# *The Basics Of*

# *The Bailey Method*

## *2006 Annual Meeting*
## *Illinois Asphalt Pavement Association*

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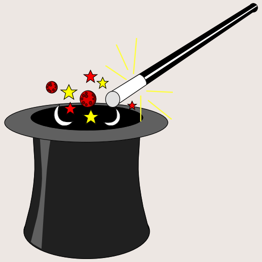
*Urbana, IL / Indianapolis, IN*

# Aggregate Blending

## **The Bailey Method**



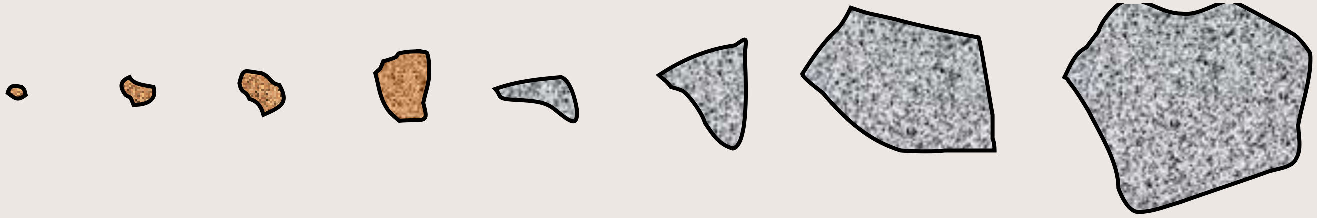
- Originally developed by Robert D. Bailey
- Evaluate aggregate **packing** characteristics
- Determine what is "**Coarse**" and "**Fine**"
- Evaluate individual aggregates **and** the combined blend by **VOLUME** as well as by **weight**

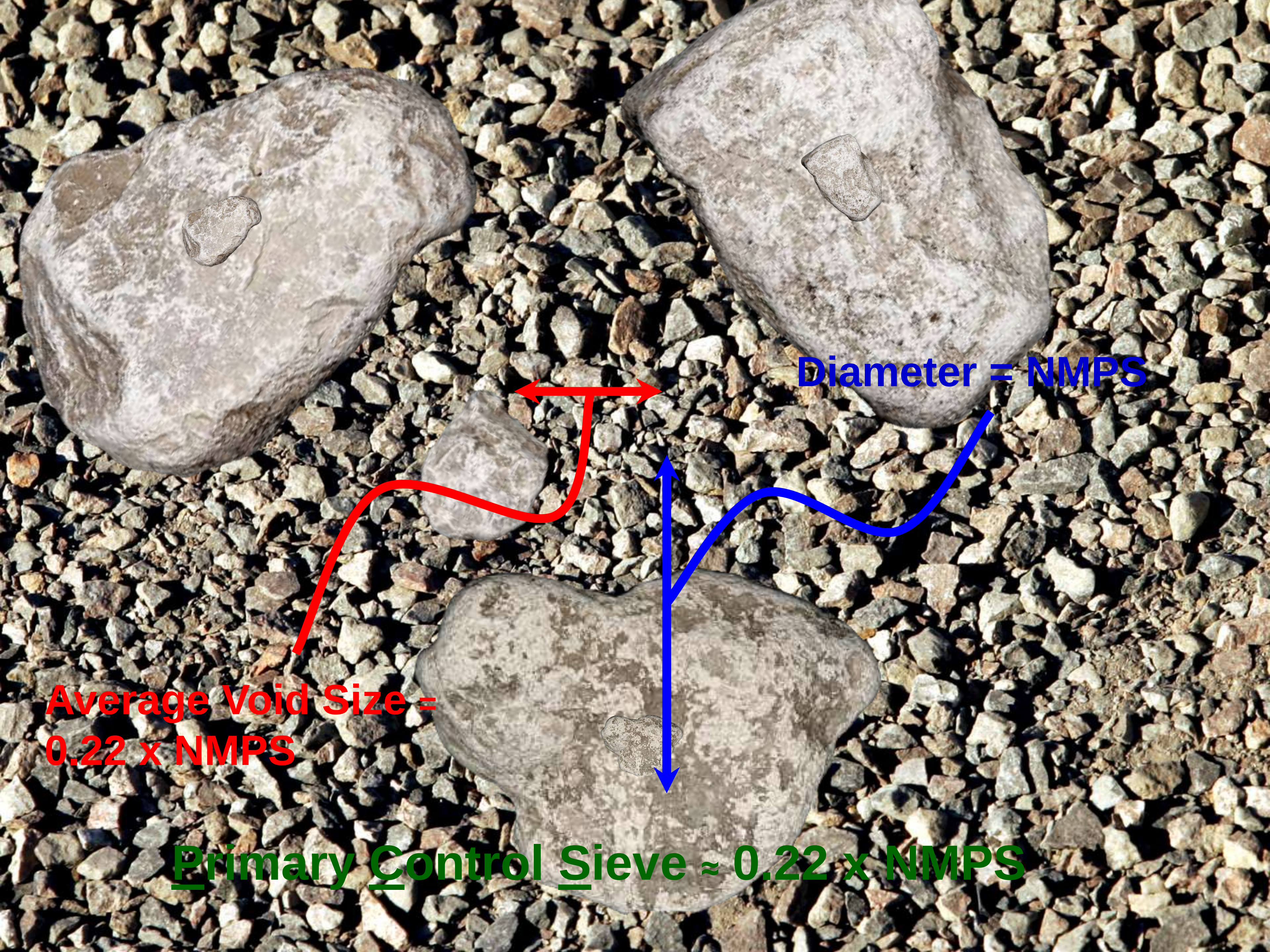
# Aggregate Packing
## What Influences the Results?

- **Gradation**
  - continuously-graded, gap-graded, etc.
- **Type & Amount of Compactive Effort**
  - static pressure, impact or shearing
- **Shape**
  - flat & elongated, cubical, round
- **Surface Texture** (micro-texture)
  - smooth, rough
- **Strength**
  – Weak vs. Strong, Influence of particle **shape**?

# Defining "Coarse" and "Fine"

- "**Coarse**" fraction
  - Larger particles that **create** voids
- "**Fine**" fraction
  - Smaller particles that **fill** voids
- Estimate void **size**
  - Using **N**ominal **M**aximum **P**article **S**ize (**NMPS**)
- **Break** between "**Coarse**" and "**Fine**"
  - **Primary Control Sieve (PCS)**




Diameter = NMPS
Average Void Size =
0.22 x NMPS
Primary Control Sieve ≈ 0.22 x NMPS

# Primary Control Sieve

| Mixture NMPS | NMPS x 0.22 | Primary Control Sieve |
|---|---|---|
| 37.5mm | 8.250mm | **9.5mm** |
| 25.0mm | 5.500mm | **4.75mm** |
| 19.0mm | 4.180mm | **4.75mm** |
| 12.5mm | 2.750mm | **2.36mm** |
| 9.5mm | 2.090mm | **2.36mm** |
| 4.75mm | 1.045mm | **1.18mm** |

**PCS** determines the **break** between **Coarse** and **Fine** in the combined blend **and** if a **given** aggregate is a **CA** or **FA**

# Evaluating Aggregates by **Volume**

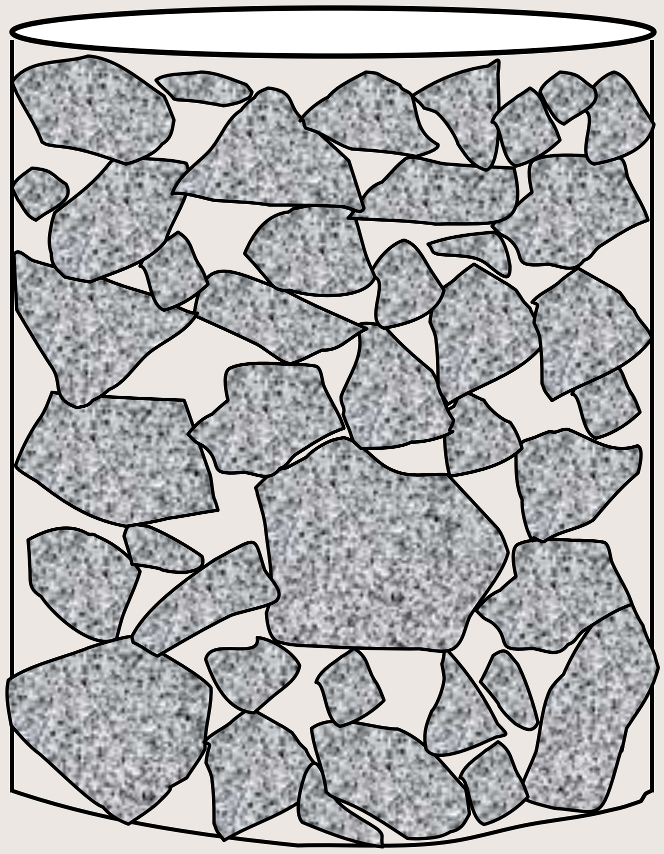
- Why?
  - Better understand **aggregate packing**
  - Control **VOLUME** of **Coarse** and **Fine** for Mix "**Type**"
- How?
  - Test the **individual** **Coarse** and **Fine** aggregates

Fine-graded

Coarse-graded

SMA

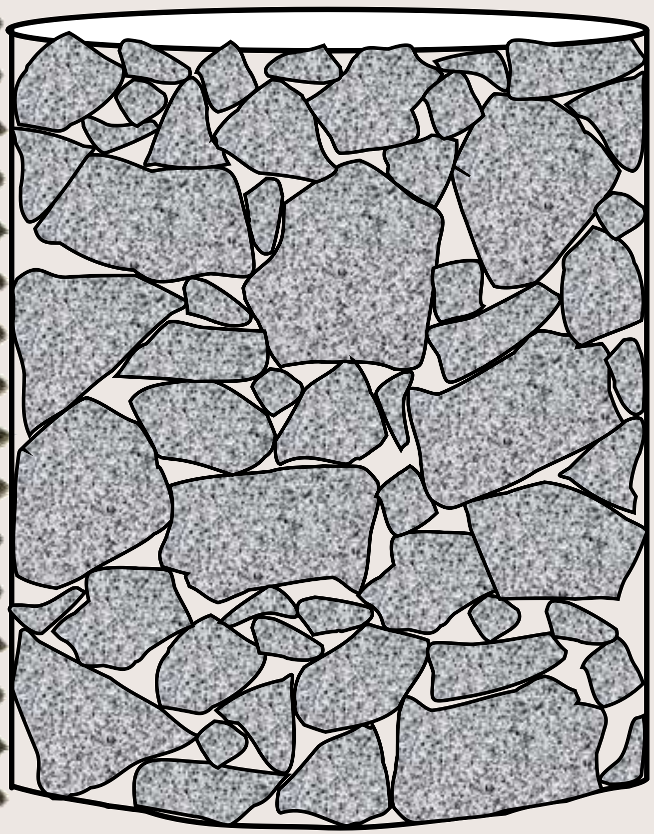
# Loose Unit Weight - CA



AASHTO T19

- **NO** compactive effort applied
- **Start** of particle-to-particle contact
- Use **shoveling** procedure
- Strike off ~ level
  - Careful **not** to compact
- Determine **LUW**
  - $Kg/m^3$ or $lbs./ft^3$
- Determine **volume** of **voids**

# Rodded Unit Weight - CA

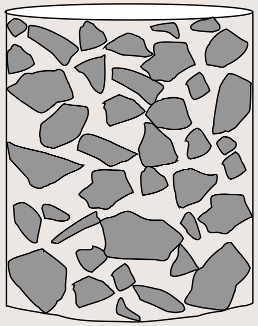


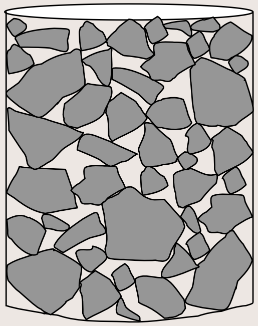
AASHTO T19

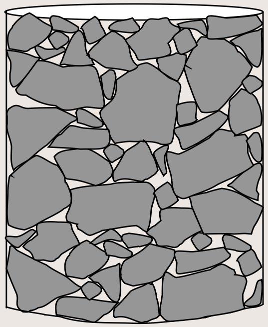
- **With** compactive effort applied
- **Increased** particle-to-particle contact
- **Three** equal lifts using **shoveling** procedure
- Rod **25** times per lift
- Strike off ~ level
  - Careful **not** to compact
- Determine **RUW**
  - Kg/$m^3$ or lbs./$ft^3$
- Determine **volume** of **voids**

# *C*hosen Unit Weight - CA(s)

**< LUW** | **LUW** | **RUW**







**Fine-Graded**

**< 90%**

**Coarse-Graded**

**95-105%**

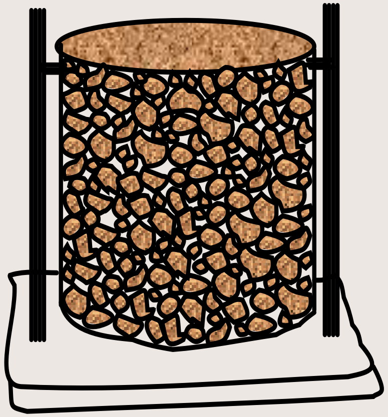
**SMA**

**110-125%**

**INCREASING CA CUW**

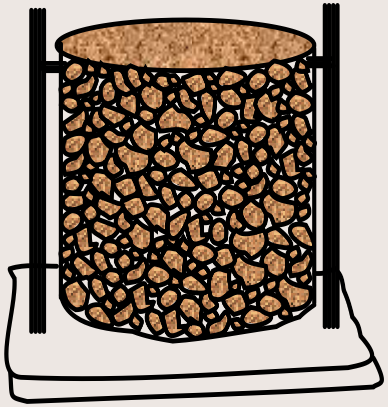
# Chosen Unit Weight - FA(s)

100%
LUW



FA CUW
"SET"
According To
Mix Type

100%
RUW



SMA

Dense-graded

# Developing the Combined Blend

1. Determine Mix **Type** & NMPS
2. Chose the **VOLUME** of **CA**
3. Blend the **CA's** by **VOLUME**
4. Blend the **FA's** by **VOLUME**
5. Chose the ***desired*** % Minus 0.075mm

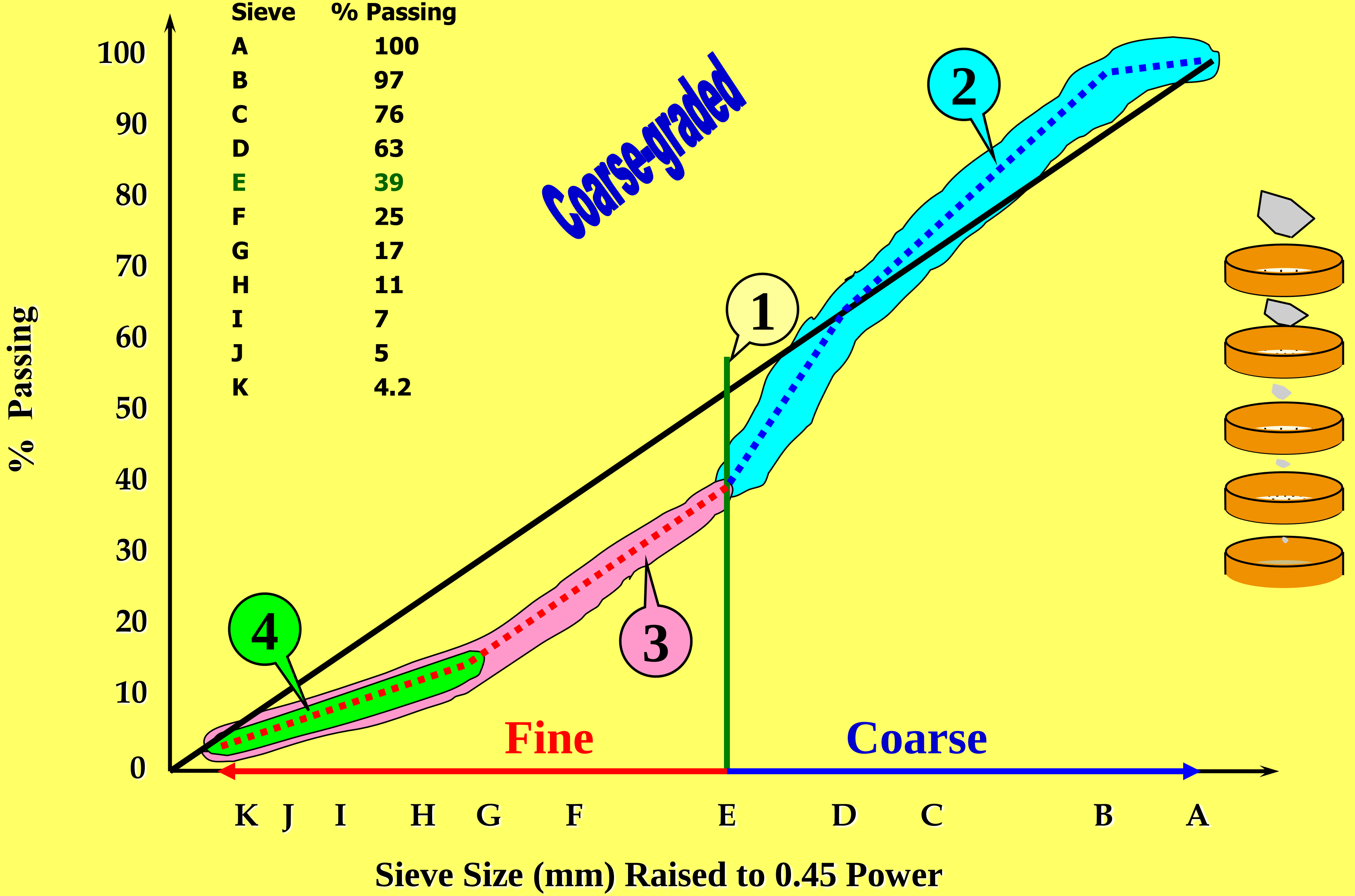
   Convert the Individual aggregate %'s from **VOLUME** to **weight**

# Combined Blend Evaluation

- Evaluation method depends on which **fraction** (**Coarse** or **Fine**) is in **control**:
  - **Coarse**-graded, **SMA**
  - **Fine**-graded

# Combined Blend Gradation

| Sieve | % Passing |
|---|---|
| A | 100 |
| B | 97 |
| C | 76 |
| D | 63 |
| E | 39 |
| F | 25 |
| G | 17 |
| H | 11 |
| I | 7 |
| J | 5 |
| K | 4.2 |



# Combined Blend Evaluation
# Coarse-Graded Mixes

**Coarse Fraction**

- Half Sieve = 0.5 x NMPS
- PCS = 0.22 x NMPS

**Fine Fraction**

- SCS = 0.22 x PCS
  - TCS = 0.22 x SCS

**1** CA CUW (% PCS)

**2** CA Ratio =

$$\frac{\%\ \text{Half Sieve} - \%\ \text{PCS}}{100 - \%\ \text{Half Sieve}}$$

**3** $FA_c$ Ratio =

$$\frac{\%\ \text{SCS}}{\%\ \text{PCS}}$$

**4** $FA_f$ Ratio =

$$\frac{\%\ \text{TCS}}{\%\ \text{SCS}}$$

# Combined Blend Evaluation

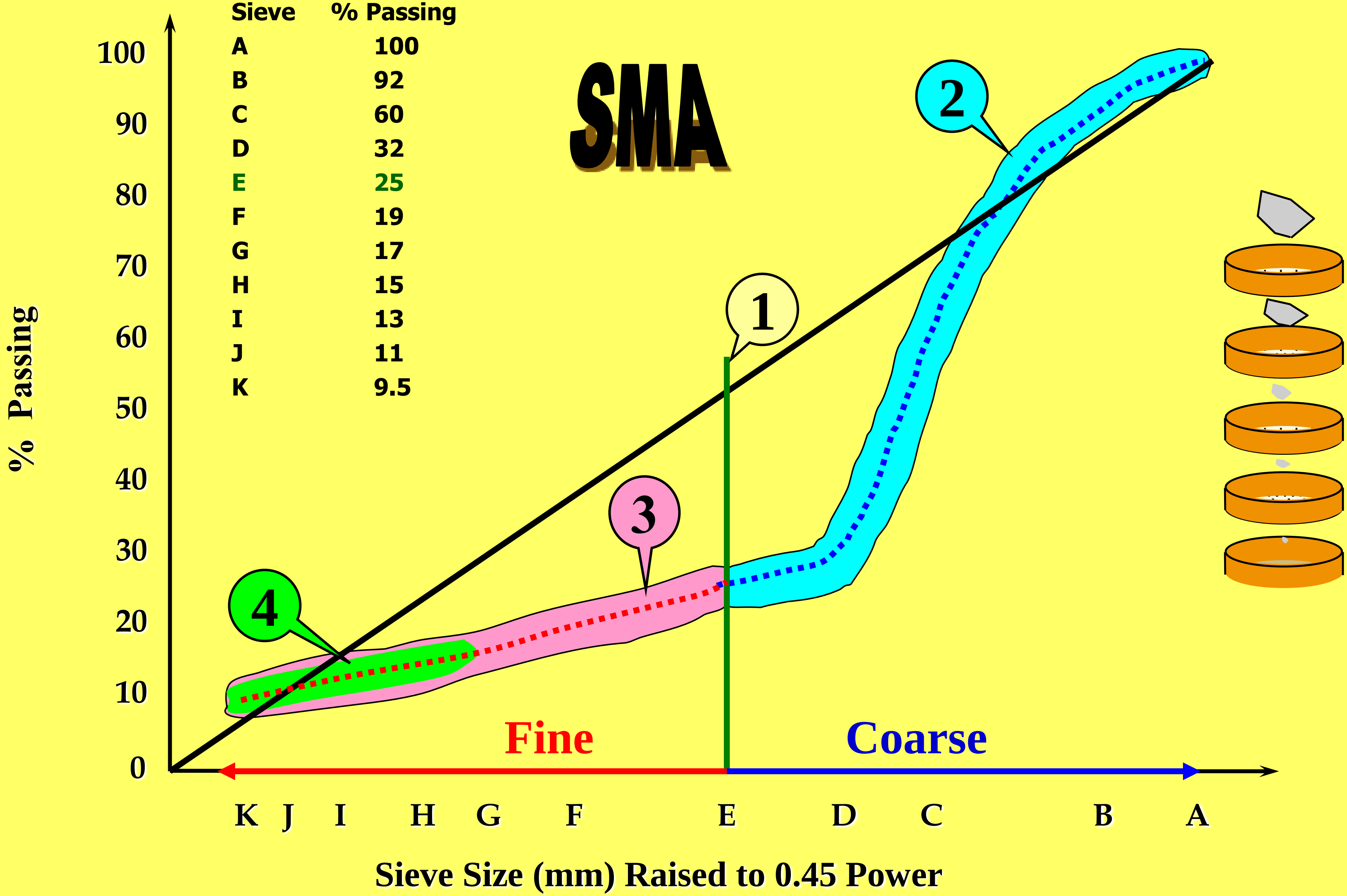
# **Coarse**-Graded Mixes

1. **CA CUW increase = VMA increase**
   - **4%** change in **PCS** ≅ **1%** change in **VMA or Voids**
   - **Range 3 - 5%**
2. **CA Ratio increase = VMA increase**
   - **0.20** change ≅ **1%** change in **VMA or Voids**
   - **Range 0.10 – 0.30**
3. **$FA_c$ Ratio increase = VMA decrease**
   - **0.05** change ≅ **1%** change in **VMA or Voids**
   - **Range 0.025 – 0.075**
4. **$FA_f$ Ratio increase = VMA decrease**
   - **0.05** change ≅ **1%** change in **VMA or Voids**
   - **Range 0.025 – 0.075**

**Has the most influence on VMA or Voids**

# Combined Blend Gradation

| Sieve | % Passing |
|---|---|
| A | 100 |
| B | 92 |
| C | 60 |
| D | 32 |
| E | 25 |
| F | 19 |
| G | 17 |
| H | 15 |
| I | 13 |
| J | 11 |
| K | 9.5 |



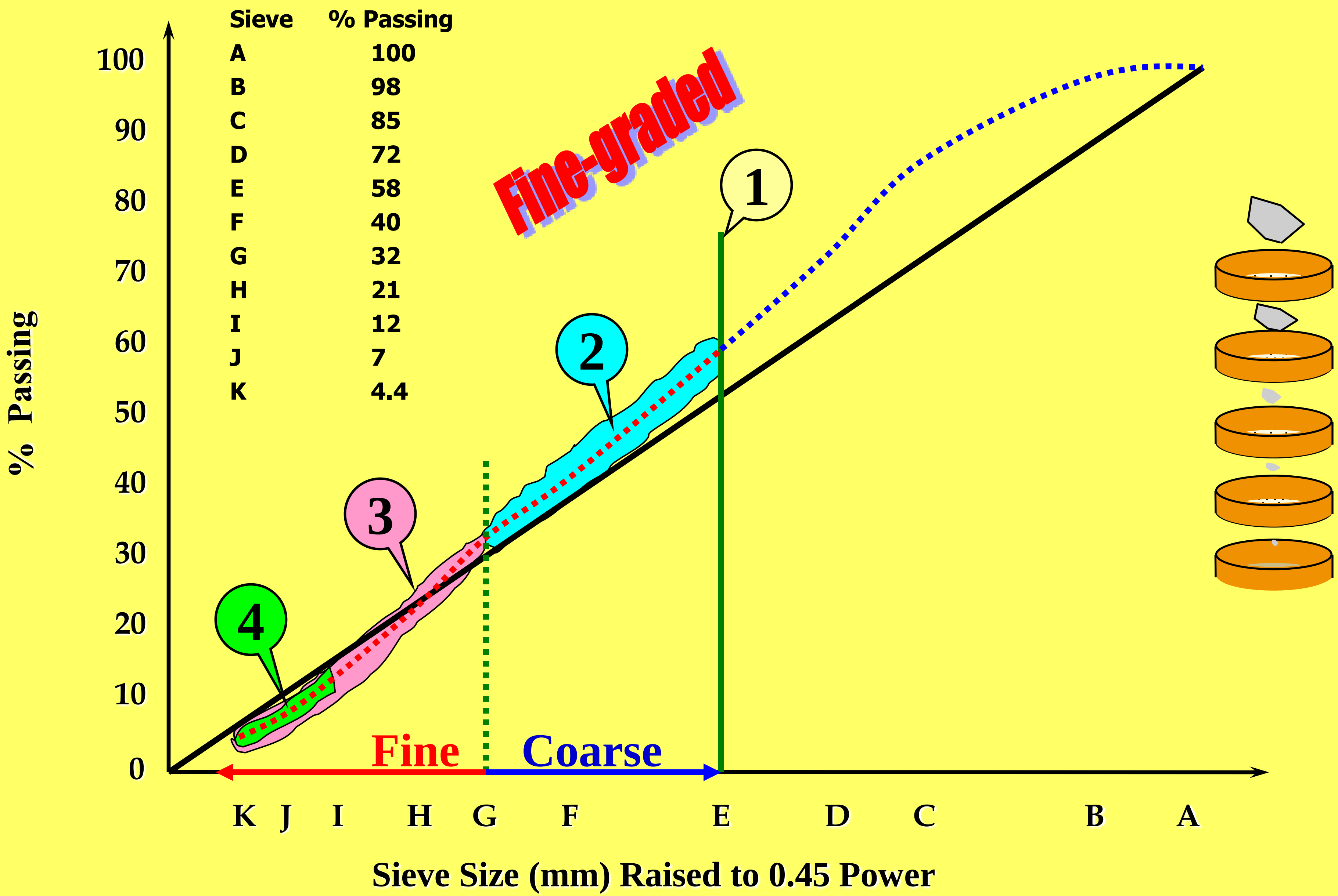
# Combined Blend Evaluation
# **SMA** Mixes

1. **CA CUW increase = VMA increase**
   - **2%** change in **PCS** ≅ **1%** change in **VMA or Voids**
   - **Range 1 - 3%**
2. **CA Ratio increase = VMA increase**
   - **0.20** change ≅ **1%** change in **VMA or Voids**
   - **Range 0.10 – 0.30**
3. **$FA_c$ Ratio increase = VMA decrease**
   - **0.10** change ≅ **1%** change in **VMA or Voids**
   - **Range 0.075 – 0.125**
4. **$FA_f$ Ratio increase = VMA decrease**
   - **0.10** change ≅ **1%** change in **VMA or Voids**
   - **Range 0.075 – 0.125**

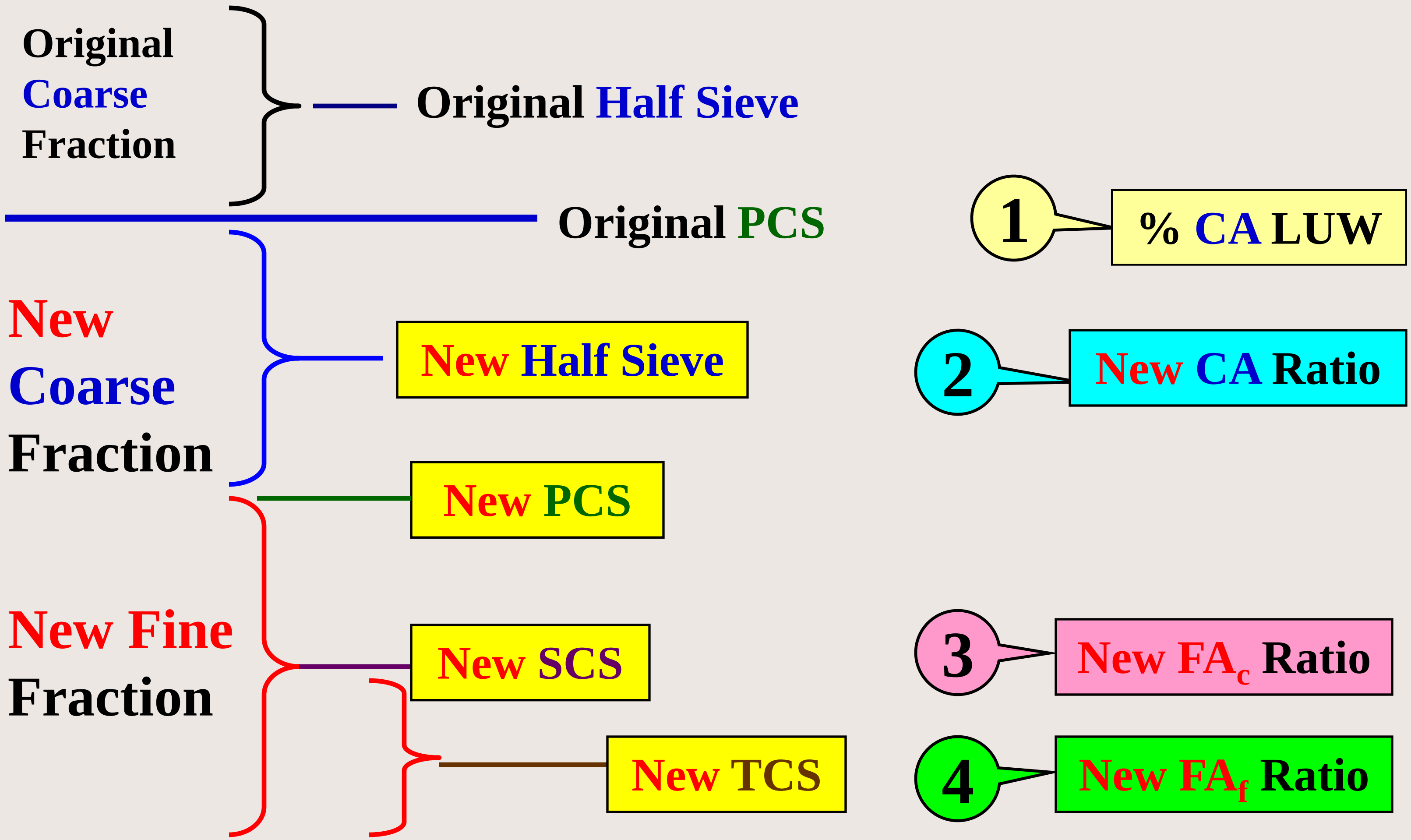
**Has the most influence on VMA or Voids**

**Has the $2^{nd}$ most influence on VMA or Voids**

# Combined Blend Gradation



# Combined Blend Evaluation
# Fine-Graded Mixes



# Combined Blend Evaluation
# Fine-Graded Mixes

1. **CA CUW decrease = VMA increase**
   - **6%** change **<u>ORIGINAL</u> PCS** ≅ **1%** change in **VMA or Voids**
   - **Range 5 - 7%**
2. **<u>New</u> CA Ratio increase = VMA increase**
   - **0.35** change ≅ **1%** change in VMA or Voids
   - **Range 0.25 – 0.45**
3. **<u>New</u> $FA_c$ Ratio increase = VMA decrease**
   - **0.05** change ≅ **1%** change in VMA or Voids
   - **Range 0.025 – 0.075**
4. **<u>New</u> $FA_f$ Ratio increase = VMA decrease**
   - **0.05** change ≅ **1%** change in VMA or Voids
   - **Range 0.025 – 0.075**

- **Old CA Ratio** <u>still</u> <u>relates</u> to **segregation** susceptibility

**Has the most influence on VMA or Voids**

# Estimating VMA or Voids
# **Coarse**-Graded Mix Example

| **Trial #1** (% Passing) | | | **Trial #2** (% Passing) | |
|---|---|---|---|---|
| **25.0mm** | **100.0** | | **25.0mm** | **100.0** |
| **19.0mm** | **97.4** | ← **NMPS** → | **19.0mm** | **98.0** |
| **12.5mm** | **76.2** | | **12.5mm** | **76.5** |
| **9.5mm** | **63.5** | ← **HALF** → | **9.5mm** | **63.6** |
| **4.75mm** | **38.2** | ← **PCS** → | **4.75mm** | **37.2** |
| **2.36mm** | **23.6** | | **2.36mm** | **22.1** |
| **1.18mm** | **18.8** | ← **SCS** → | **1.18mm** | **16.5** |
| **0.60mm** | **13.1** | | **0.60mm** | **11.8** |
| **0.30mm** | **7.4** | ← **TCS** → | **0.30mm** | **6.8** |
| **0.15mm** | **5.7** | | **0.15mm** | **5.2** |
| **0.075mm** | **4.0** | | **0.075mm** | **3.5** |

# Estimating VMA or Voids
# Trial #2 vs. Trial #1

- **PCS**
  37.2 – 38.2 = - 1.0
- **Increases** VMA or Voids
  1.0/4.0 = + 0.25%
- **CA** ratio
  0.725 – 0.693 = + 0.032
- **Increases** VMA or Voids
  0.032/0.2 = + 0.16%
- **FA$_c$** ratio
  0.444 – 0.492 = - 0.048
- **Increases** VMA or Voids
  0.048/0.05 = + 0.96%
- **FA$_f$** ratio
  0.412 – 0.394 = + 0.018
- **Decreases** VMA or Voids
  0.018/0.05 = - 0.36%
- Total Estimated Change:
  - **Plus ~ 1.0% VMA**

| Sample | Mix Design | 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|
| Identification | | | | | Proposed |
| 19.0mm | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 |
| 12.5mm | 98.8 | 95.9 | 95.7 | 98.9 | 97.5 |
| 9.5mm | 71.2 | 71.0 | 68.4 | 70.7 | 70.7 |
| 6.25mm | 40.1 | 40.6 | 39.4 | 39.4 | 39.8 |
| 4.75mm | 25.7 | 26.6 | 26.0 | 24.9 | 25.6 |
| 2.36mm | 21.7 | 21.2 | 20.7 | 20.4 | 22.0 |
| 1.18mm | 17.4 | 16.9 | 16.5 | 16.0 | 17.4 |
| 0.600mm | 14.8 | 14.1 | 14.0 | 13.1 | 14.6 |
| 0.300mm | 13.1 | 12.1 | 11.7 | 11.1 | 12.7 |
| 0.150mm | 10.9 | 10.0 | 9.5 | 9.3 | 10.6 |
| 0.075mm | 9.2 | 7.8 | 8.2 | 7.4 | 8.3 |
| % AC | 5.70 | 5.86 | 5.65 | 5.72 | 5.72 |
| % AC Absptn | 0.41 | 0.61 | 0.23 | 0.46 | 0.46 |
| Actual VMA | 17.9 | 18.5 | 17.6 | 18.7 | |
| Actual Voids | 4.0 | 4.8 | 3.4 | 4.9 | |
| CA | 0.307 | 0.327 | 0.308 | 0.313 | 0.297 |
| FAc | 0.682 | 0.665 | 0.676 | 0.642 | 0.664 |
| FAf | 0.736 | 0.709 | 0.679 | 0.710 | 0.726 |
| PCS | Compares Each Sample to the Mix Design | 0.17 | 0.33 | 0.43 | -0.10 |
| CA | | 0.20 | 0.01 | 0.06 | -0.10 |
| FAc | | 0.23 | 0.08 | 0.53 | 0.24 |
| FAf | | -0.36 | -0.76 | -0.35 | -0.13 |
| Total | | 0.23 | -0.34 | 0.68 | -0.09 |
| Est VMA | | 18.1 | 17.6 | 18.6 | 17.8 |
| Act VMA | | 18.5 | 17.6 | 18.7 | 0.0 |
| Diff in VMA | | -0.4 | 0.0 | -0.1 | 17.8 |
| Est Voids | | 4.3 | 3.3 | 4.8 | 4.0 |
| Act Voids | | 4.8 | 3.4 | 4.9 | 0.0 |
| Diff in Voids | | -0.5 | -0.1 | -0.1 | 4.0 |
| PCS | Compares Each Sample to the Previous Sample | 0.17 | 0.17 | 0.10 | -0.53 |
| CA | | 0.20 | -0.19 | 0.05 | -0.16 |
| FAc | | 0.23 | -0.15 | 0.45 | -0.29 |
| FAf | | -0.36 | -0.40 | 0.41 | 0.21 |
| Total | | 0.23 | -0.57 | 1.02 | -0.77 |
| Est VMA | | 18.1 | 17.9 | 18.6 | 17.9 |
| Act VMA | | 18.5 | 17.6 | 18.7 | 0.0 |
| Diff in VMA | | -0.4 | 0.3 | -0.1 | 17.9 |
| Est Voids | | 4.3 | 3.8 | 4.8 | 4.1 |
| Act Voids | | 4.8 | 3.4 | 4.9 | 0.0 |
| Diff in Voids | | -0.5 | 0.4 | -0.1 | 4.1 |

# The Four Main Principles

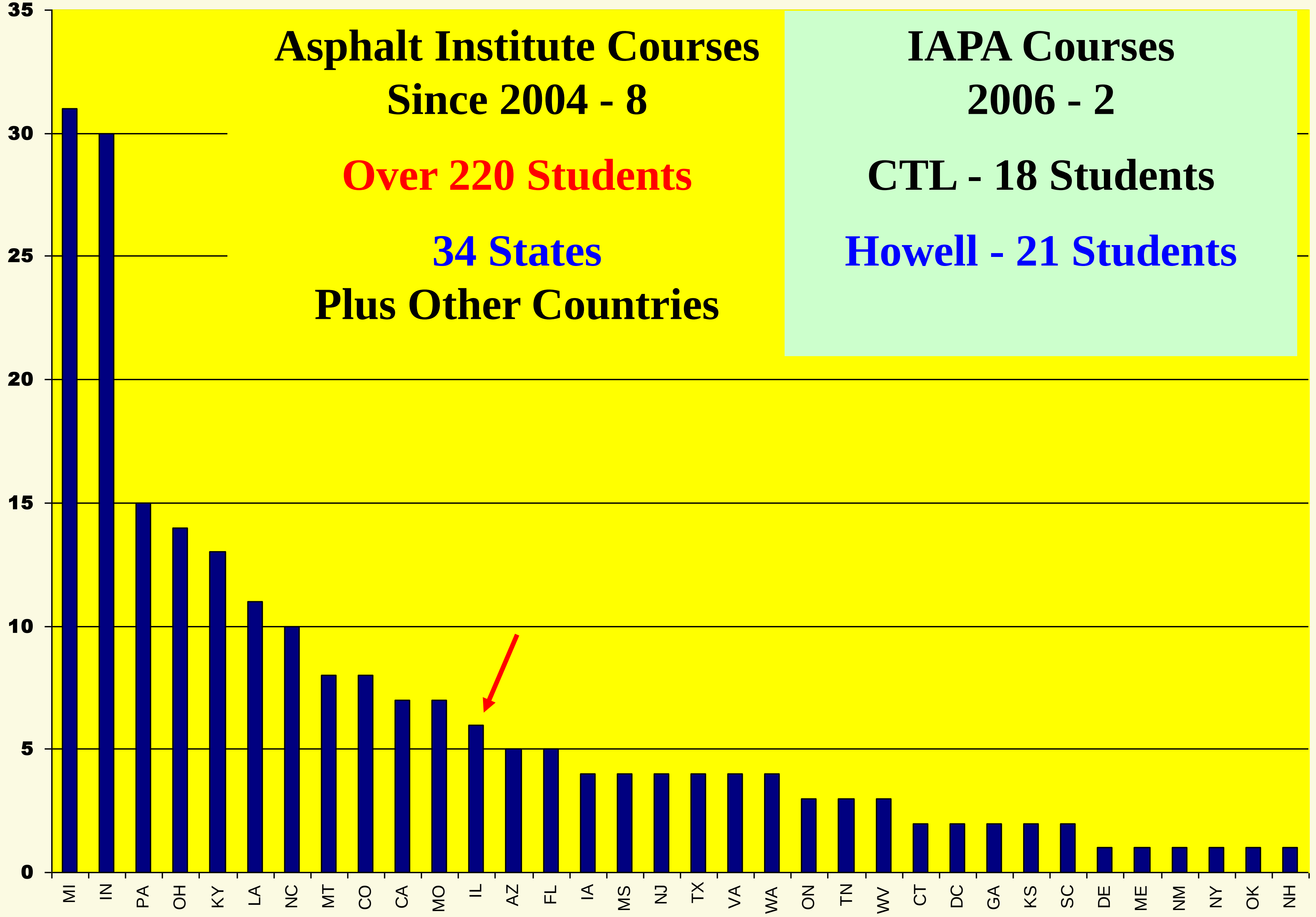
1. **% PCS** (**Volume** of **CA**)
   - **Increase/decrease** in VMA depends on mix **type**
2. **CA ratio** (Control with **CA Volume** blend)
   - **Low** values can be susceptible to **segregation**
   - **High** values can be difficult to **compact**
   - **As it increases, VMA increases**
3. **$FA_c$ ratio** (Control with **FA Volume** blend)
   - **As it increases, VMA decreases**
4. **$FA_f$ ratio** (Control with % minus 0.075mm)
   - **As it increases, VMA decreases**

# So How Does the Method ***Help***?

- In Developing **New** Blends:
  - Field Compactability
  - Segregation Susceptibility
- In Evaluating **Existing** Blends:
  - What’s worked and what hasn’t?
  - More clearly define principle ranges
- In **Estimating** VMA/Void changes:
  - Between Design trials
  - Between QC and/or QA samples
- **Saves Time and Reduces Risk!**

**It's a TOOL!**

**Not a SPEC!**



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# Questions or Comments?

**Thank You!**

**Bill Pine**

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