentage of total weight passing a sieve.
- It is determined by Sieve analysis [course & fine aggregates] and hydrolysis [for fillers]
- It can be shown in tabular or graphic forms. In graphic representation, the horizontal axis represents the sieve size in logarizmic scale while the vertical axis represents the cumulative percentage passing in arithmetic scale.
- There are different sieve series with slightly different sieve size. Some of the common sieves are:

	ASTM	BS
	3in [76mm]	75mm
	2 in [50.8mm]	63mm
	1.5 in [38mm]	50mm
	1 in [25.4mm]	37.5mm
	¾ in [19 mm]	28mm
	3/8 in [9.5mm]	20mm
	No.4 [4.75mm]	14mm
	No.8 [2.38mm]	10mm
	No.10 [2.00mm]	6.3mm
	No.20 [850 μm]	5mm
	No.40 [425 μm]	3.35mm
	No.60 [250μm]	2mm
	No. 140 [106 μm]	1.18mm
	No. 200 [75μm]	600μm
	Pan	425μm
		300μm
		212μm

- Aggregate gradation usually classified as
    1) Well graded or densely graded
    2) Uniformly graded
    3) Gap graded



INTRODUCTION TO PAVEMENT MATERIALS

- In referring to Aggregates different manuals, including ERA, uses maximum size of aggregates. The two commonly used designations are:
    1. ***Maximum Size***: is the smallest sieve through which 100% of the aggregate passes.
    2. ***Nominal Size***: is the largest sieve that retains some of the aggregate particles, but generally not more than 10%.

INTRODUCTION TO PAVEMENT MATERIALS

Example: Identify the Maximum and nominal sizes of the aggregates envelopes ?

Test sieve (mm)	Percentage by mass of total aggregate passing test sieve		
	Nominal maximum particle size		
	37.5 mm	20 mm	10 mm
50	100	-	-
37.5	80 – 100	100	-
20	60 – 80	80 – 100	100
10	45 – 65	55 – 80	80 – 100
5	30 – 50	40 – 60	50 – 70
2.36	20 – 40	30 – 50	35 – 50
0.425	10 – 25	12 – 27	12 – 30
0.075	5 – 15	5 – 15	5 – 15

- ***Blending of aggregates to meet specifications***
  - For many reasons especially, to achieve maximum density, desirable gradation limits are provided in d/t TSM [technical Specifications].
  - However, in almost all cases, ether pit runs or crusher run materials don't fulfill specification requirements.
  - In addition, for purpose of handling and avoiding segregation, crusher products are stocked pile with d/t grained size.
  - Hence in order to achieve specification requirements, aggregates must be blended at proper proportion to obtain the required gradation.
- How to determine the proportion of the d/t blend materials?

TRIAL & ERROR



Crushed Stone/
Aggregate

Aggregate
Production





Crushed Stone Base course / GB1
; Addis-Ambo Road Project

Introduction to Pavement Materials

- ***Naturally occurring granular materials, boulders, weathered rocks (GB2 and GB3)***
  - A wide range of materials including
    - lateritic,
    - calcareous and
    - quartzitic gravels,
    - river gravels,
    - boulders and other transported gravels,
    - granular materials resulting from the weathering of rocks can be used successfully as base course materials


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Introduction to Pavement Materials

Crushed Gravel Base course, GB2



Introduction to Pavement Materials

Crushed Gravel Base course, GB2





TEST FOR GRANULAR MATERIALS

- It is clear that all materials have the same property to respond to the stress acting on them
- Material characterization and testing is mandatory in order to ensure that quality materials are used
- There are d/t types of tests recommended to be conducted on soils, gravel and aggregates
- According to ERA pavement design manual, the following tests had been recommended for *Soils as well as gravels*

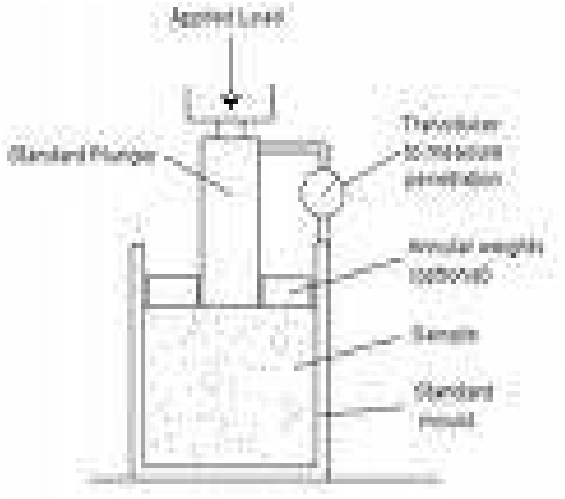
Tests on Soils

	Designation/ Test method	Designation
1	ASTM D698	Moisture-Density Relations of Soils/Soil-Aggregate Mix (Light)
2	ASTM D1557	Moisture-Density Relations Using Modified Effort (Heavy)
3	ASTM D1883 or AASHTO T193	CBR Test for Laboratory-Compacted Soils
4	ASTM D424 or AASHTO T90	Plastic Limit and Plasticity Index

Tests on Gravels

	Designation/ Test method	Designation
1	ASTM D698	Moisture-Density Relations
2	ASTM D1883 or AASHTO T193	CBR Test for Laboratory-Compacted Soils
3	ASTM C136 or AASHTO T27	Particle Size Distribution
4	ASTM D424 or AASHTO T90	Plastic Limit and Plasticity Index
5	BS 812, Part 105	Flakiness Index
6	BS 812, Part 111	Ten Per Cent Fines Value (TFV)
7	ASTM C535-89	Los Ángeles Abrasión Test (LAA)
8	BS 812, Part 110	Aggregate Crushing Value (ACV)
9	BS 812, Part 112	Aggregate Impact Test

- California Bearing Ratio (CBR)
  - CBR test is a standardized penetration test in which plunger with specific dimension penetrates a Compacted material (soil/gravel) at a fixed rate of penetration.
  - During the test, elastic and permanent deformations takes place







- The test procedure is
  1. Prepare a specimen according to the test methods
  2. Sock the specimen for 72 hrs
  3. Place the specimen on the testing machine properly
  4. Apply the force slowly and record the force at the penetrations of 2.5mm and 5mm
- According to the procedure, the forces recorded at 2.5mm and 5mm penetration is compared with a standard loads

- CBR= $\frac{X}{Y} * 100\%$
  - Where
  - X= the force on the specimen at 2.5mm /5mm penetration
  - Y= the force on a standard aggregate at 2.5mm/5mm penetration
- N:B; Y= 13.2 kn for 2.5mm penetration and
- = 20 Kn for 5mm penetration
- Example: CBR test is conducted on a

INTRODUCTION TO PAVEMENT MATERIALS

- Reading Assignment
  1. Summarize the testing procedures for the following material tests
     I. Gradation/Particle size distribution
     II. Atterberg limit tests with the determination of plasticity Index
  2. What does plasticity Index (PI) refers to ? What do you understand by PI?
  3. How to determine the blending proportion of Aggregates? [refer; Highway materials , Atkins]