A practical guide for the application of procedures for designing asphalt mixes as per Sabita Manual 35/TRH8

4. – Mix type selection

SARF Manual 24 – 20/21 Jun. 2022

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Manual 24 Elements

- Design Situation
- Design Objectives
- **Mix Type Selection**
- Constituents and Proportioning
- Lab Design Procedure

You are here

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Mix type selection

- Performance of an asphalt layer - ***closely related to the structure of all aggregates in the mix***
- Determines
  - Mechanical properties
    - Resistance to fatigue
    - Resistance to permanent deformation
  - Permeability
  - Durability
  - Compactability

First steps

- A ***Clear understanding*** of interaction between ***aggregate structure and mix performance is essential*** for optimal mix proportions
- This is the ***starting point*** of any ***new mix*** design (~~adopting a grading type or, worse, a grading envelope~~)

First steps

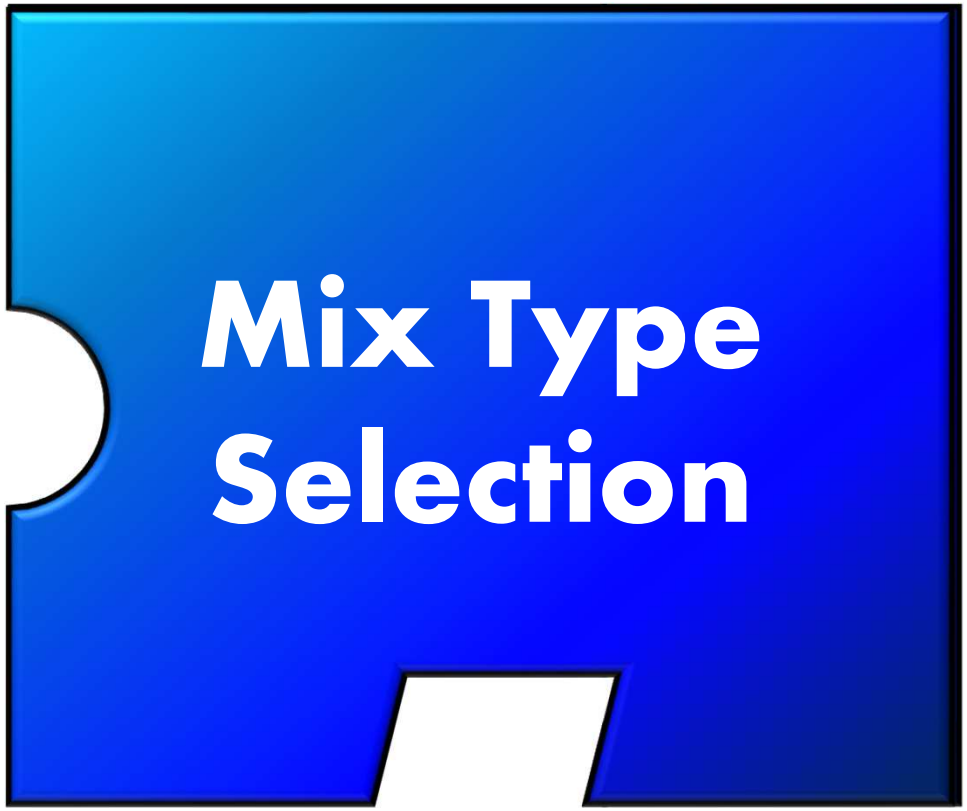
- Using ***gradings*** as a starting point has the distinct disadvantage of having ***little*** or no evident ***bearing*** on ***performance characteristics***
- Mixes with the same (mass-based) grading could display significantly different behaviour

Use of gradings

- Gradings are useful where mix types have been ***established and standardised*** for particular sources & applications

- ***Gradings*** are key to ***quality assurance*** procedures:
  - Why?
    - Mixes laid are representative of the materials used during the laboratory design process to ensure designed behaviour is achieved

Mix type selection



Mix Classification

Classification

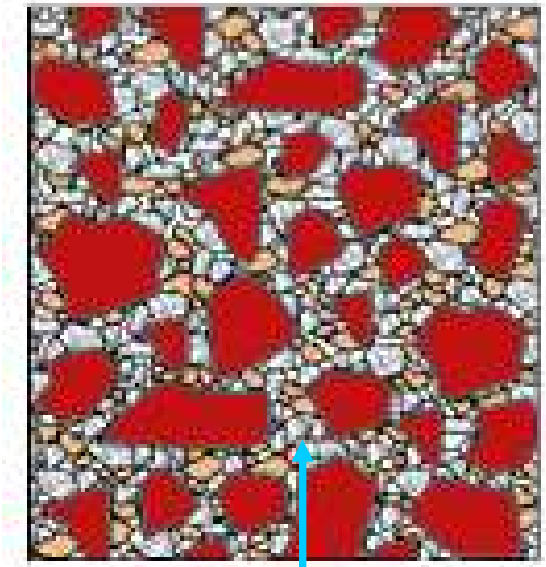
First critical choice

SAND SKELETON

STONE SKELETON

Sand skeleton mixes

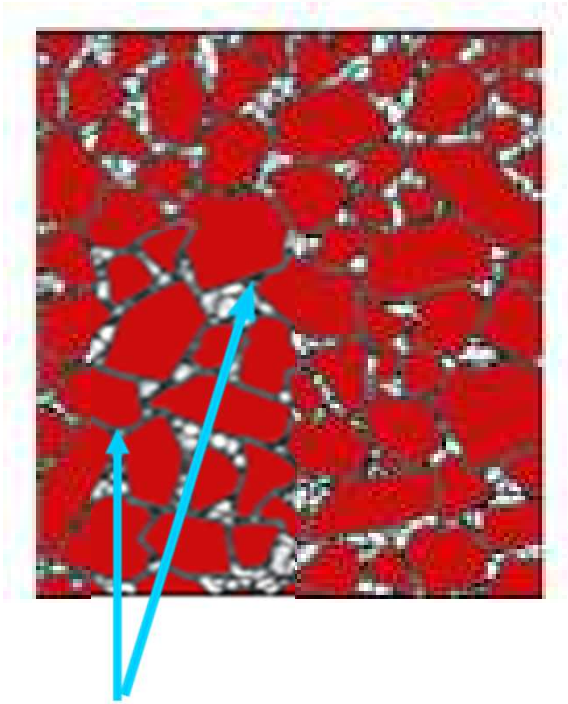
- Loads are mainly ***carried*** by the ***finer aggregate (FA)*** fraction
- ***Larger aggregate*** provide ***bulk*** (volume filling by replacement of FA)
- ***Little contact*** between the individual ***larger aggregate (CA)*** particles
  - Semi-gap graded asphalt
  - Gap-graded asphalt
  - Most continuously graded asphalt.



Continuous matrix of fine aggregate

Stone skeleton mixes

- Loads ***carried*** by an ***interlocking matrix of the coarser aggregate***
- Contact between the coarser aggregate achieved by ***ensuring that the finer fractions*** (mastic) ***do not overfill the air spaces*** available between the larger aggregate



Contact between coarse aggregate

Methods

- Number of analytical methods to analyse and define aggregate structure
- Sabita Manual 35 recommends the ***Bailey Method***
  - Systematic technique to ***establish which aggregate fraction – coarse or fine – is in control of the aggregate structure***.

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Bailey principles

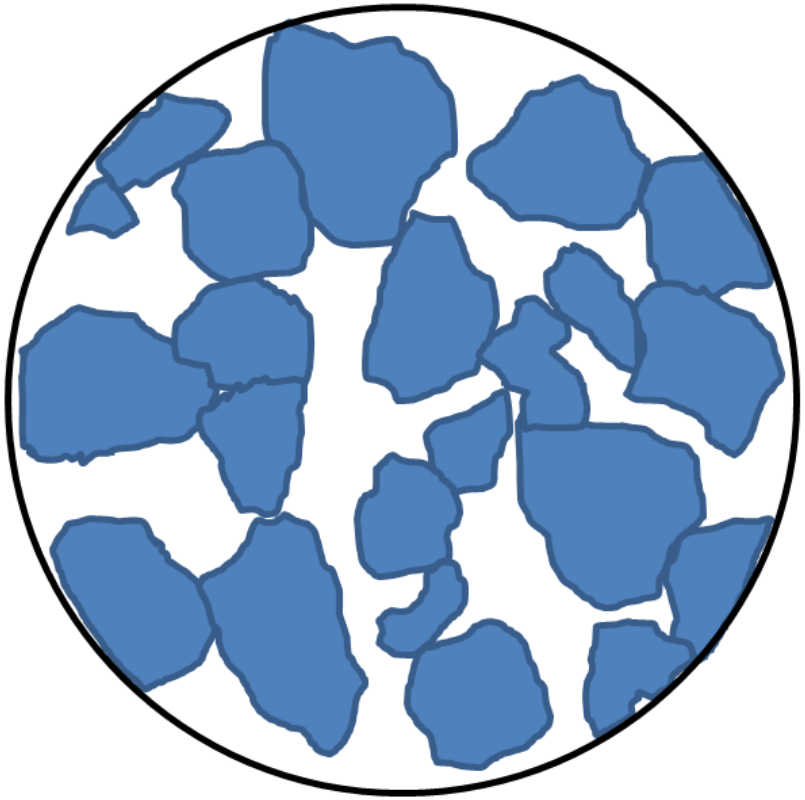
- Brief introduction here
- ***Courses*** presented by ***AsAc***
- Evaluates ***packing characteristics***
- Determines what is "***coarse***" and "***fine***"
- Evaluates individual aggregates and blends by volume and weight
- Optimises composition for function and constructability

Coarse and Fine

- ***CA - Coarse*** aggregate ***create voids***
- ***FA - Fine*** aggregates ***fill the voids***

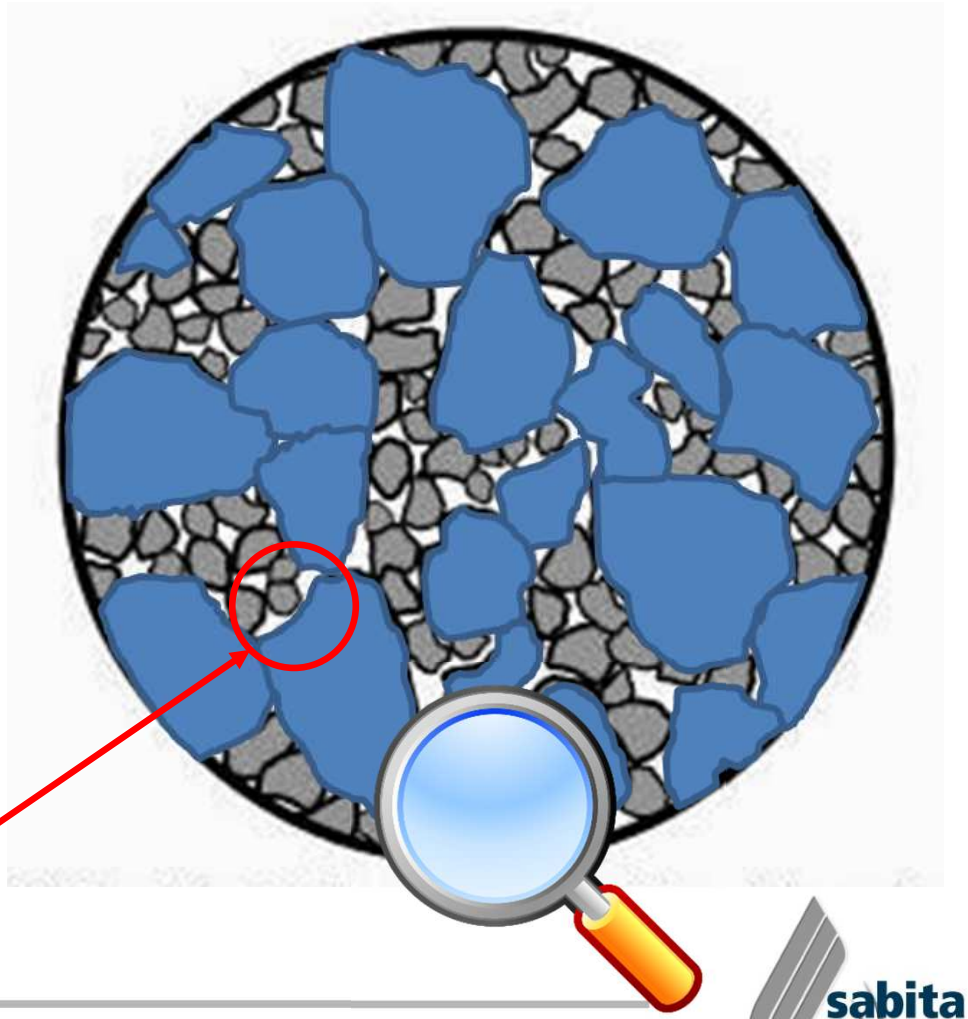
- You therefore need to estimate void size by determining the break between coarse and fine

Aggregate matrix in Mix



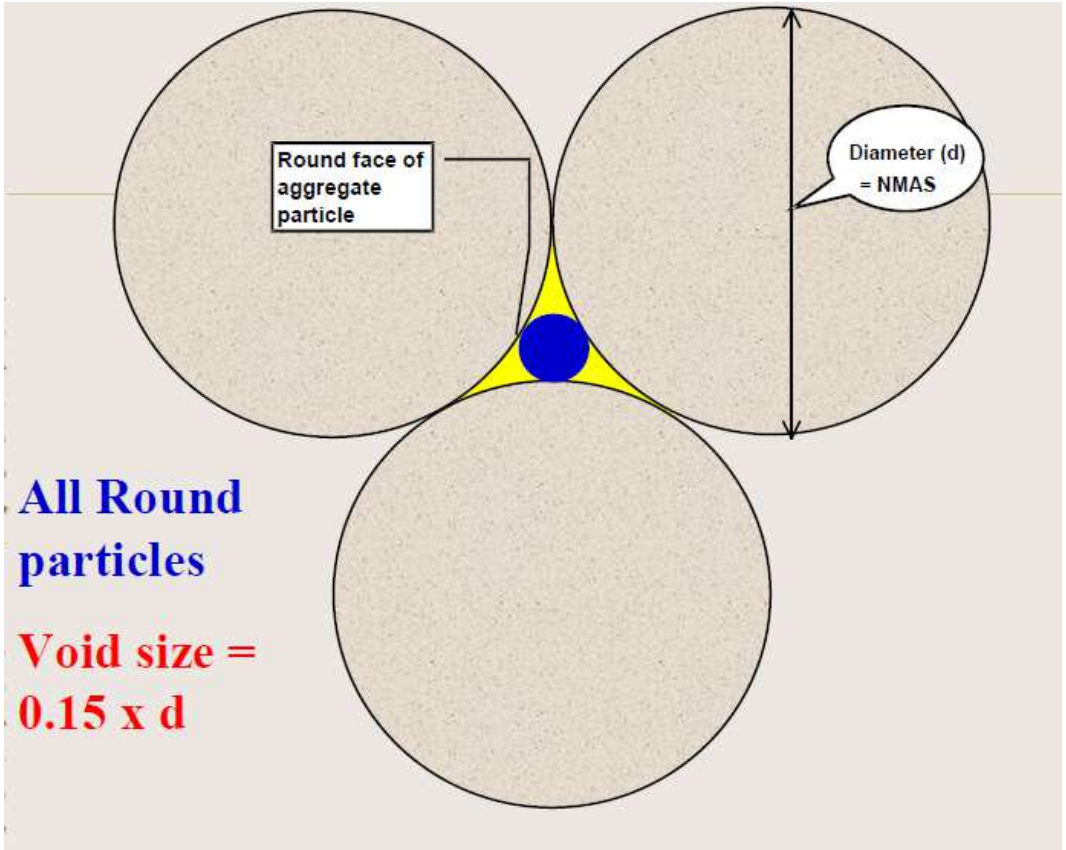
CA Creates Voids

FA Fills Voids



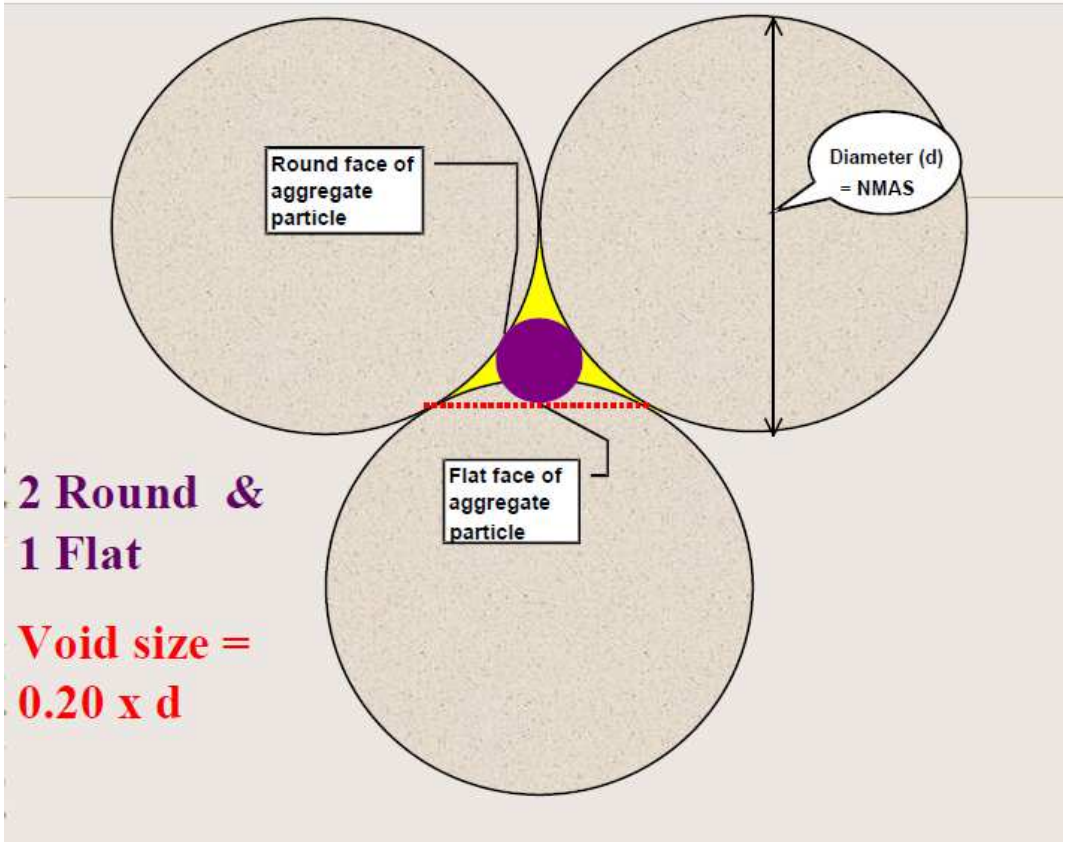
Void Size???

Volumetric cases for Void Size



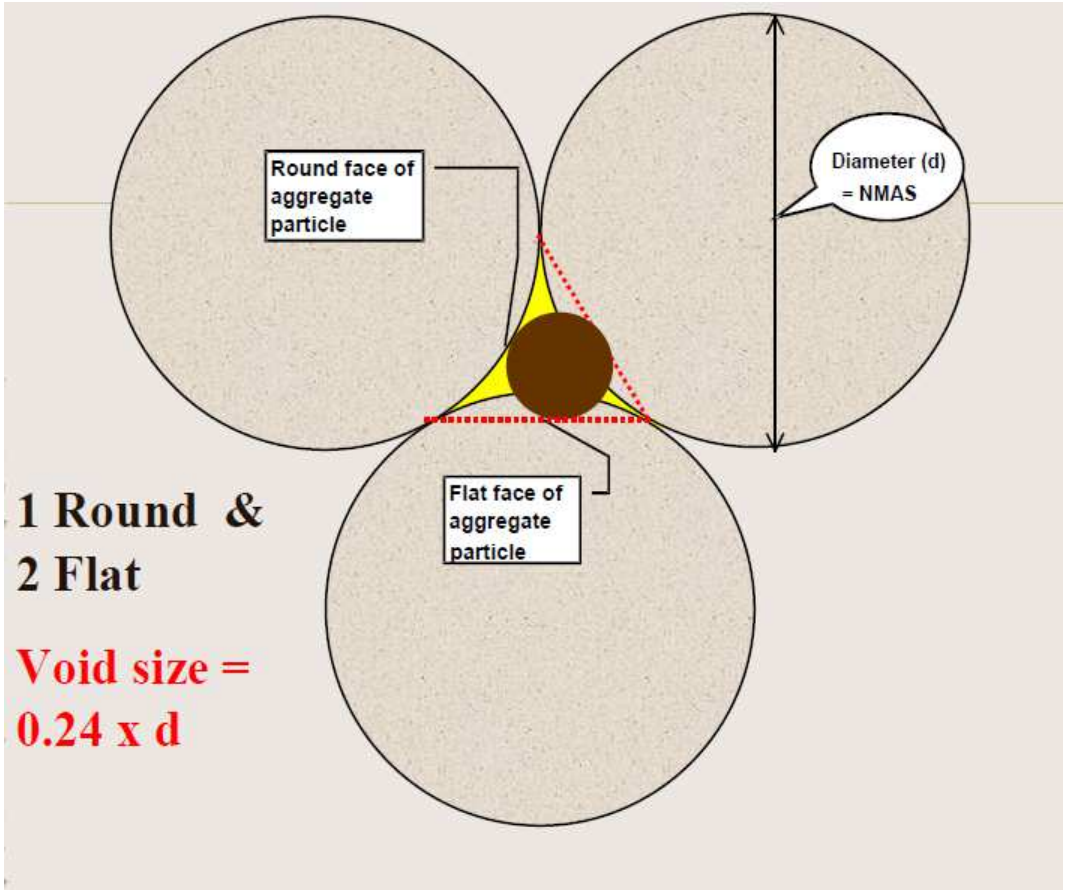
Case 1 of 4: void size of ***three round particles*** touching
Void size is ***0.15 of particle size diameter*** (NMAS)

Volumetric cases for Void Size



Case 2 of 4: void size of ***2 round & 1 flat face particles*** touching
Void size is ***0.20 of particle size diameter*** (NMAS)

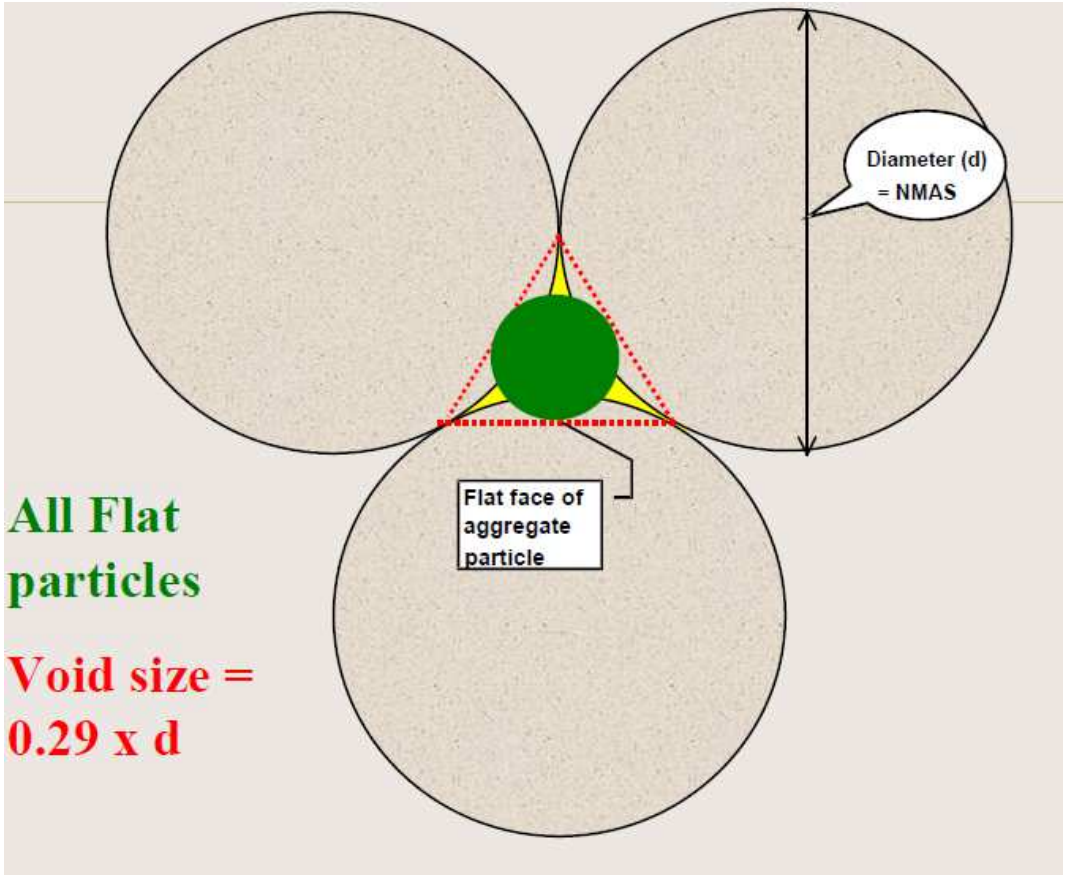
Volumetric cases for Void Size



Case 3 of 4: void size of ***1 round & 2 flat face particles*** touching

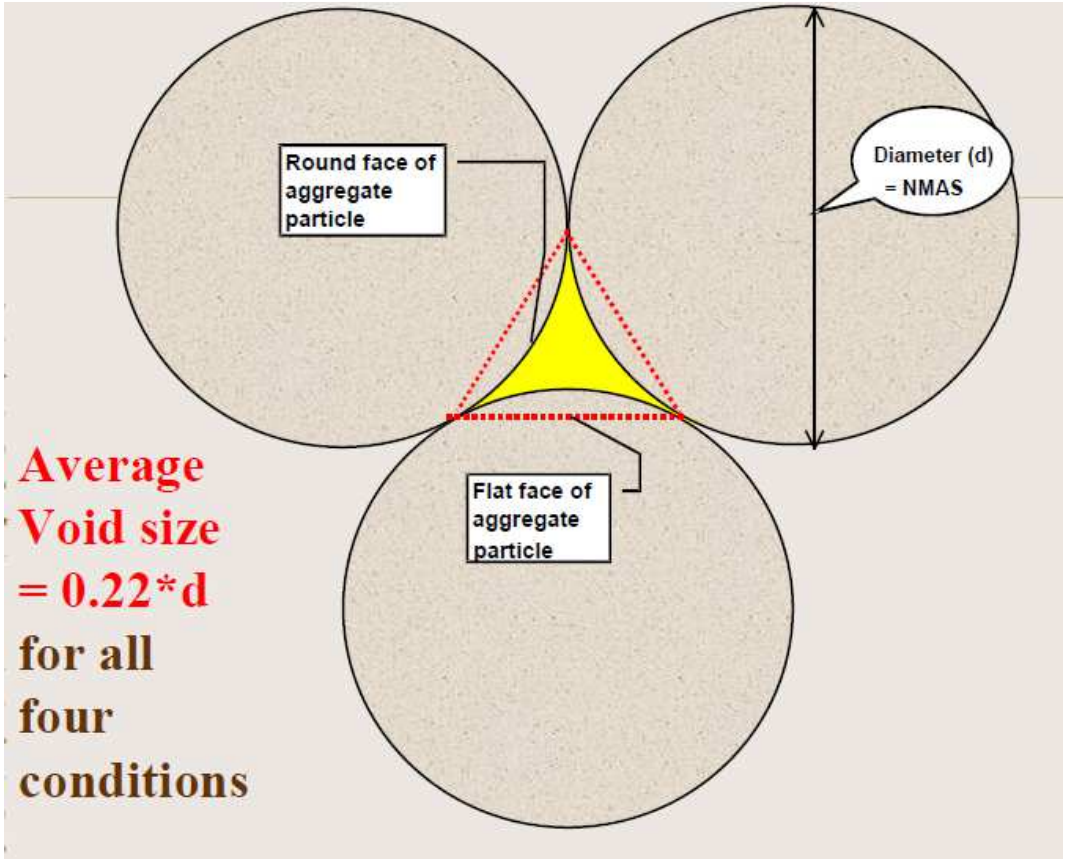
Void size is ***0.24 of particle size diameter*** (NMAS)

Volumetric cases for Void Size



Case 4 of 4: void size of ***3 flat face particles*** touching Void size is ***0.29 of particle size diameter*** (NMAS)

Volumetrics – average situation



Average case : Void size is ***0.22 of particle size diameter*** (NMAS) i.e. ***Primary Control Sieve (PCS) = 0.22 x NMAS***

Bailey method parameters

- Only ***some parameters*** introduced
- ***Primary control sieve*** (PCS) define the ***division between coarse and fine aggregate*** of a <u>specific</u> mix
- 0.22 x NMAS

NMPS (mm)	PCS (mm)
37.5	10
28	7.1
20	5
14	2
10	2
7.1	1

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Aggregate packing

- Control ***volumes*** of ***coarse*** and ***fine*** aggregate according to ***mix type***
- ***Design by volume***
- Determine unit weights
- Calculate volume of solids in coarse fraction
- Calculate volume of voids it contains

Unit weights

- ***Loose*** unit weight (***LUW***)
- ***Rodded*** unit weight (***RUW***)
- ***Chosen*** unit weight (***CUW***)
- LUW & RUW - according to ***AASHTO T 19***
  - ***Specific mould volumes!!!***

Designation: C 29/C 29M – 97

American Association of State Highway and Transportation Officials Standard AASHTO No.: T19/T19M

Standard Test Method for Bulk Density ("Unit Weight") and Voids in Aggregate[1]

This standard is issued under the fixed designation C 29/C 29M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope

1.1 This test method covers the determination of bulk density ("unit weight") of aggregate in a compacted or loose condition, and calculated voids between particles in fine, coarse, or mixed aggregates based on the same determination. This test method is applicable to aggregates not exceeding 5 in. [125 mm] in nominal maximum size.

NOTE 1—Unit weight is the traditional terminology used to describe the property determined by this test method, which is weight per unit volume (more correctly, mass per unit volume or density).

1.2 The values stated in either inch-pound units or SI units are to be regarded separately as standard, as appropriate for a specification with which this test method is used. An exception is with regard to sieve sizes and nominal size of aggregate, in which the SI values are the standard as stated in Specification E 11. Within the text, SI units are shown in brackets. The values stated in each system may not be exact equivalents; therefore each system must be used independently of the other, without combining values in any way.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*
C 125 Terminology Relating to Concrete and Concrete Aggregates[2]
C 127 Test Method for Specific Gravity and Absorption of Coarse Aggregate[2]
C 128 Test Method for Specific Gravity and Absorption of Fine Aggregate[2]
C 138 Test Method for Unit Weight, Yield, and Air Content (Gravimetric) of Concrete[2]
C 670 Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials[2]
C 702 Practice for Reducing Samples of Aggregate to Testing Size[2]
D 75 Practice for Sampling Aggregates[3]
D 123 Terminology Relating to Textiles[4]
E 11 Specification for Wire Cloth and Sieves for Testing Purposes[5]

2.2 *AASHTO Standard:*
T19/T19M Method of Test for Unit Weight and Voids in Aggregate[6]

3. Terminology

3.1 *Definitions*—Definitions are in accordance with Terminology C 125 unless otherwise indicated.

3.1.1 *bulk density, n—of aggregate*, the mass of a unit volume of bulk aggregate material, in which the volume includes the volume of the individual particles and the volume of the voids between the particles. Expressed in lb/ft^3 [kg/m^3].

3.1.2 *unit weight, n*—weight (mass) per unit volume. (Deprecated term–used preferred term **bulk density**.)

3.1.2.1 *Discussion*—Weight is equal to the mass of the body multiplied by the acceleration due to gravity. Weight may be expressed in absolute units (newtons, poundals) or in gravitational units (kgf, lbf), for example: on the surface of the earth, a body with a mass of 1 kg has a weight of 1 kgf (approximately 9.81 N), or a body with a mass of 1 lb has a weight of 1 lbf (approximately 4.45 N or 32.2 poundals). Since weight is equal to mass times the acceleration due to gravity, the weight of a body will vary with the location where the weight is determined, while the mass of the body remains constant. On the surface of the earth, the force of gravity imparts to a body that is free to fall an acceleration of approximately 9.81 m/s^2 (32.2 ft/s^2).

3.2 *Definitions of Terms Specific to This Standard:* **D 123.**

3.2.1 *voids, n—in unit volume of aggregate*, the space between particles in an aggregate mass not occupied by solid mineral matter.

3.2.1.1 *Discussion*—Voids within particles, either permeable or impermeable, are not included in voids as determined by this test method.

[1] This test method is under the jurisdiction of ASTM Committee C-9 on Concrete and Concrete Aggregates and is the direct responsibility of Subcommittee C09.20 on Normal Weight Aggregates.
Current edition approved July 10, 1997. Published September 1997. Originally published as C 29 – 20 T. Last previous edition C 29/C 29M – 91a.
[2] *Annual Book of ASTM Standards*, Vol 04.02.
[3] *Annual Book of ASTM Standards*, Vol 04.03.
[4] *Annual Book of ASTM Standards*, Vol 07.01.
[5] *Annual Book of ASTM Standards*, Vol 14.02.
[6] Available from American Association of State Highway and Transportation Officials, 444 N. Capitol St. NW, Suite 225, Washington, DC 20001.

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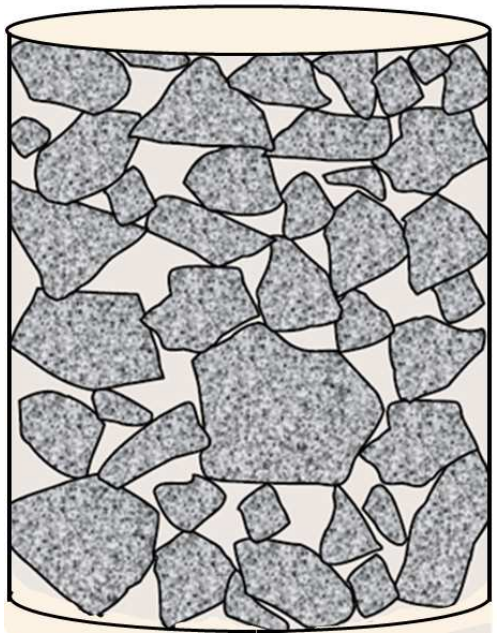
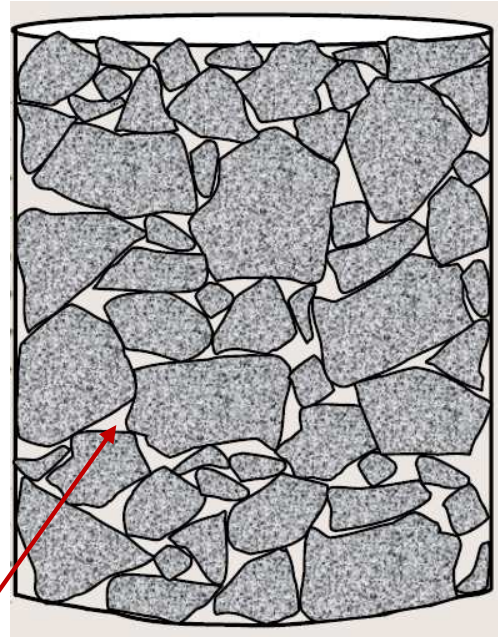
Loose unit weight (LUW)

- ***No compactive effort***
- ***Start*** of ***particle-to-particle contact***
- Shovelling procedure to fill mould
- Strike off level (no compaction)
- Determine ***LUW (kg / m^3)***
- Determine ***volume of voids***



Rodded unit weight (RUW)

- With ***compactive effort*** applied – 3 equal lifts
- ***Increased particle-to particle contact***
- Determine ***RUW (kg/m³)***
- Determine ***volume of voids***



Less voids

Unit weight and mix type

- *Sand skeleton*
  - CA volume ***< 80% LUW***
  - Little or ***no particle-to-particle contact in CA***
  - ***Large aggregates float*** in matrix of fine aggregate
- *Stone skeleton* ***(general <u>but</u> be careful !!!!)***
  - CA volume between LUW and RUW ***(95 – 105% LUW)***
  - Significant ***particle-to-particle contact in CA***
- Stone skeleton (***Stone mastic asphalt SMA***)
  - CA volume ***110 – 125% RUW***
  - ***Comprehensive particle-to-particle contact*** in CA

- Mixes, with ***CUW 80% - 95% of LUW can be problematic*** - should be avoided:
  - Possible risk factors:
    - tenderness
    - Segregate susceptibility
    - Can present compaction issues and
    - gradings of these mixes – are often close to the maximum density line which can limit achievement of both:
      - sufficient binder
      - adequate air voids.

Fine aggregate

- ***Similar principles applied to FA***, depending on mix type
- Not dealt with here
- ***Course on Bailey method AsAc***

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Mix classification

- Stone skeleton (Coarse aggregate Interlock):

> 50 % aggregate ***retained on the PCS*** (i.e. < 50% passes the PCS

- Sand skeleton (All Fine graded, some coarse graded mixtures)

≤ 50 % aggregate ***retained on the PCS*** (i.e. ≥ 50% passes the PCS.

Quick check
But Bailey Analysis will help confirm behaviour

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Mix classification

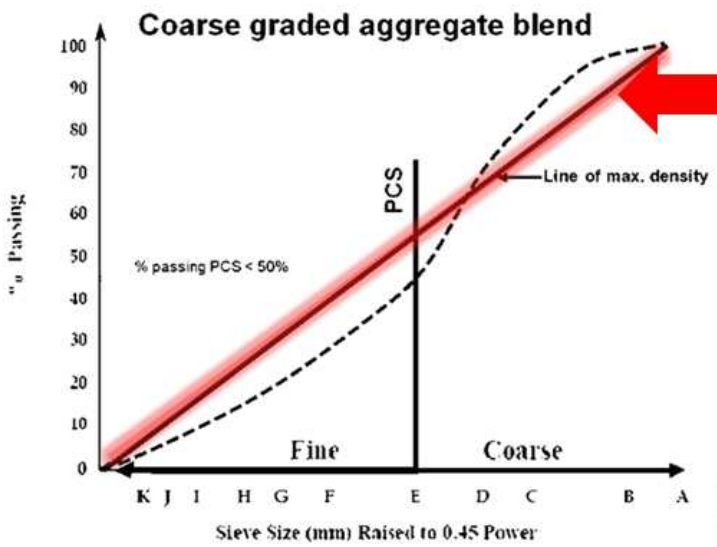
Important Note:

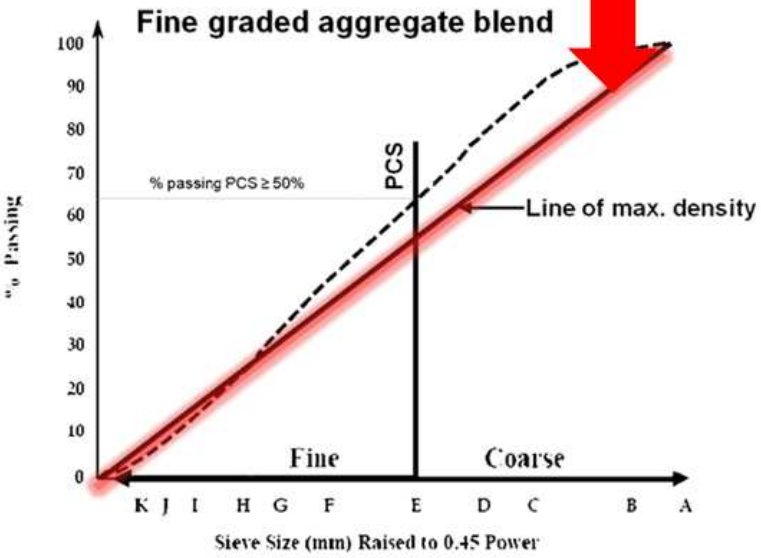
Sand and **Stone Skeleton** Mix types are **not** to be **confused** with **Bailey** Definitions of **Fine Graded** and **Coarse Graded** Mixtures as it is dictated by gradation and **BEHAVIOUR**.

When you have attaned full interlock of the **STONE** skeleton, i.e. in the Coarse aggregate (CA) fraction one moves from loose unit weight condition (LUW) where CA interlock starts to rodded unit weight (RUW) condition where the interlock of the CA fraction is fully achieved.

An increase in fine aggregate or mastic here will disrupt the Stone skeleton and diminish load carrying capacity!

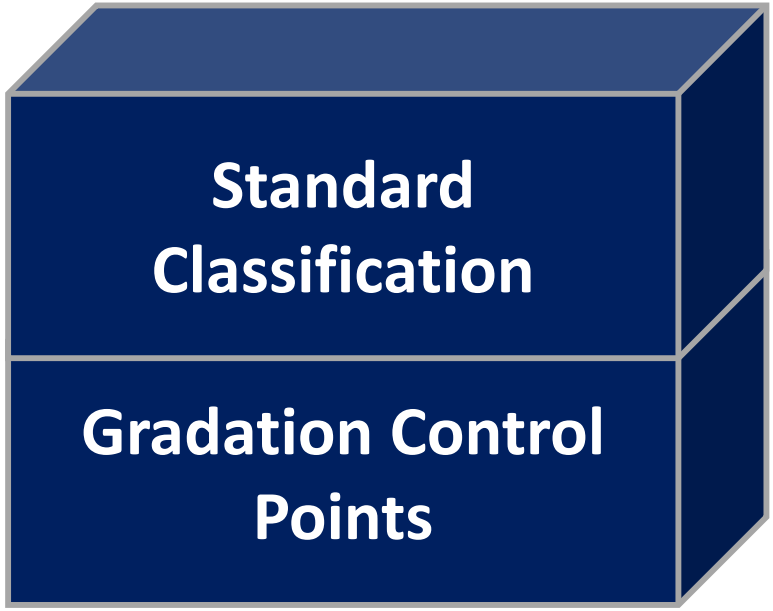
Mix classification





General idea is to deviate from the max density line

Mix Gradations



Limitations of grading

- Traditionally mixes were classified in terms of their gradings
- Practice has been ***discontinued in Manual 35:***
  - change in aggregate shape over the years due to advances in crushing technology
  - traditional gradings used for decades do not necessarily guarantee optimal designs today
  - increased heavy traffic loads that occur early in the life of the layer

Limitations of grading

- ***Examination of the aggregate packing*** is now the ***primary step*** in the design of asphalt
- ***Gradings*** have a crucial role in ***quality assurance***

Why????

Grading terminology

Continuously graded

- ***Near maximum density line***. Many mixes used in SA have this type of gradation, sometimes with ***unacceptably low VMA***

Gap Graded

- ***Low proportion*** of particles in the ***mid-size range***
- Coarse stone plums in sand matrix
- Considered where ***permeability of the mix is a critical*** requirement
- Require some ***texturing*** to improve skid resistance

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Grading terminology

Open Graded

- Small proportion of fine aggregates
- ***High air voids***
- Used for porous asphalt and thin friction courses.

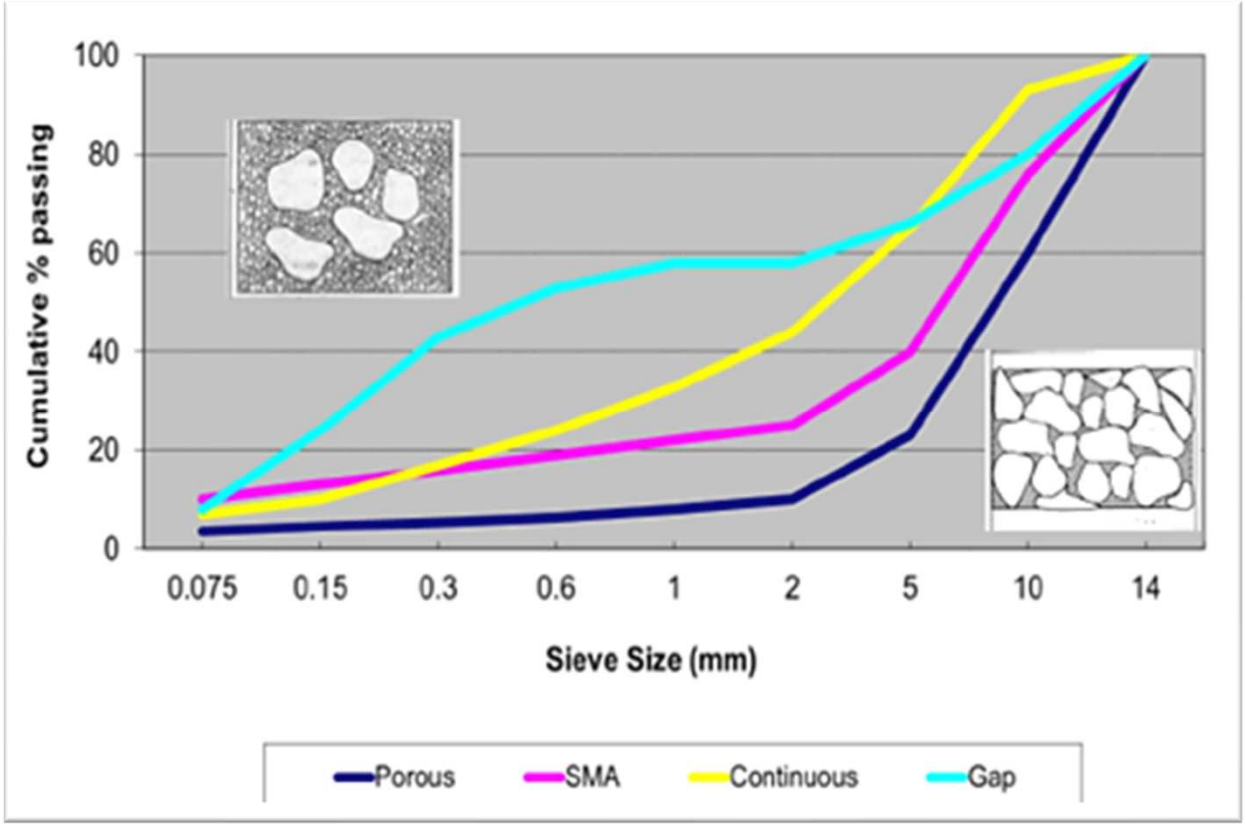
Uniformly Graded

- Particles are ***single sized***
- Applies to ***aggregate fractions***

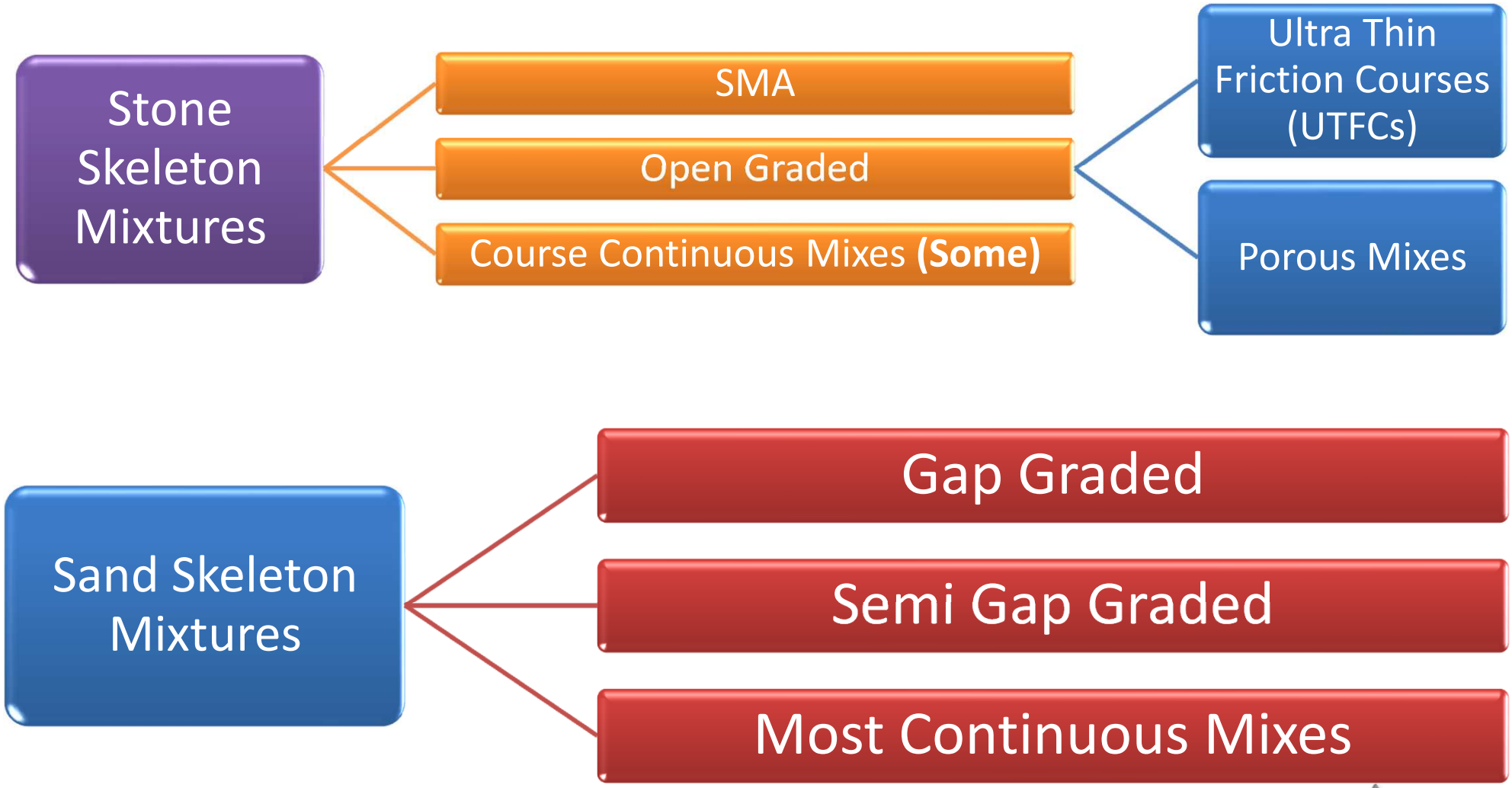
Grading types

- Sand-skeleton mix types e.g. **Gap graded** quite distinct from stone-skeleton types such as **"SMA"** and **"Porous"**

- Note that **continuously graded** mixes could be ***either type!***
  (***limitation of using grading to characterise mix behaviour***)



Standard classification



Standard classification

How would you classify a typical BTB?

Sieve Size (mm)	%1 Passing
37.5	100
20	92
14	83
10	72
7.1	58
5	52
2	32
1	21
0.6	16.2
0.3	11.8
0.15	8.6
0.075	6.0

Max density gradations

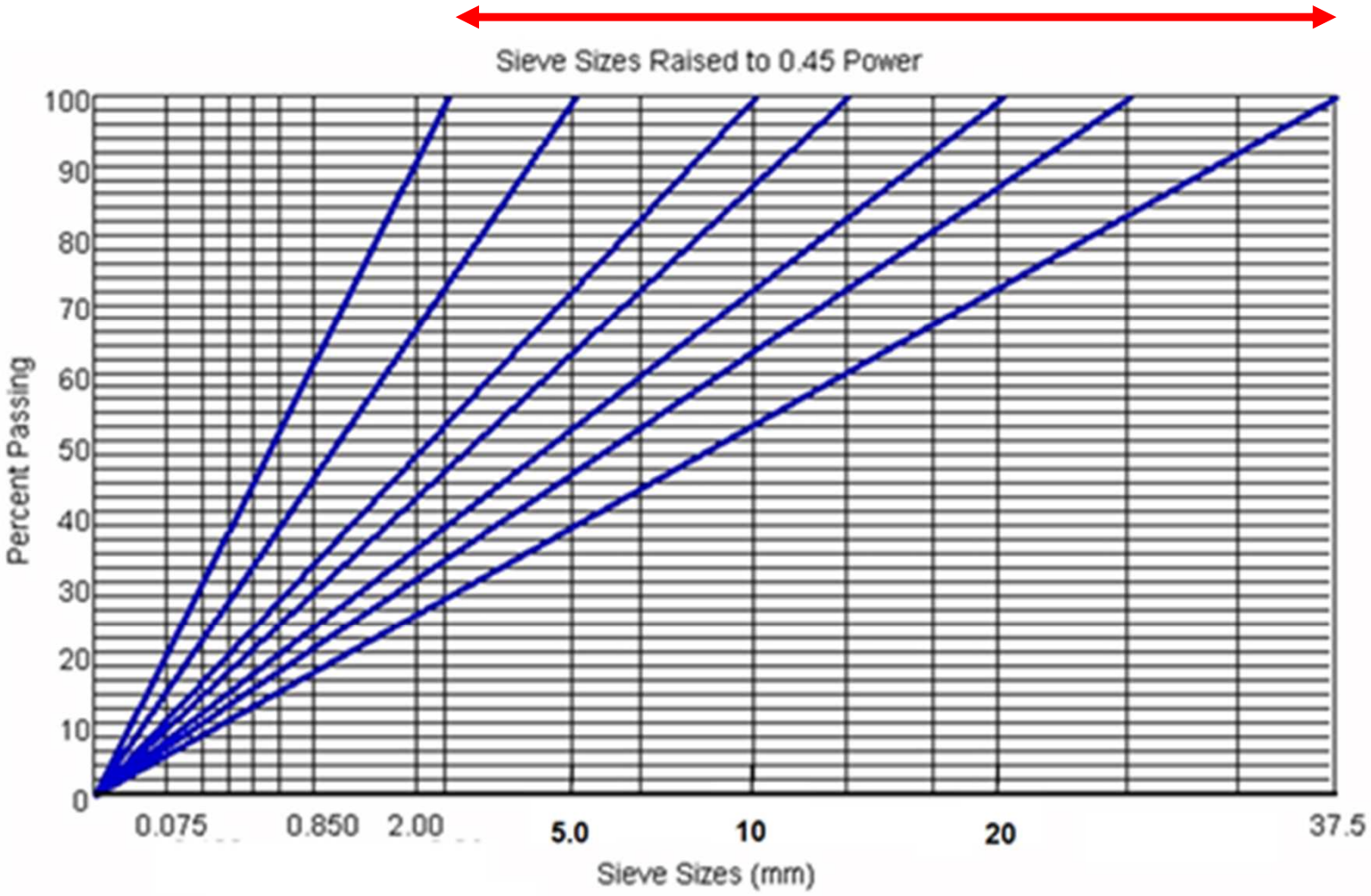
1960s - FHWA introduced the standard gradation graph widely used in the asphalt industry today - where the exponent of n = 0.45 was adopted, i.e.:

$$p_i = \left(\frac{d_i}{D}\right)^{0.45}$$

Graph - different than other gradation graphs because it uses the ***sieve size raised to the power 0.45 as the x-axis units***

Note: Gradings close to these maximum density lines ***limits the space available*** for ***adequate binder volumes*** while providing ***sufficient voids***.

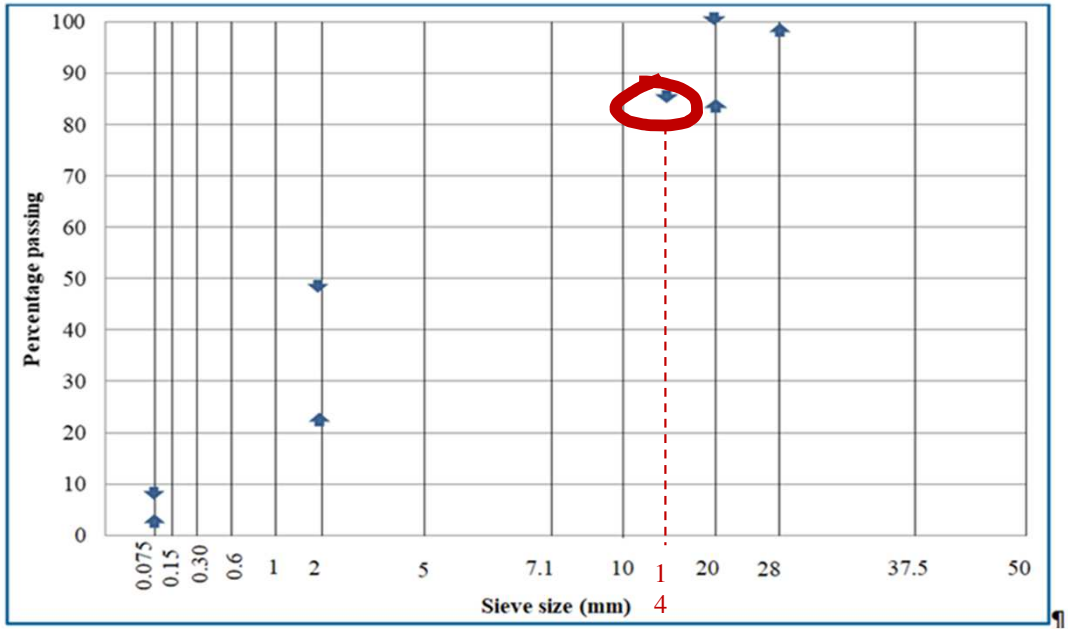
Max density lines (n = 0.45)



Note:
The max. dens. Line moves as mix size changes!

Grading control points

- Manual 35 – Suggested control points for ***sand skeleton mixes (ONLY)***
- Note: Aids with keeping mix size relevant!
- E.g. For 20 mm NMPS:



- Control points - ***guidelines only ONLY relevant to sand skeleton types*** (For Stone skeleton – Speciality manuals)
- Gradation of (continuously graded) sand skeleton mixes ***should not be too close to the 0.45 power maximum density curve***
  - VMA is likely to be too low leading to low binder content to attain minimum voids in the mix
- To ***optimise aggregate proportions***, use the ***Bailey method***, (used with success in SA).

Mix type selection

Selection guidelines

- Take into account all ***key elements*** of the ***design situation*** (section 3.1)
- ***Informed decision*** on the selection of the ***mix type***
  - ***Application;***
  - ***Type;***
  - ***Size; etc.***

Selection considerations

Selected *mix type determines the grading*

- ***Friction and noise - opposing dynamics*** (except open-graded asphalt and purpose designed friction courses)
- Thin layer asphalts ***for low speed, light to moderate traffic*** in residential areas - typically ***sand-skeleton mixes***
- ***Stone-skeleton*** mixes preferred for ***high traffic volumes*** where ***friction & rut resistance*** are key considerations

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Selection considerations

Selected *mix type determines the grading*

- ***Continuous gradings that ensure sand-skeletons*** are frequently selected for ***general use***
- The term "***continuously graded asphalt***" has ***little specific meaning***
- For adequate ***skid resistance of gap- & semi gap-graded*** wearing courses, ***pre-coated chippings*** are usually applied prior to rolling -> be vigilant of permeability and durability!
- Refer Table 7 in Manual 35

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We are HERE in the process

Questions?