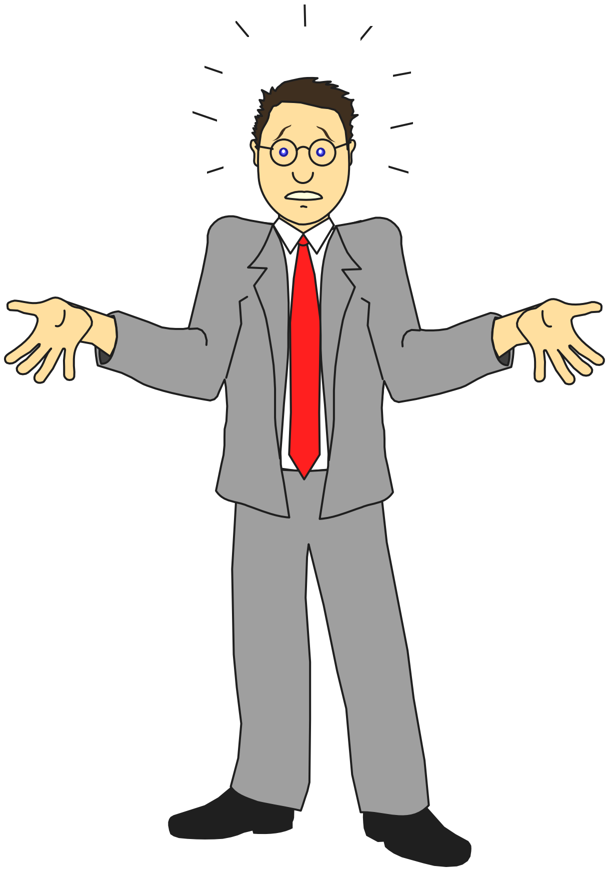
The Bailey Method

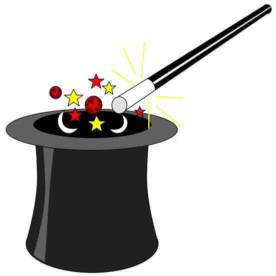
Achieving Volumetrics and HMA Compactability

Aggregate Blending
Where do you start?



- Trial and ***Error***?
  - Specification Bands
    - Coarse
    - Medium
    - Fine
  - Which blend is **best**?
  - How will it work in the field during placement?
  - How will it perform?
- Is there a more ***systematical*** way to find a starting point?

Aggregate Blending
The Bailey Method



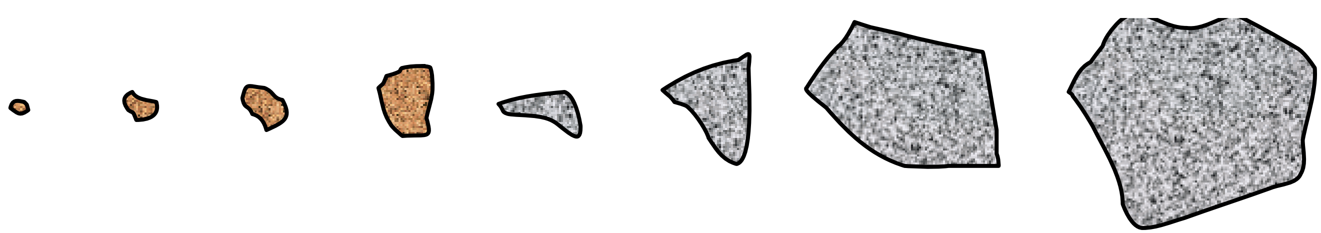
- Originally developed by Robert D. Bailey (Illinois Department of Transportation)
- Focus is Aggregate **packing!**
- Determine “**Coarse**” and “**Fine**”
- Evaluate individual agg’s **and** combined blend by **VOLUME** as well as by **weight**

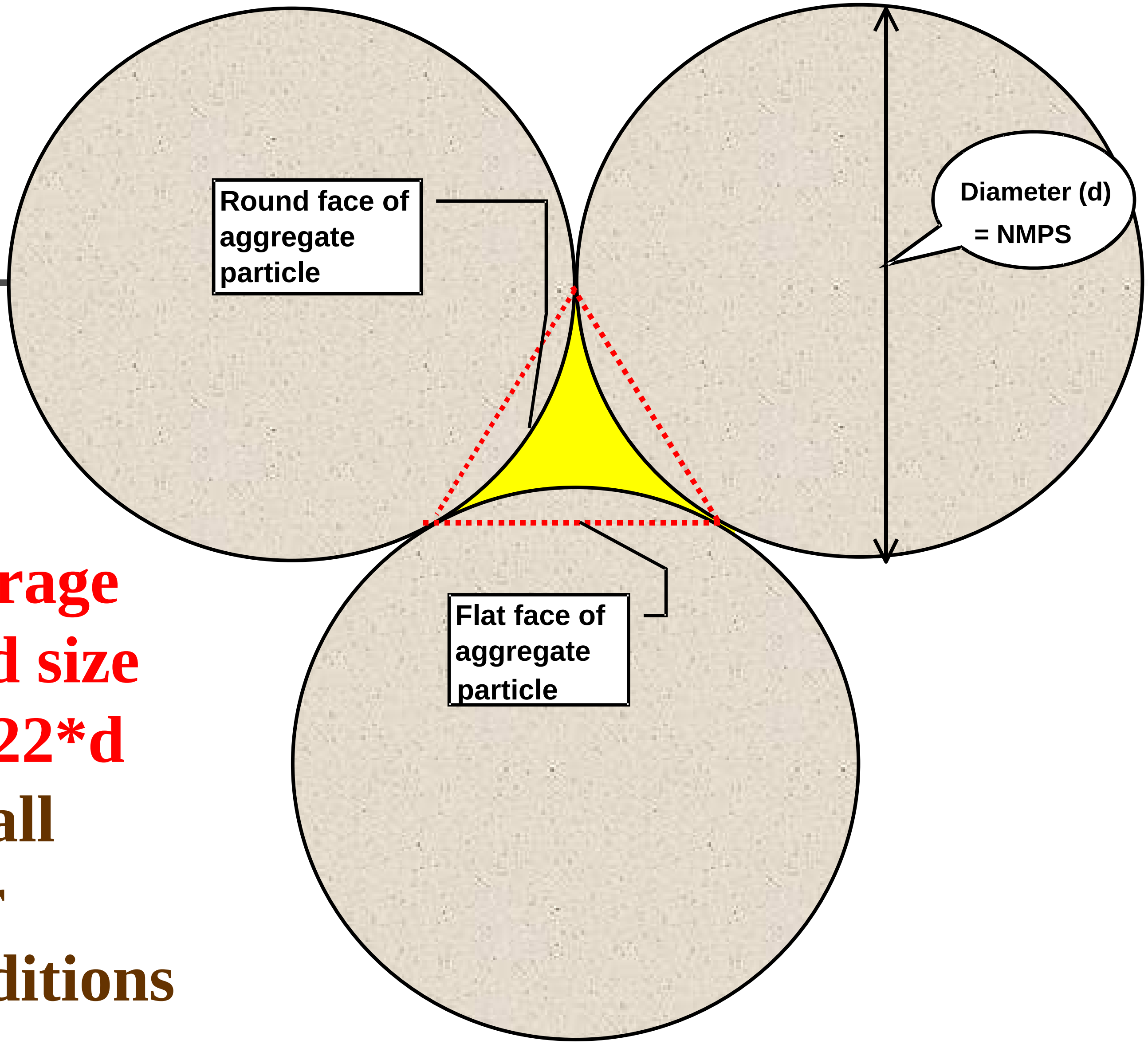
Aggregate Packing
What Influences the Results?

- **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**
  - degradation or lack thereof

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)**





Average Void size = 0.22*d for all four conditions

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**

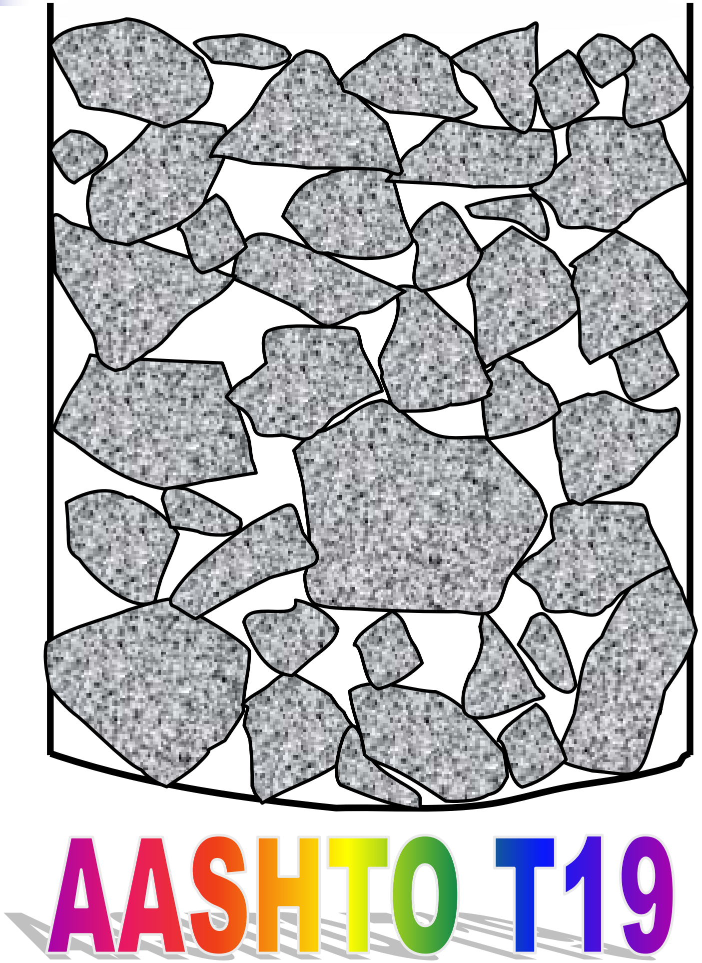
- Why?
  - Better understand **aggregate packing**
  - Control **VOLUME** of **Coarse** and **Fine** for Mix "**Type**"
- How?
  - Test the **individual** **Coarse** and **Fine** aggregates

Fine-graded

Coarse-graded

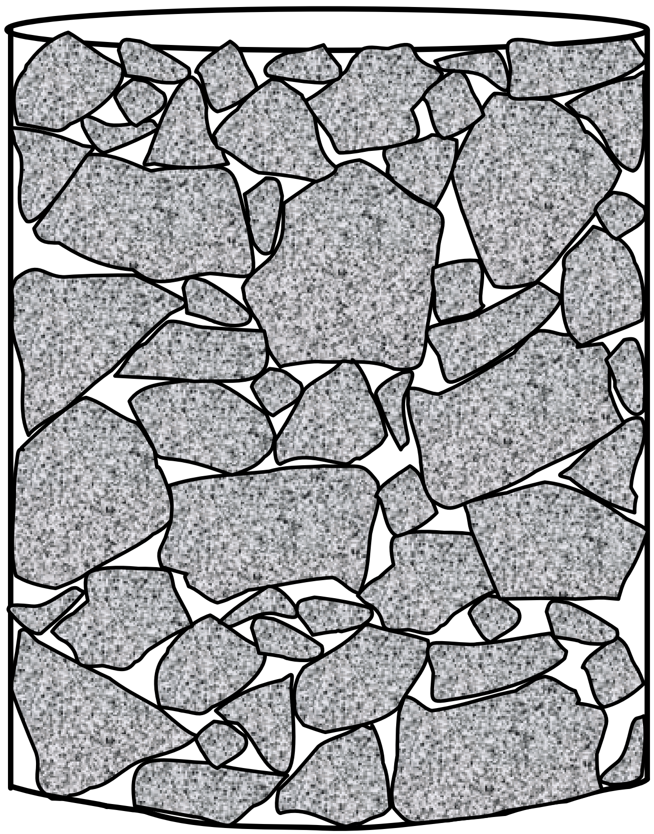
SMA

Loose Unit Weight - CA



- **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

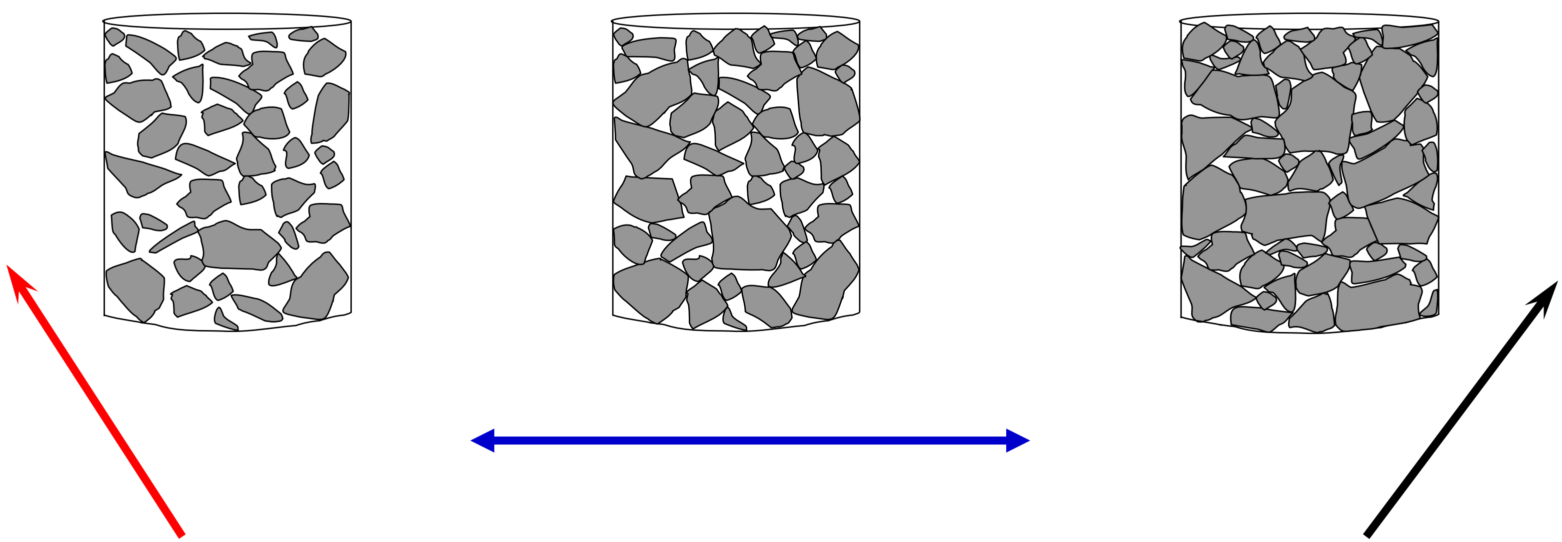


AASHTO T19

- **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**

Chosen Unit Weight - CA(s)

< LUW | LUW | RUW

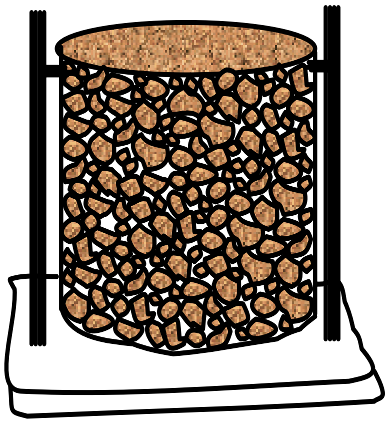


Fine-Graded | Coarse-Graded | SMA

< 90% | 95-105% | 110-125%

*C*hosen Unit Weight - FA(s)

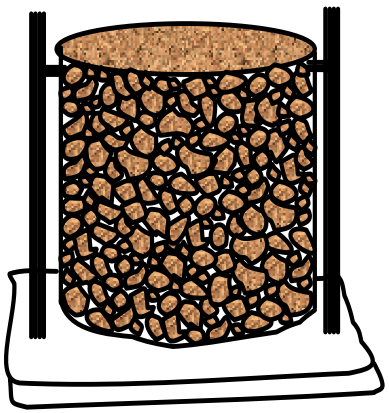
100%
LUW



SMA

FA CUW
"SET"
According To
Mix Type

100%
RUW



Dense-graded

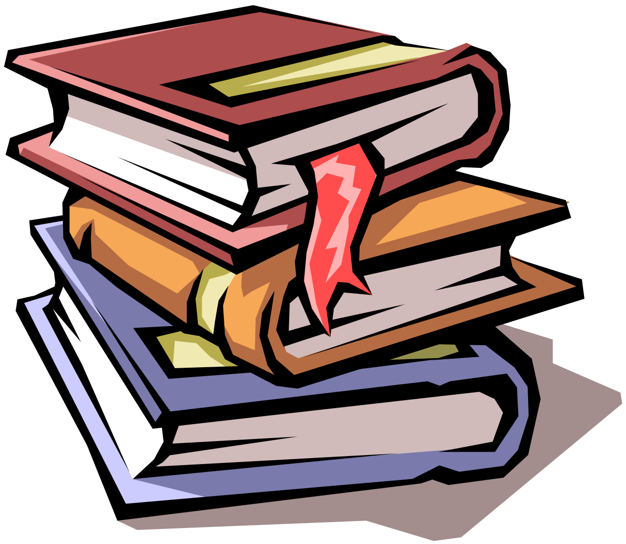
Developing the Combined Blend

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

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

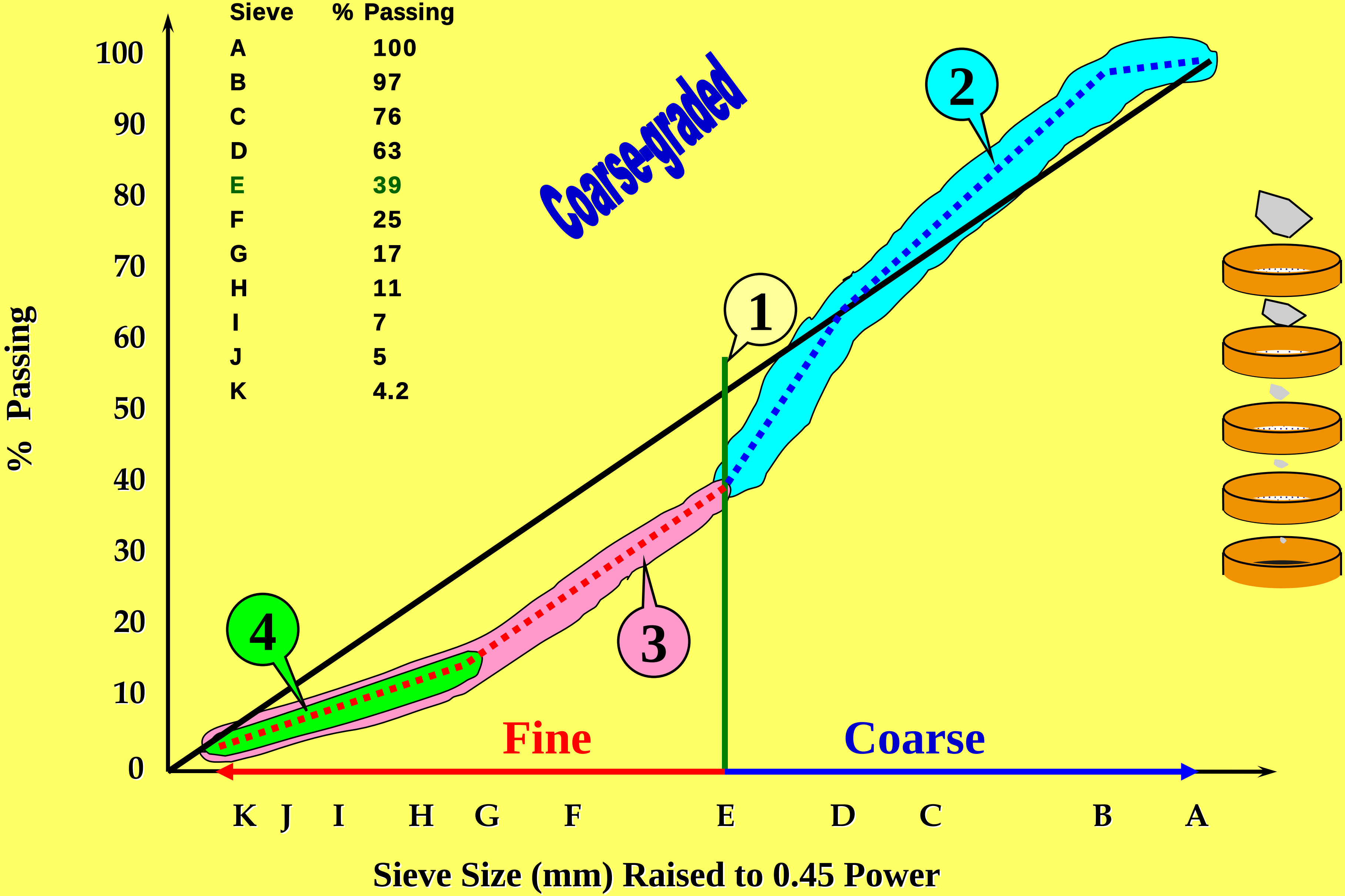
Combined Blend Evaluation

- 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 =**

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

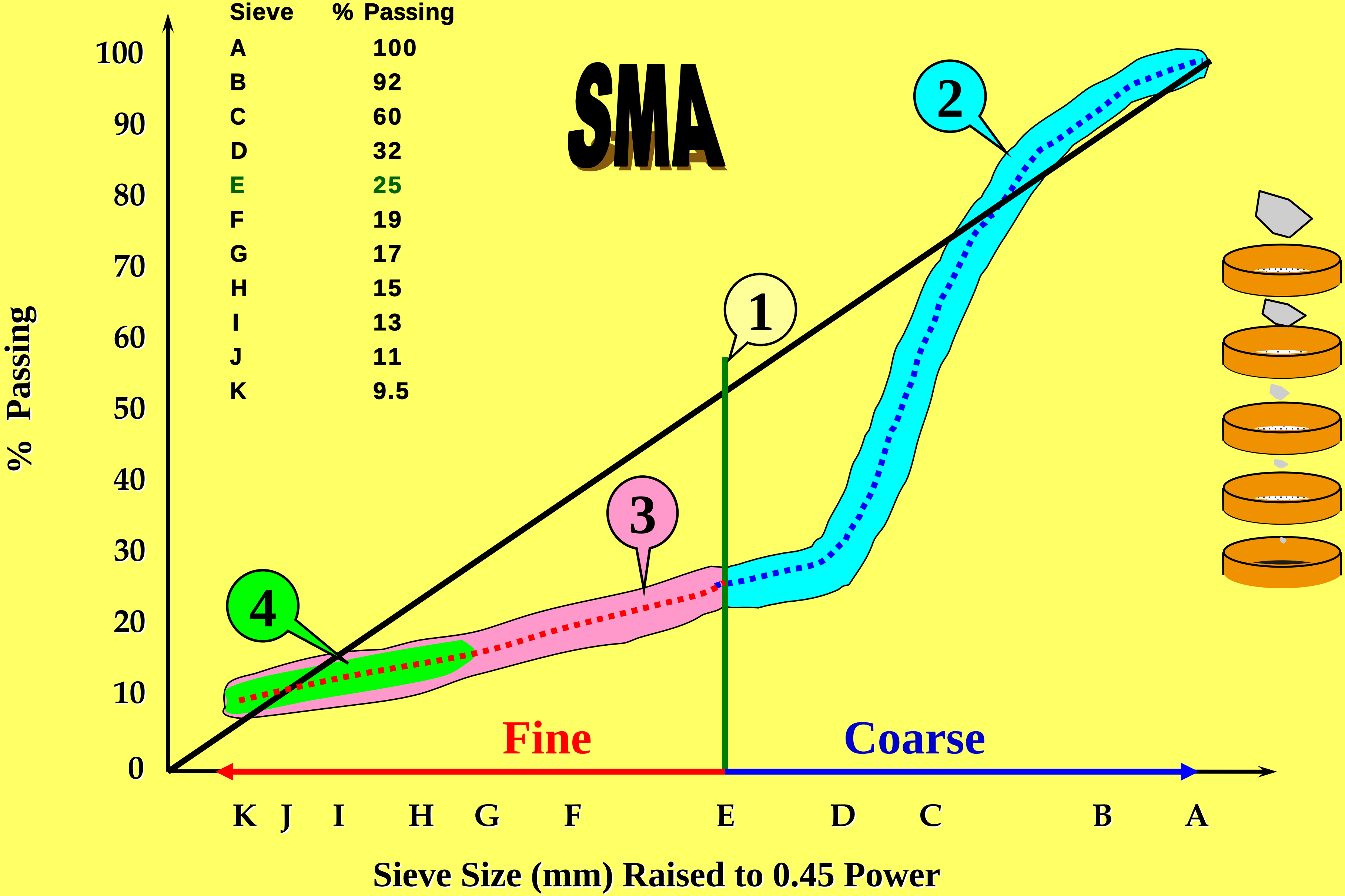
Combined Blend Evaluation
Coarse-Graded Mixes

1. **CA CUW increase = VMA increase**
   - **4%** change in **PCS** ≅ **1%** change in **VMA or Voids**
2. **CA Ratio increase = VMA increase**
   - **0.20** change ≅ **1%** change in **VMA or Voids**
3. **FA_c Ratio increase = VMA decrease**
   - **0.05** change ≅ **1%** change in **VMA or Voids**
4. **FA_f Ratio increase = VMA decrease**
   - **0.05** change ≅ **1%** change in **VMA or Voids**

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

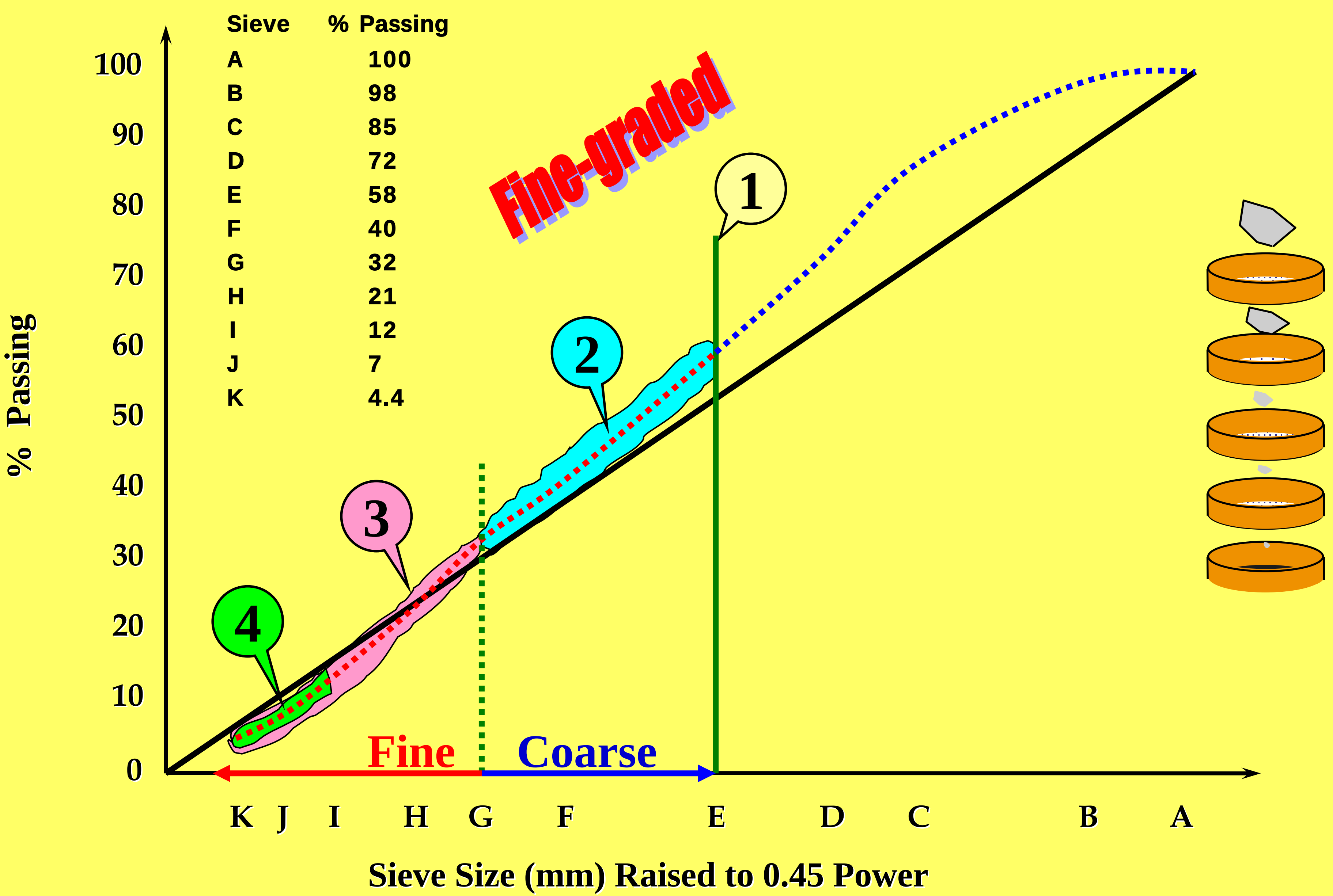
SMA Mixes

Has the most influence on VMA or Voids

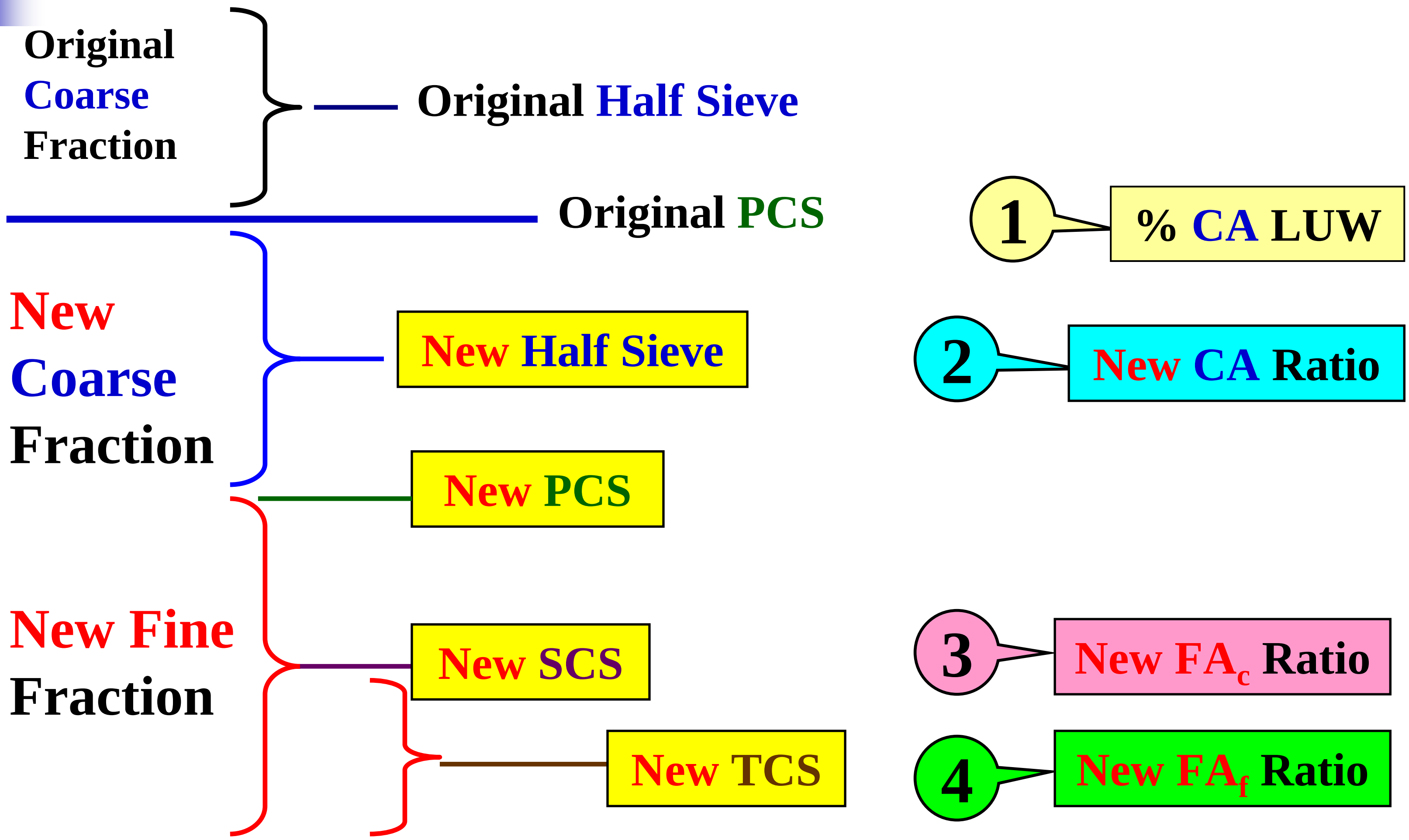
1. **CA CUW increase = VMA increase**
   - **2%** change in **PCS** ≅ **1%** change in **VMA or Voids**
2. **CA Ratio increase = VMA increase**
   - **0.20** change ≅ **1%** change in **VMA or Voids**
3. **FA_c Ratio increase = VMA decrease**
   - **0.10** change ≅ **1%** change in **VMA or Voids**
4.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

Has the 2nd 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 **original** **PCS** ≅ **1%** change in **VMA or Voids**
2. **New CA Ratio increase = VMA increase**
   - **0.35** change ≅ **1%** change in VMA or Voids
3. **New FA_c Ratio increase = VMA decrease**
   - **0.05** change ≅ **1%** change in VMA or Voids
4. **New FA_f Ratio increase = VMA decrease**
   - **0.05** change ≅ **1%** change in VMA or Voids

Has the most influence on VMA or Voids

- **Old CA Ratio** still relates to **segregation** susceptibility

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

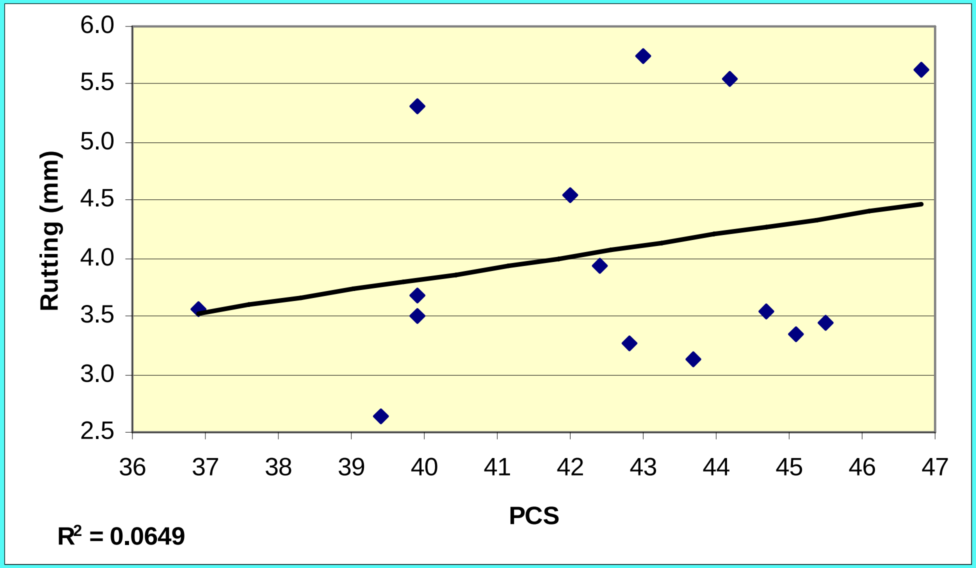
- **PCS**
  37.2% - 38.2% = **-** 1.0%
- **CA** ratio
  0.725 – 0.693 = **+** 0.032
- **FA_c** ratio
  0.444 – 0.492 = **-** 0.048
- **FA_f** ratio
  0.412 – 0.394 = **+** 0.018

- **Increases** VMA or Voids
  - 1.0/4.0 = **+** 0.25%
- **Increases** VMA or Voids
  - 0.032/0.2 = **+** 0.16%
- **Increases** VMA or Voids
  - 0.048/0.05 = **+** 0.96%
- **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

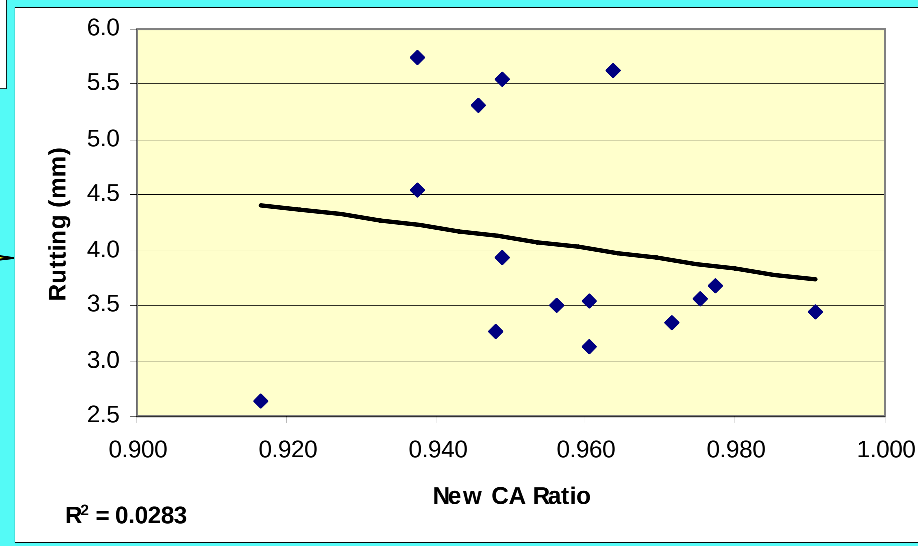
Predicting Performance

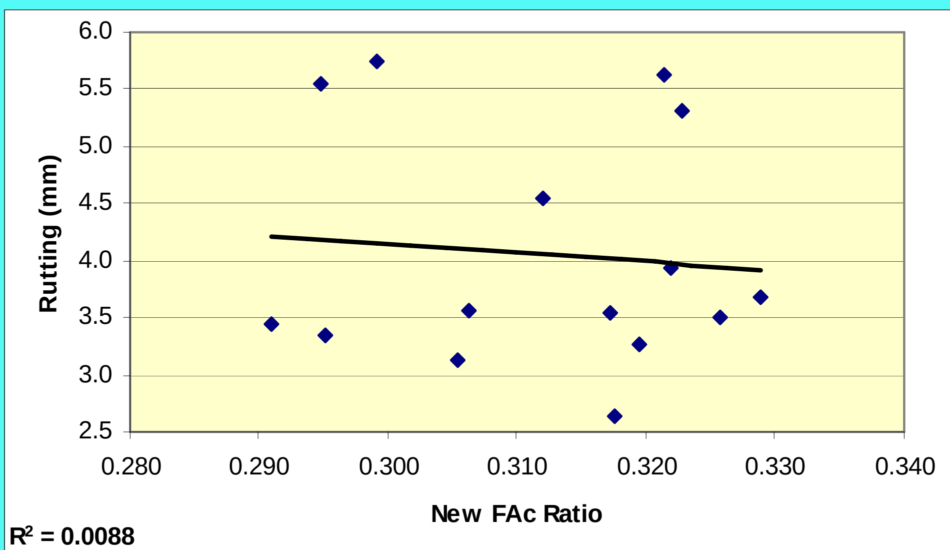
- We can relate to volumetric changes well
- We can relate blend gradations and the four main principles to compactibility and segregation
- But…….performance includes much more!



Rutting vs. PCS

Rutting vs. New CA Ratio

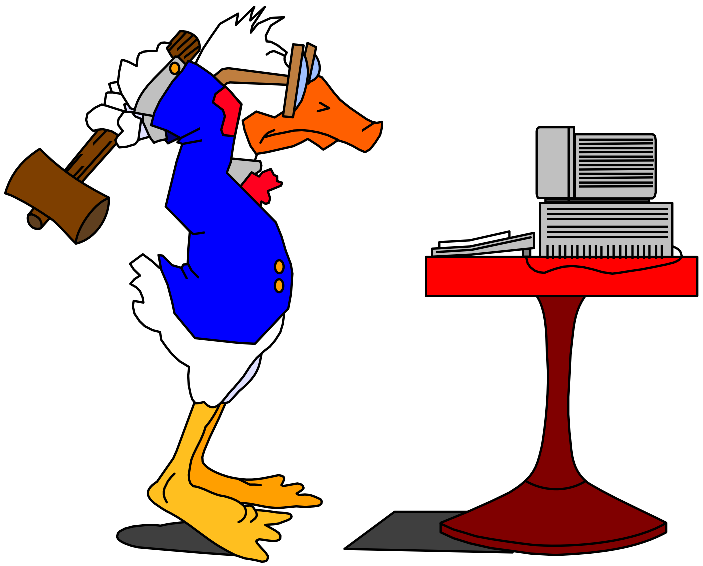




Rutting vs. New FA_c Ratio

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

- In Developing **New** Blends:
  - Field Compactibility
  - 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
  - QC samples
  - **Saves Time and Reduces Risk!**



Questions or Comments?

Thank You!