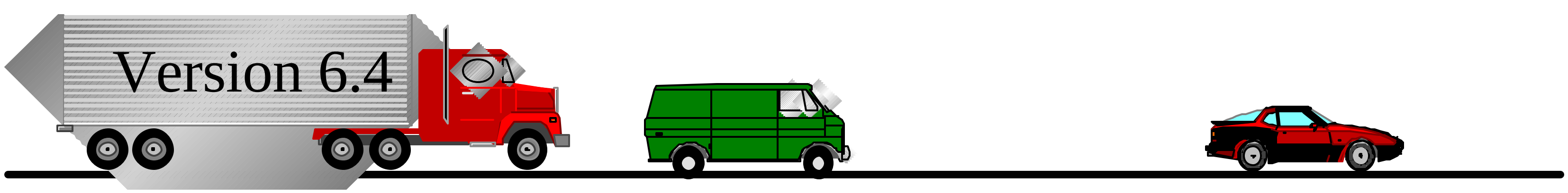
Superpave
Asphalt Mixture Design

Workshop

Federal Highway Administration



This Workshop & Workbook developed by

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Foreword

- The focus of this workshop is to provide a detailed example of Superpave *volumetric* asphalt mixture design

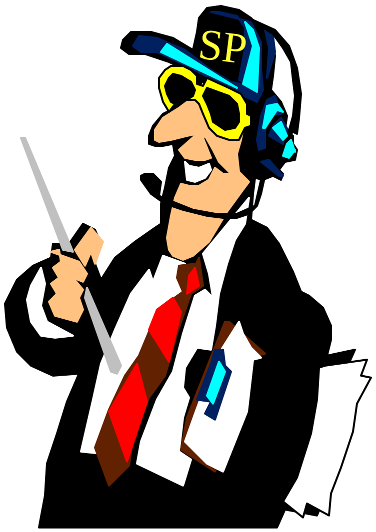
Superpave Overview

- The final product of the SHRP asphalt program area is Superpave. Superpave is an acronym which stands for:

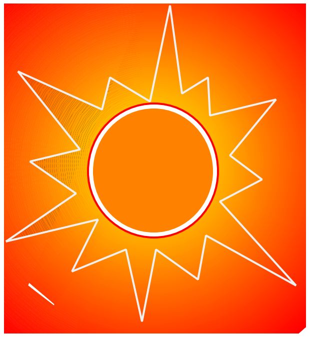
Superior **Per**forming Asphalt **Pave**ments

Major Steps in Superpave

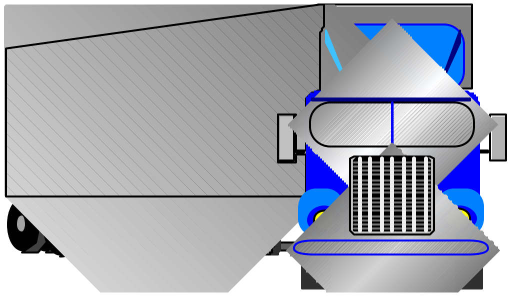
- Selection of Materials,
- Selection of a Design Aggregate Structure,
- Selection of the Design Binder Content,and
- Evaluation of Moisture Sensitivity of the Design Mixture.



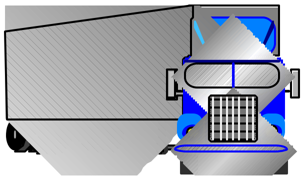
Criteria



- Environment,
- Traffic level & speed, and
- Pavement structure.



SIMUALTION BACKGROUND

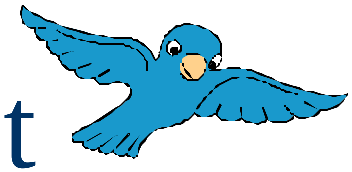


- Location: Hot Mix, USA
- Estimated, 20-year, design traffic is 6,300,000 ESAL's
- Posted traffic speed is 80 kph *(50 mph)*
  - Estimated, ave speed is 72 kph *(45 mph)*
- 19.0 mm Surface Course
  - Such that the top of the pavement layer from the surface is less than 100 mm.

Update:

- All Superpave mixes are designed volumetrically.
- Currently under NCHRP study 9-19, *“Superpave Models Development,”* being conducted under the direction of Dr. Matt Witczak, a simple performance test is being identified/ developed.

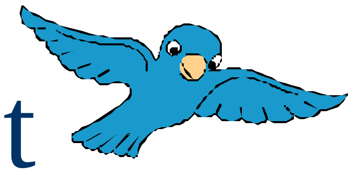
A simple performance test



- Superpave mix design is volumetrically based.
  - Does not include a “strength test”

- NCHRP 9-19, “Superpave Support and Performance Models Program”
  - Dr. Matt Witczak (Arizona State University)
  - Dr. Ed Harrigan (NCHRP)
  - http://www2.nas.edu/trbcrp/

A simple performance test

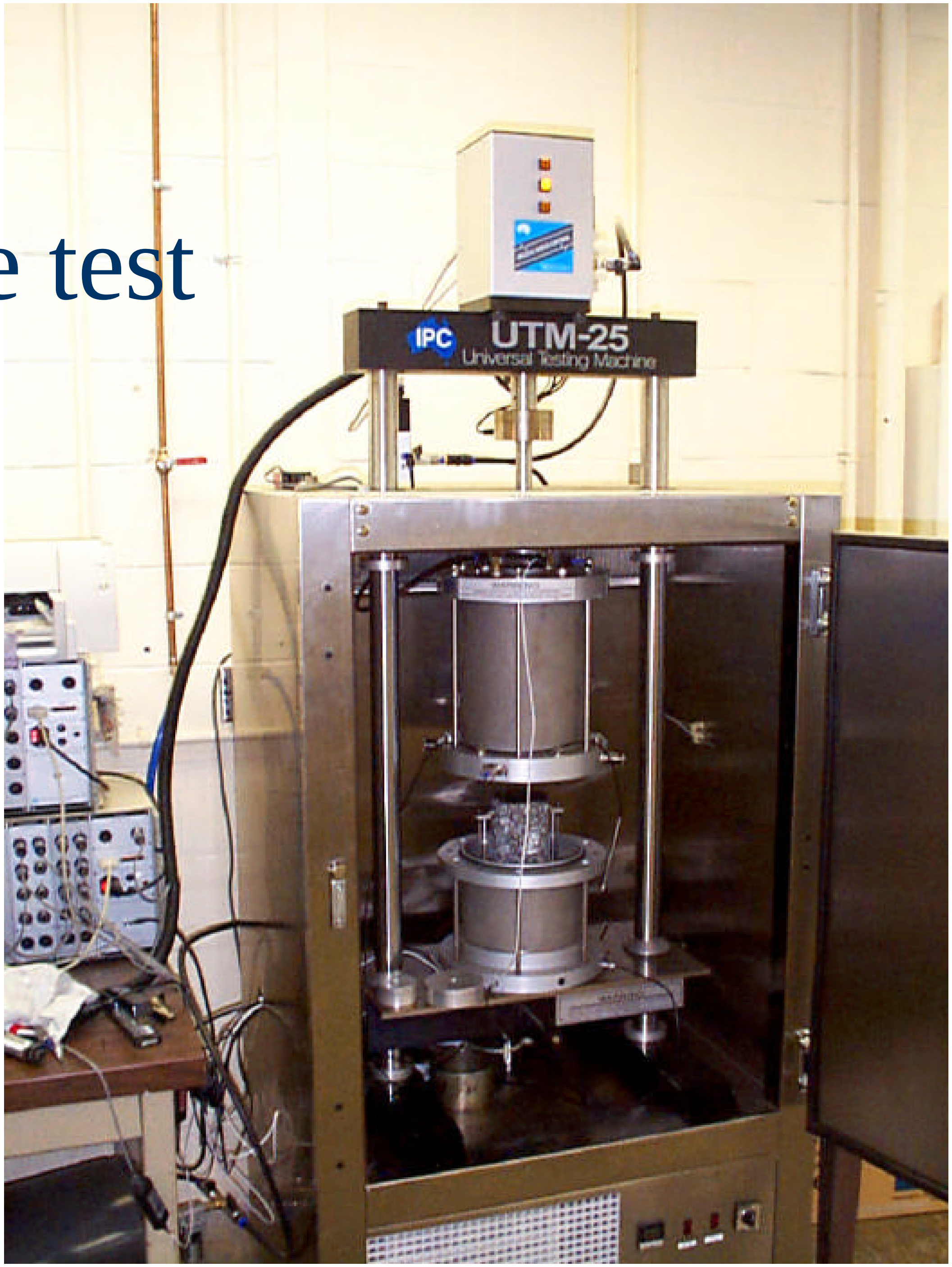


- Objective:
- To evaluate and recommend a fundamentally based, but simple, performance test(s) in support of the Superpave volumetric mix design procedure.

Spring 2000

A simple performance test

- Flow Time
- E*, G*



Selection of Materials

Performance Grade Binder

Mineral Aggregate

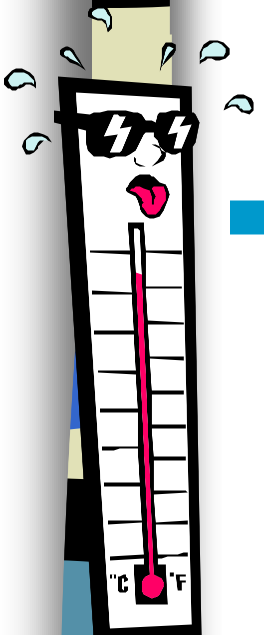
Modifiers / Additives

Selection of Materials

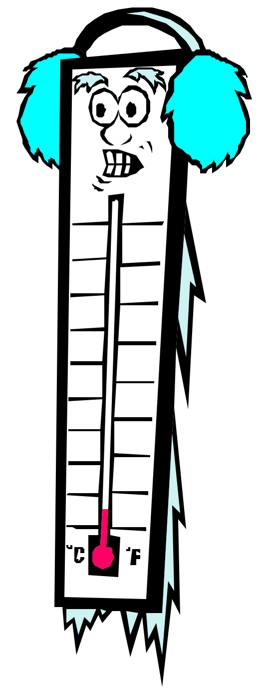
- The PG binder required for the project is based on environmental data, traffic level, and traffic speed.

- The SHRP researchers developed algorithms to convert high and low air temperatures to pavement temperatures.

SHRP Temperature Models



- $T_{(pav)} = (T_{(air)} - 0.00618\ Lat^2 + 0.2289\ Lat + 42.4)\ 0.9545 - 17.78$
  - where T(pav) is the high pavement temp at 20 mm below the surface, °C
- $T_{(d)} = T_{(air)} + 0.051\ d - 0.000063\ d^2$
  - where $T_{(d)}$ is low pavement temp at a depth, d, in mm, °C

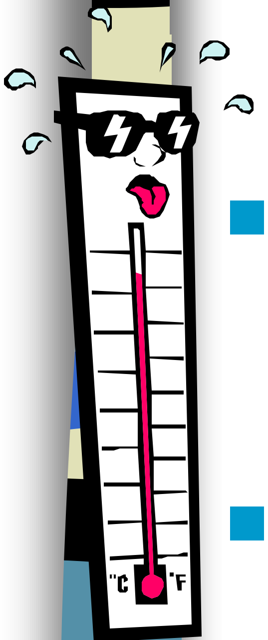


Binder ETG & Lead States

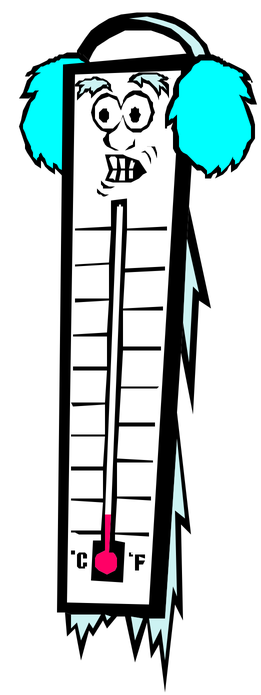
- The original SHRP low temp algorithm **do not** correctly determine the low-pavement-temperature. The FHWA LTPP program has developed a new algorithm based on over 30 weather stations from across North America.

- The Binder ETG feels the new LTPP algorithm is far more accurate and should be used in all AASHTO documents.

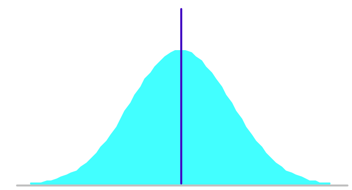
LTPP Temperature Models



- High, $T_{(pav)} = 54.32 + 0.78\ T_{(air)} - 0.0025 Lat^2 - 15.14 \log_{10}(H+25) + z(9 + 0.61 \sigma_{air}^2)^{1/2}$
- Low, $T_{(pav)} = -1.56 + 0.72\ T_{(air)} - 0.004\ Lat^2 + 6.26 \log_{10}(H+25) - z\ (4.4 + 0.52 \sigma_{air}^2)^{1/2}$
- with Reliability



Reliability

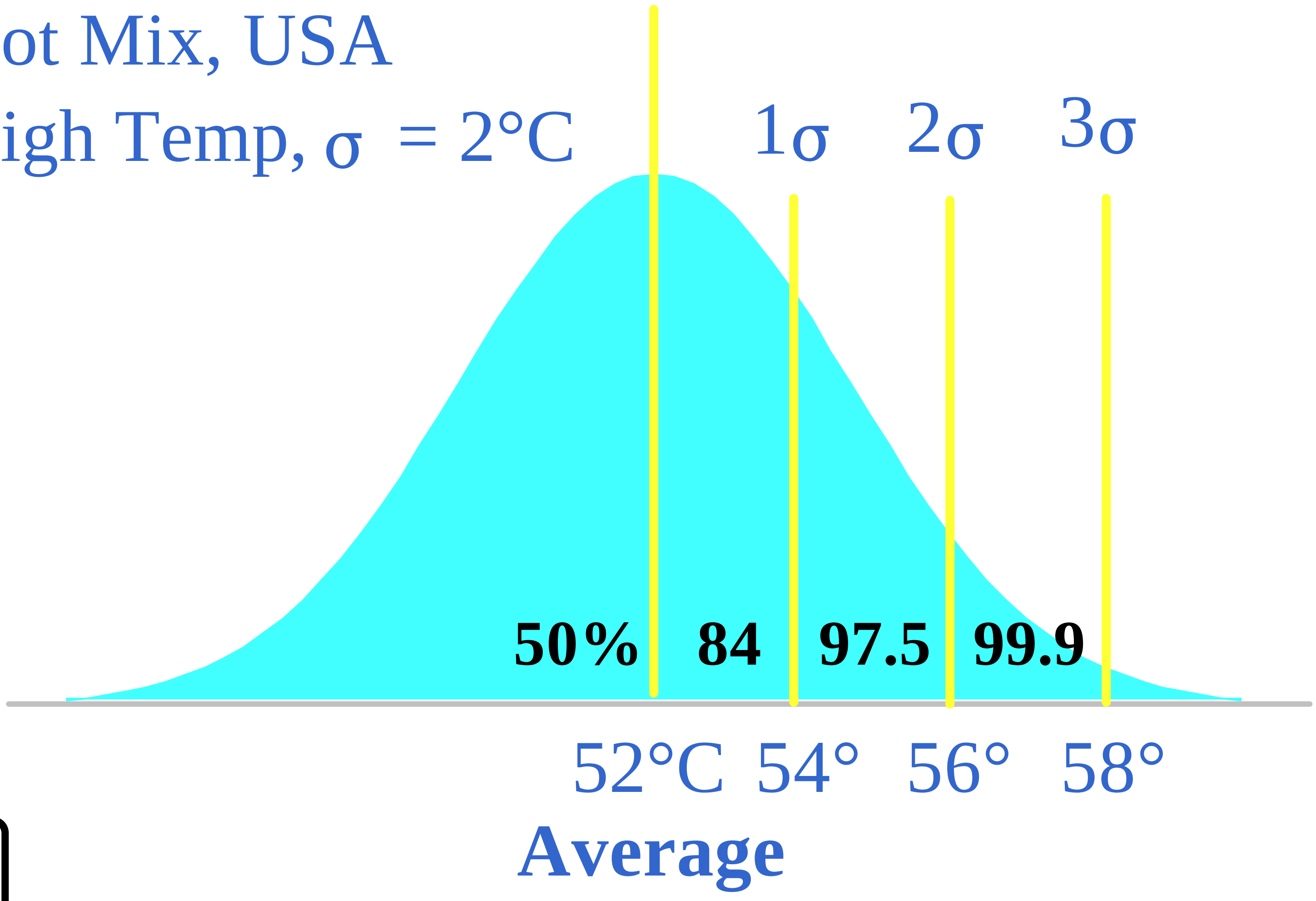


- A factor of safety can be incorporated into the performance grading system based on temperature reliability. The 50 % reliability temperatures represent the straight average of the weather data. The 98 % reliability temperatures are determined based on the standard deviations of the low ($\sigma_{\text{Low Temp}}$) and high ($\sigma_{\text{High Temp}}$) temperature data.

Reliability

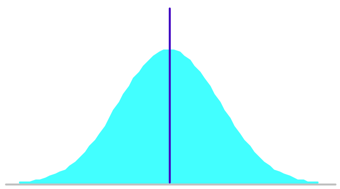
Hot Mix, USA

High Temp, σ = 2°C



Reliability

- $T_{\text{max at 98\%}} = T_{\text{max at 50\%}} + 2 * \sigma_{\text{High Temp}}$
- $T_{\text{min at 98\%}} = T_{\text{min at 50\%}} - 2 * \sigma_{\text{Low Temp}}$



PG “Grade Bumping”

- Traffic level and speed are also considered in selecting the project PG binder either through reliability or “grade bumping.” A table is provided in AASHTO MP-2 to provide guidance on grade selection.

- This table was developed by the Superpave Lead States.

Grade Bumping

Traffic ESAL's	Adjustment to Binder PG Grade		
	Standing	Slow	Standard
< 0.3	-	-	-
0.3 to < 3	2	1	-
3 to < 10	2	1	-
10 to < 30	2	1	-
≥ 30	2	1	1

Author’s Note

- Use either reliability or the table to address high traffic levels and slower speeds. Both methods can effectively “bump” the PG grade such that the appropriate binder is used.

- However, using them together will result in an unnecessarily stiff binder, which may cause problems during production and lay down.

PG grade Increments

Average 7-day Maximum Pavement Temperature						
46	**52**	**58**	**64**	**70**	**76**	**?**
Average 1-day Minimum Pavement Temperature						
+2	**-4**	**-10**	**-16**	**-22**	**-28**	**?**

Hot Mix, USA

Project Location & Historical Temperature Data

A. Latitude is 41.1 degrees,
B. 7-day ave. max. air temp. is 33.0°C with a σ of 2°C, and
C. 1-day ave. min. air temp. is -21.0°C with a σ of 3°C.

- **SHRP Algorithms**
- High Pvmt 53.2°C
- Low Pvmt -21.0°C
- PG 58-22 at 50%
- PG 58-28 at 98%

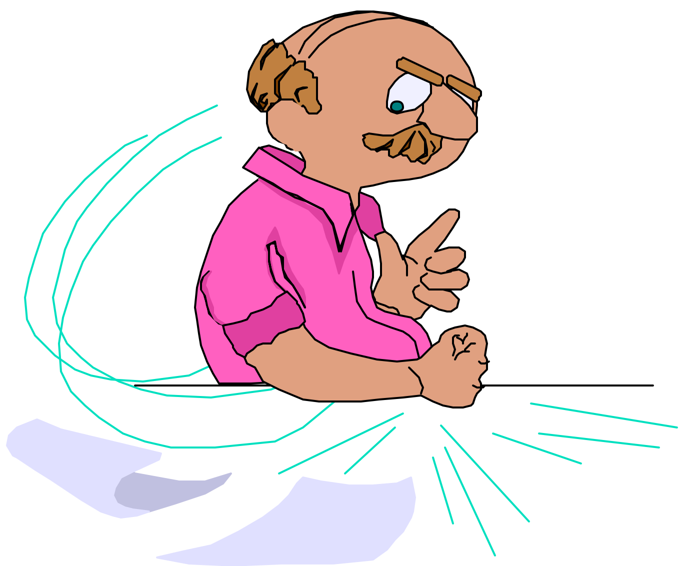
- **LTPP Algorithms**
- High Pvmt 50.8°C
- Low Pvmt -14.7°C
- PG 52-16 at 50%
- PG 58-22 at 98%

PG Selection

- For Hot Mix, USA, the 50 % reliability LTPP performance grade is a PG 52-16.
- The project traffic level and speed do not require grade bumping.
- However, the traffic speed is just above the threshold for grade bumping, and
- Historically in this area pavements have shown susceptibility to low-temperature cracking.

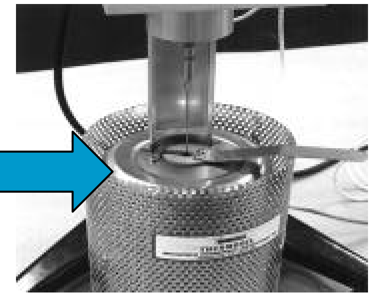
PG Selection

- Such that, the agency shall require a
- **PG 58-22**.

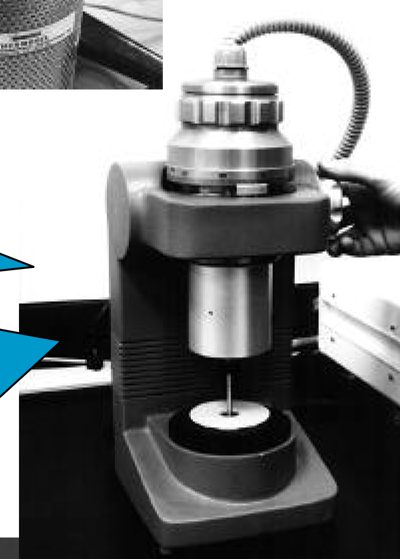


Performance Grade (PG) Binders AASHTO MP-1

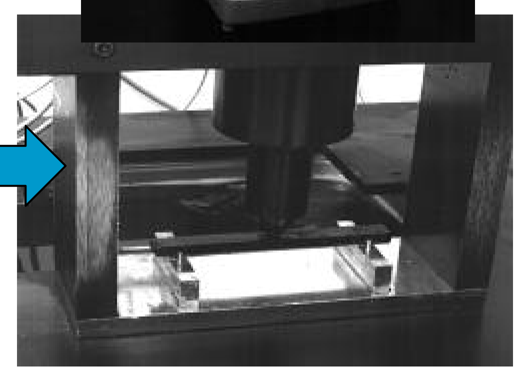
- Construct-ability check
  - Pump-ability



- Rutting check
- Fatigue cracking check



- Low-temp cracking check



Binder Selection, PG 58-22

Test	Temperature	Property
Unaged	Original	
Flash Point Rotational Viscosity Dynamic Shear	230°C min 135°C PG High Temp	Safety Pump-ability Rutting
Aged	R.T.F.O.	After Construction
Mass Loss Dynamic Shear	 PG High Temp	Age Susceptibility Rutting
Aged	P.A.V	5 to 7 years
Dynamic Shear Creep Stiffness, BBR	Intermediate Temp PG Low Temp + 10	Fatigue Cracking Low Temp Cracking

Binder, PG 58-22

- **Q.** Will a modified binder be required to satisfy this PG grade?

Binder, PG 58-22 = 80 < 90

Typically, if the difference between the high and low temperatures is less than 90°C, modification is not required !

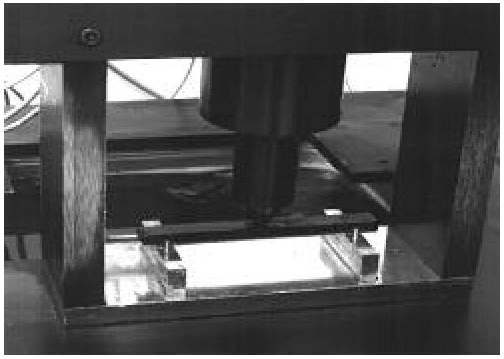
Binder ETG - AASHTO MP1(*)

- The Superpave low temp binder spec has been revised using a new scheme to determine the critical thermal cracking temperature.

- The new scheme unites the rheological properties obtained using the BBR and the failure properties acquired the DTT.

NEW! PG Binders, AASHTO MP1(*)

- Low-temp cracking check

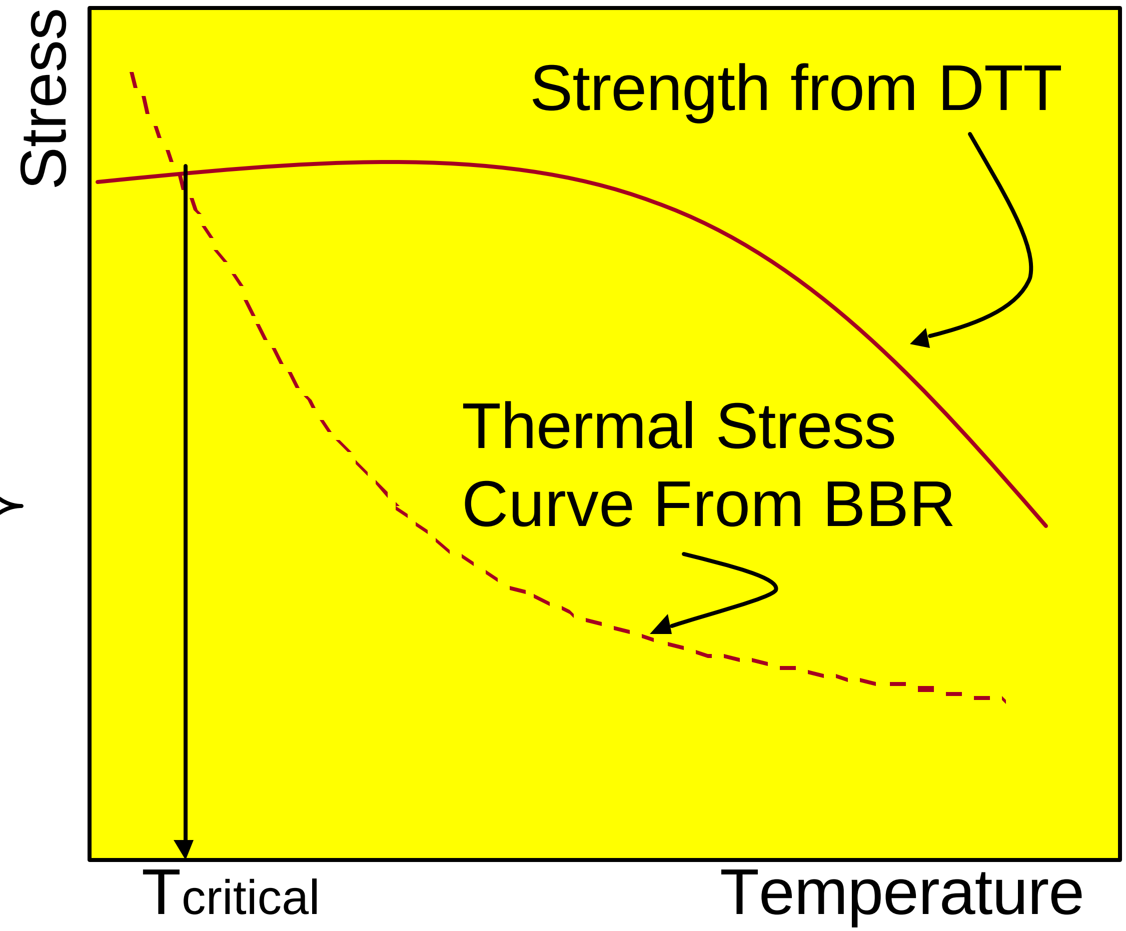


- Bending Beam Rheometer
- Direct Tension Test

The Low-Temperature Binder Specification
AASHTO MP1(*)

Role of DTT and BBR

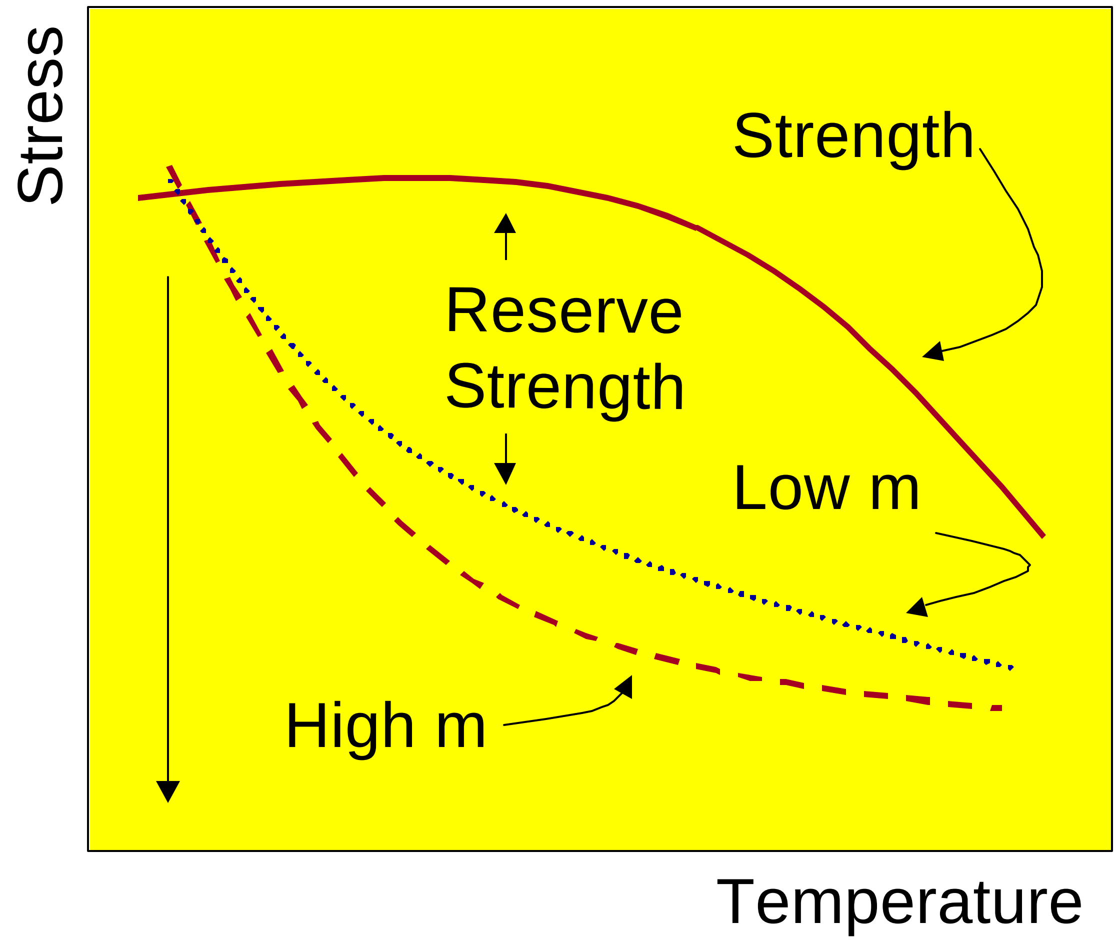
Thermal stress curve (dotted line) is computed from BBR data. Failure Strength is measured using the DTT. Where they meet, determines critical cracking temperature, Tc.



Reserve Strength for Low and High m-value

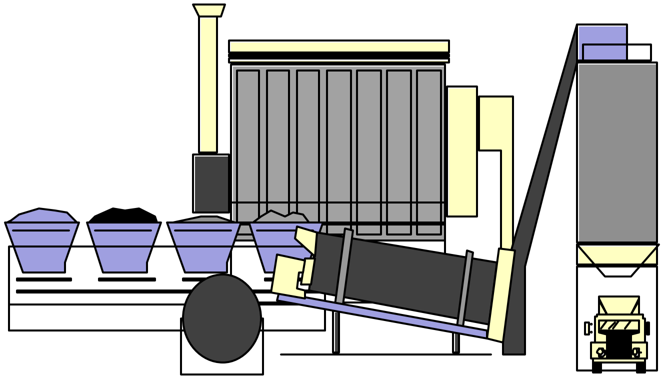
Role of S and m-value……

Binder with low m-value has less reserve strength than high m-value binder and thus has less resistance to thermal fatigue.

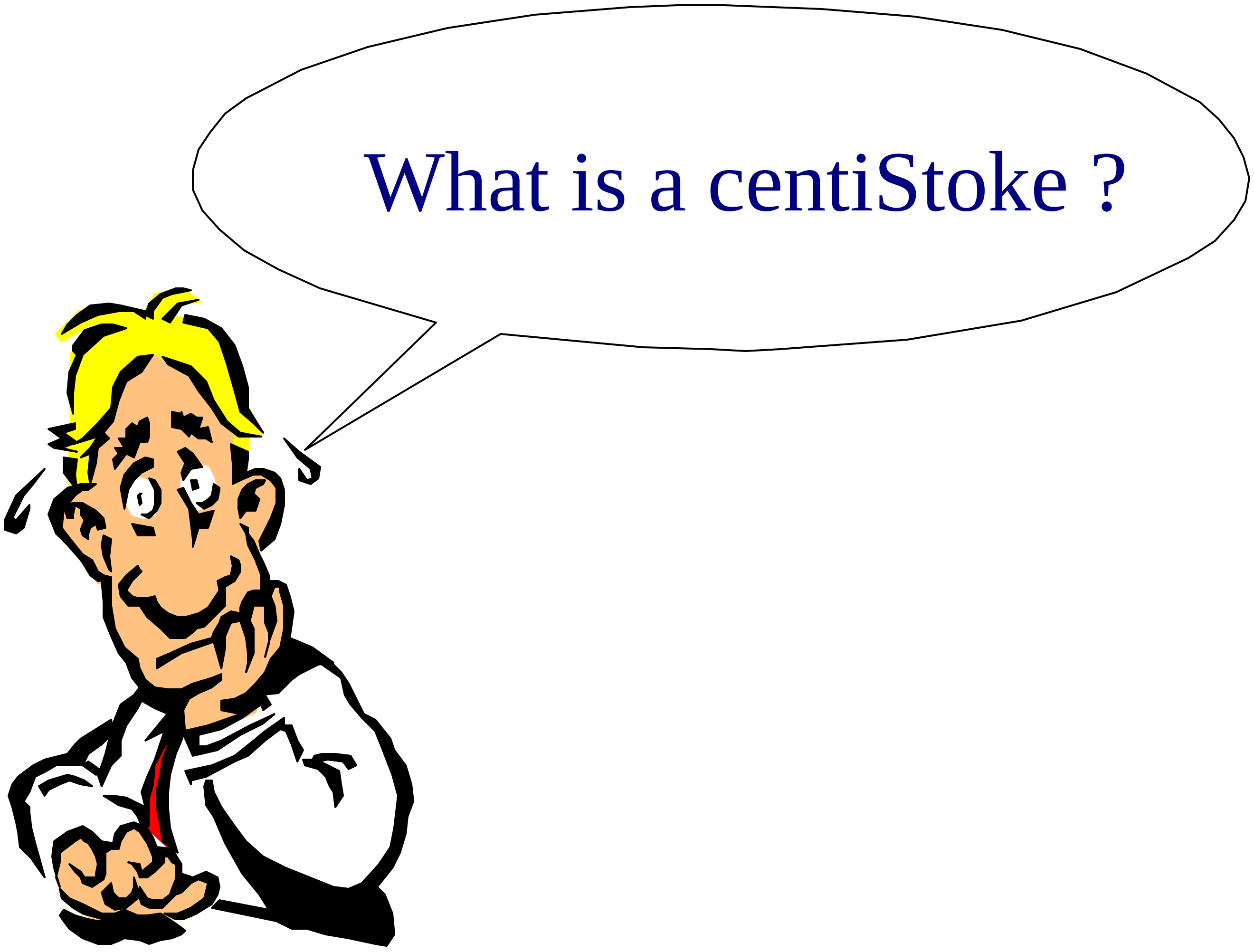


Binder tests required for design

- Rotational Viscosity
  - SHRP adopted the Asphalt Institutes guidelines based on the temperature-viscosity relationship
  - Mixing Temperature: 150 to 190 centiStokes, cSt
  - Compaction Temperature: 250 to 310 cSt



Question ?



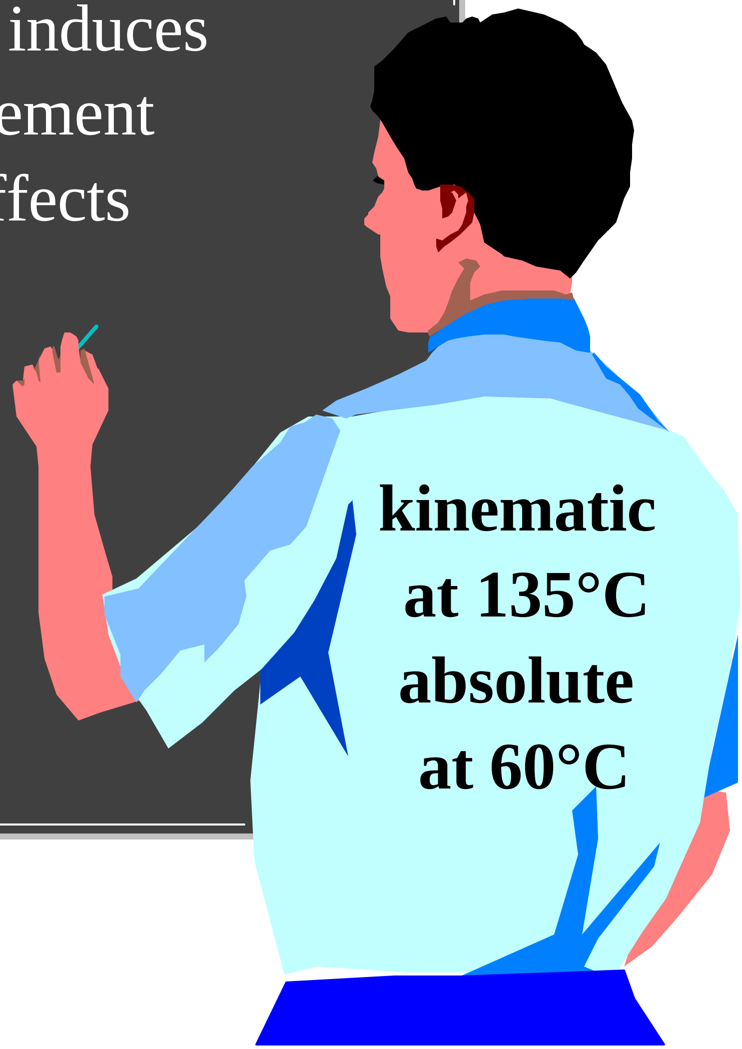
centi - metric prefix for 1/100

Stoke - great physicist from the 18 century, *so. . .*

*a **centiStoke***

is square centimeter per second or one hundredth of a great dead dude.

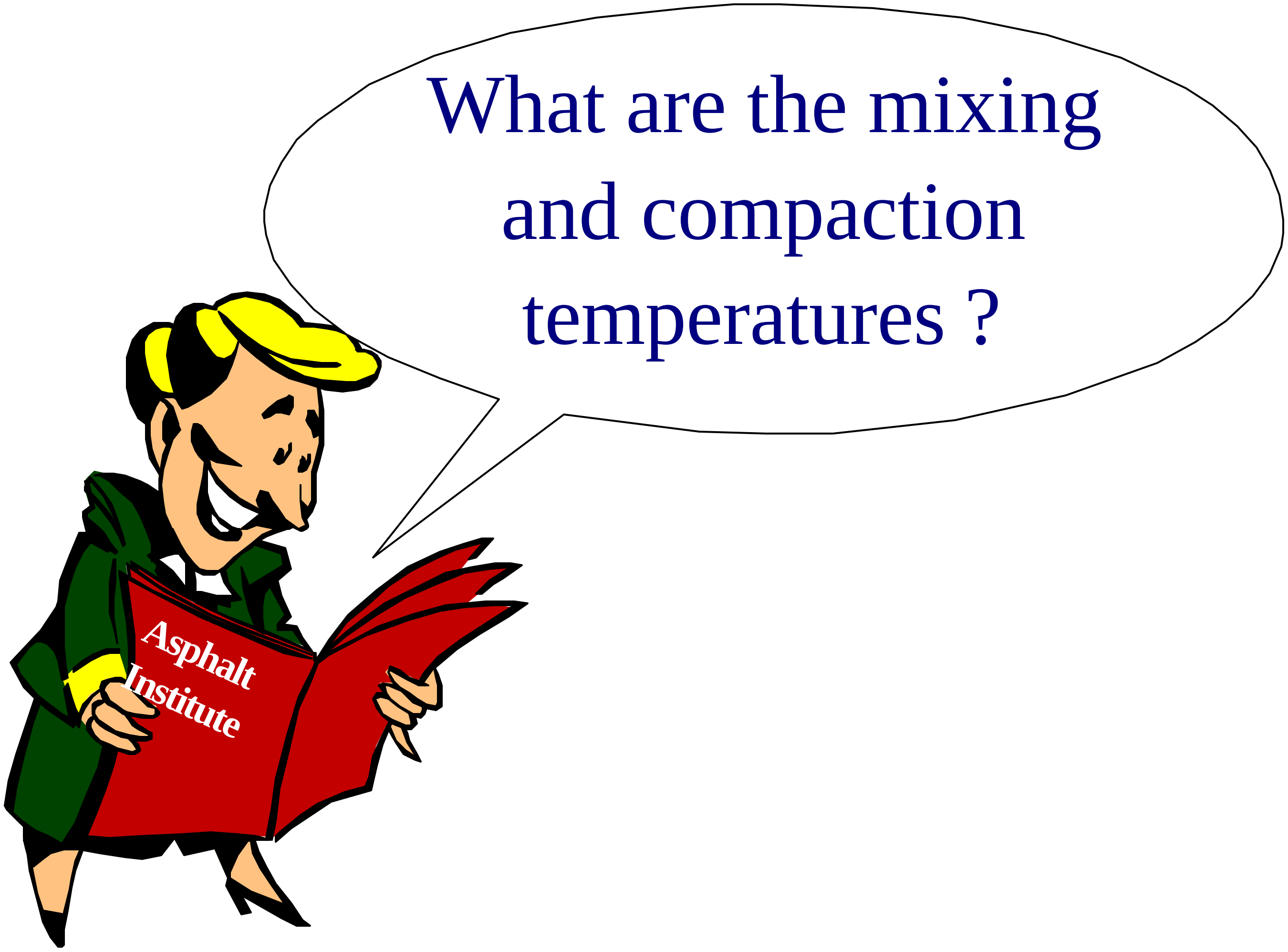
centiStoke is the unit of measurement for kinematic viscosity. Gravity induces the flow in this viscosity measurement and the density of the material effects the rate of flow. **centiPoise** is the unit of absolute viscosity measure. A partial vacuum or rotational viscometer is used where gravity effects are negligible.



Project Binder, PG 58-22

- G_b = 1.030
- Viscosity at 135°C = 364 cP = 0.364 Pa-s
- Viscosity at 160°C = 100 cP = 0.100 Pa-s

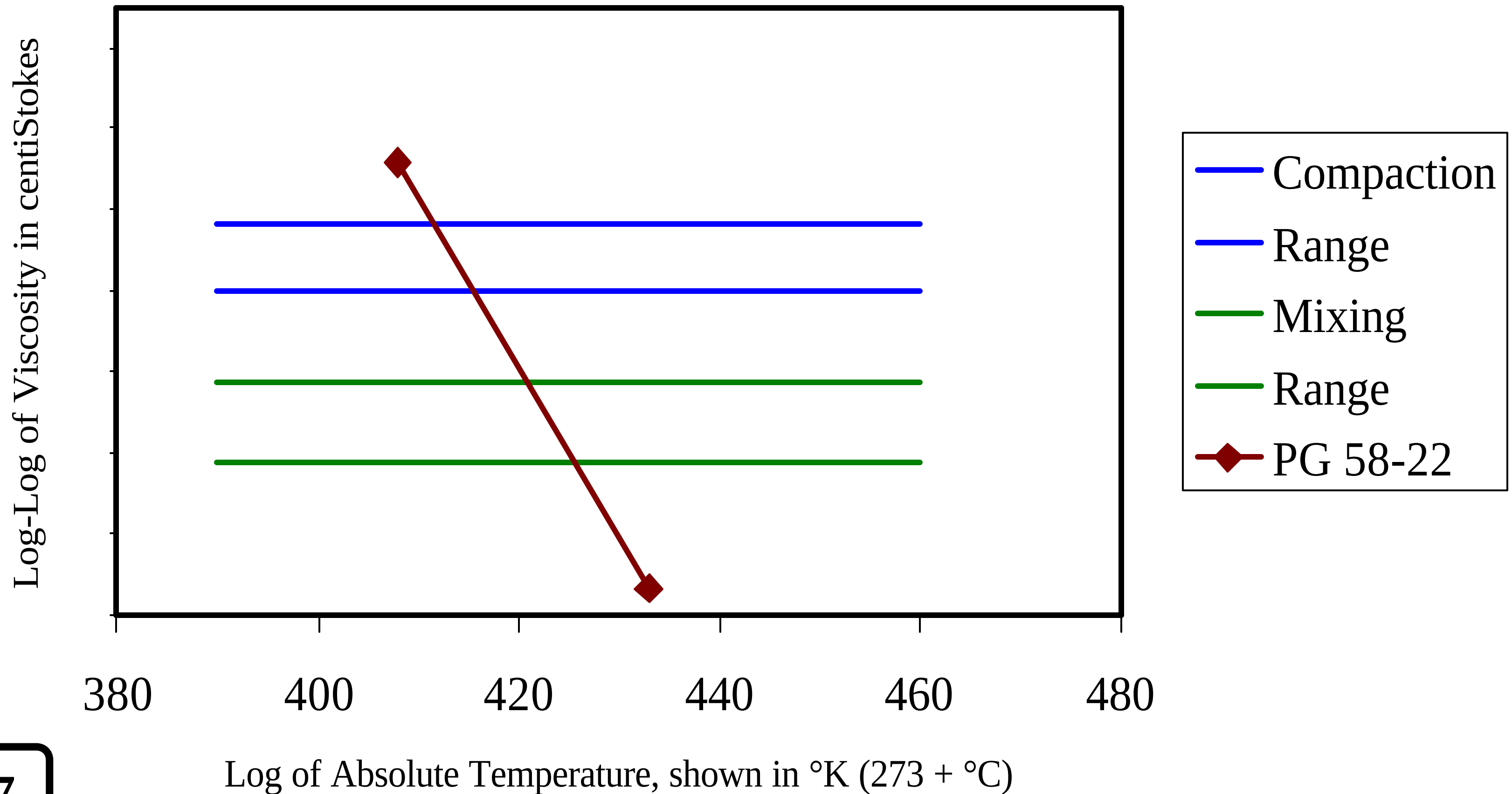
Question ?


What are the mixing and compaction temperatures ?
Asphalt Institute

Answer.

- First the temperature correction factors for G_b are calculated at the test temperatures:
  - $CF_{135^\circ C}$ = -.0006(135°C) + 1.0135 = 0.933
  - $CF_{160^\circ C}$ = -.0006(160°C) + 1.0135 = 0.918
- Then the test results are then converted from Pascal-seconds to centiStokes.

Temperature-Viscosity Chart



Summary of Binder Mix Testing

- Mixing Temperature Range
  – 148°C to 152°C

- Compaction Temperature Range
  – 138°C to 142°C

Notes on Equiviscous Temperatures

- *This relationship **does not** work for all modified asphalt binders.*

- *The conversion from centipoise to centiStokes is important, however it is not required. Determining mixing and compaction temperatures using centipoise will only effect the results by 1 to 2°C.*

Selection of Materials

Performance Grade Binder

Mineral Aggregate

Modifiers / Additives

Superpave utilizes a completely new system for testing, specifying, and selecting asphalt binders. While no new aggregate tests were developed, current methods of selecting and specifying aggregates were refined and incorporated.

Aggregate Selection

- The G_{sb} (bulk) and G_{sa} (apparent) are determined for each aggregate. The specific gravities are used in trial binder content and VMA calculations.

Stockpiles	Gsb	Gsa
Coarse	2.567	2.680
Intermediate	2.587	2.724
Man. Fines	2.501	2.650
Natural Fines	2.598	2.673

Specific Gravity Tests for Aggregates

- Two tests are needed
  – Coarse aggregate
  (retained on the 4.75 mm sieve)

  – Fine aggregate
  (passing the 4.75 mm sieve)

Coarse Aggregate Specific Gravity

- ASTM C127
  - Dry aggregate
  - Soak in water for 24 hours
  - Decant water
  - Use pre-dampened towel to get SSD
  - Determine mass of SSD agg in bucket
  - Determine mass under water
  - Dry to constant mass
  - Determine oven dry mass

Coarse Aggregate Specific Gravity

Coarse Aggregate Specific Gravity

Coarse Aggregate Specific Gravity

Calculations

- $G_{sb} = A / (B - C)$
  - A = mass oven dry
  - B = mass SSD
  - C = mass under water
- $G_{s,SSD} = B / (B - C)$
- $G_{sa} = A / (A - C)$
- Water absorption capacity, %
  - Absorption % = [(B - A) / A] * 100

Fine Aggregate Specific Gravity

- ASTM C128
  - Dry aggregate
  - Soak in water for 24 hours
  - Spread out and dry to SSD
  - Add 500 g of SSD agg to pyc of known volume
    - Pre-filled with some water
  - Add more water, agitate until air bubble are removed
  - Fill to line, determine the mass of the pycnometer, aggregate and water
  - Empty aggregate into pan and dry to constant mass
  - Determine oven dry mass

Fine Aggregate Specific Gravity


Fine Aggregate Specific Gravity

Fine Aggregate Specific Gravity

Fine Aggregate Specific Gravity

Calculations

- G_{sb} = A / (B + S - C)
  - A = mass oven dry
  - B = mass of pycnometer filled with water
  - C = mass pycnometer, SSD agg and water
  - S = mass SSD aggregate
- $G_{s,SSD}$ = S / (B + S - C)
- G_{sa} = A / (B + A - C)
- Water absorption capacity, %
  - Absorption % = [(S - A) / A] * 100

Consensus Property Standards

- Coarse Aggregate Angularity
  - ASTM D 5821
- Fine Aggregate Angularity
  - AASHTO T 304-96
- Flat & Elongated Particles
  - ASTM D 4791
- Sand Equivalent
  - AASTHO T 176

Source Property Standards

Set by Specifying Agency (DOT)

- LA Abrasion
  - AASHTO T 96
- Soundness
  - AASHTO T 104
- Clay Lumps & Friable Particles
  - AASHTO T 112

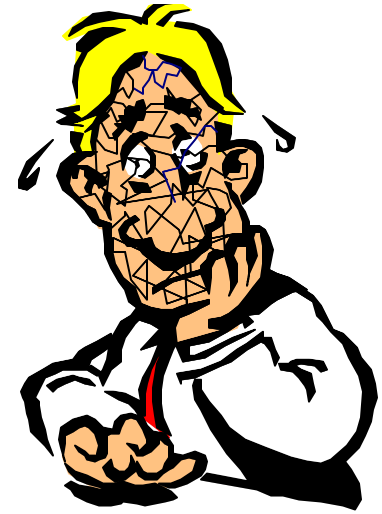
Author's Note

- An aggregate which does not individually comply with the criteria is <u>not</u> eliminated from the aggregate blend.

- However, its percentage of use in the total aggregate blend is limited.

Coarse Aggregate Angularity, CAA

- What is a fractured face?



- ASTM D5821, Percentage of Fractured Particles in Coarse Aggregates

- FRACTURED FACES - "*A face will be considered a 'fractured face' only if it has a projected area at least as large as one quarter of the maximum projected area (maximum cross-sectional area) of the particle* ***and the face has sharp and well defined edges.***"

Coarse Aggregate Angularity, CAA

. . .and the face has sharp and well defined edges."

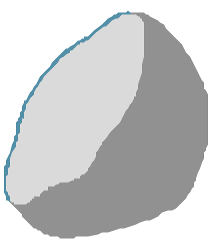
Coarse Aggregate Angularity, CAA

0% Crushed **100% with 2 or More Crushed Faces**

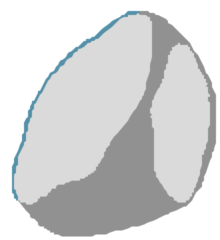
Coarse Aggregate Angularity, CAA

Traffic ESALs	Depth from Surface ≤ 100 mm	Depth from Surface > 100 mm	
.	.	.	
3 to < 10	85/80	60/ -	Minimum
.	.	.	
.	.	.	

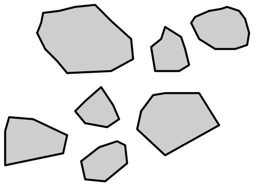
85% one fractured face



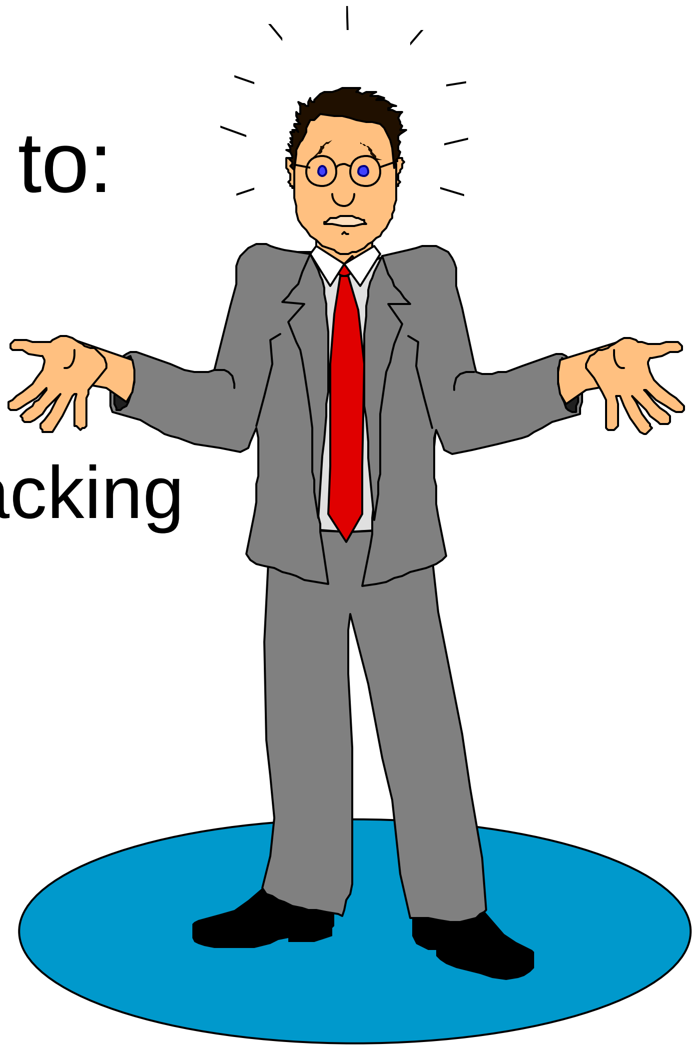
80% two+ fractured faces



Coarse Aggregate Angularity

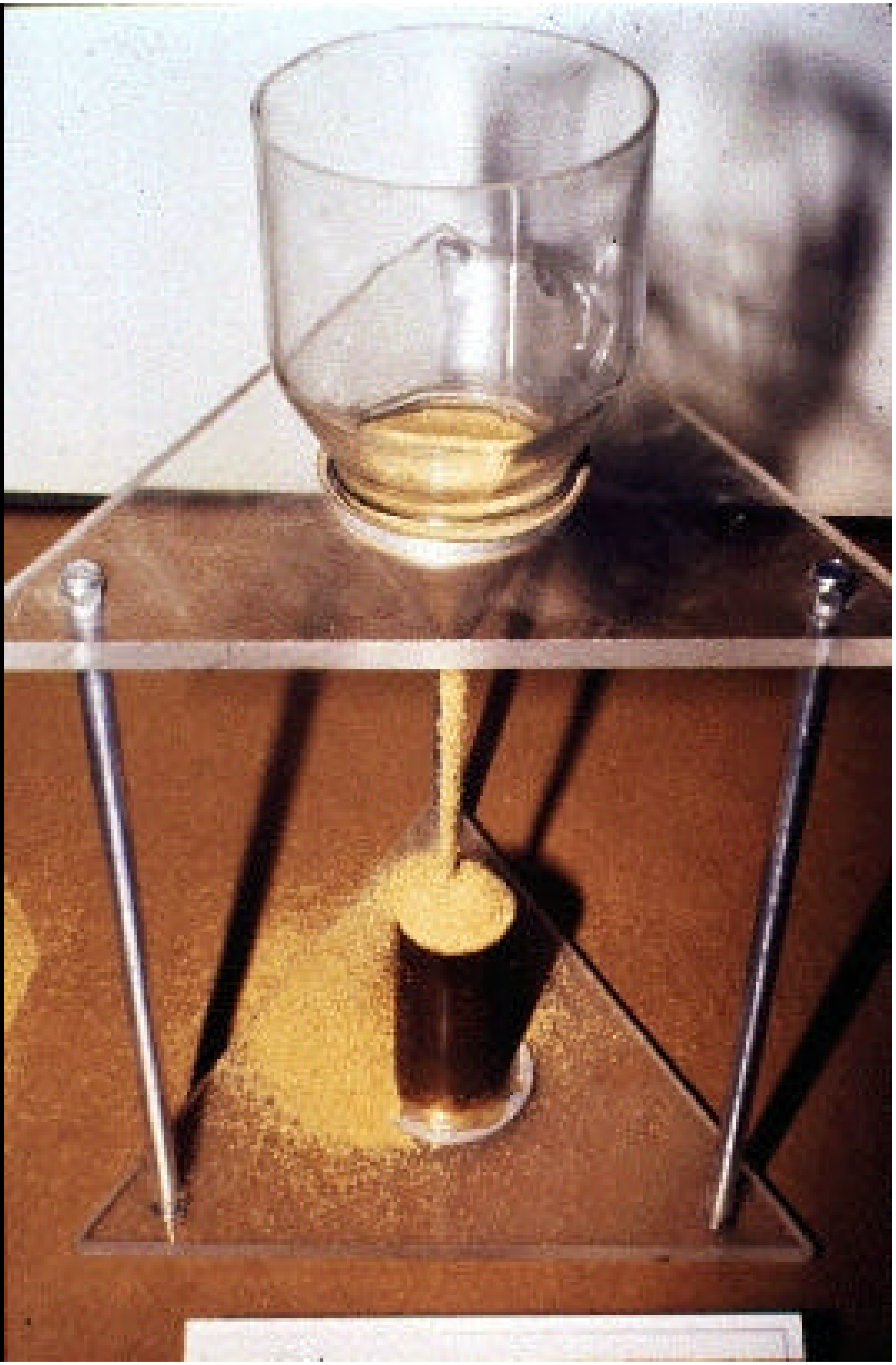


- Increase Resistance to:
  - Rutting
  - Fatigue Cracking
  - Low-temperature Cracking
- Effect:
  - Production
  - Lay-down

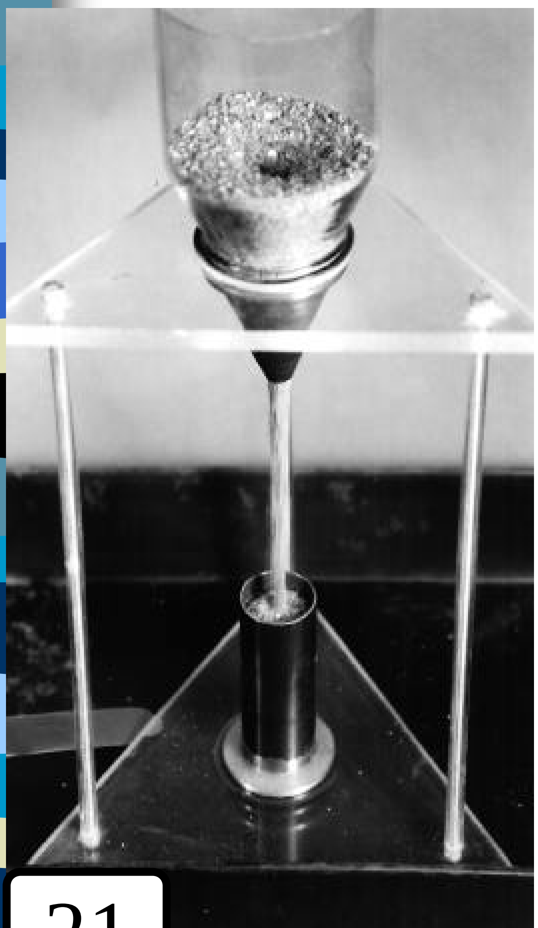


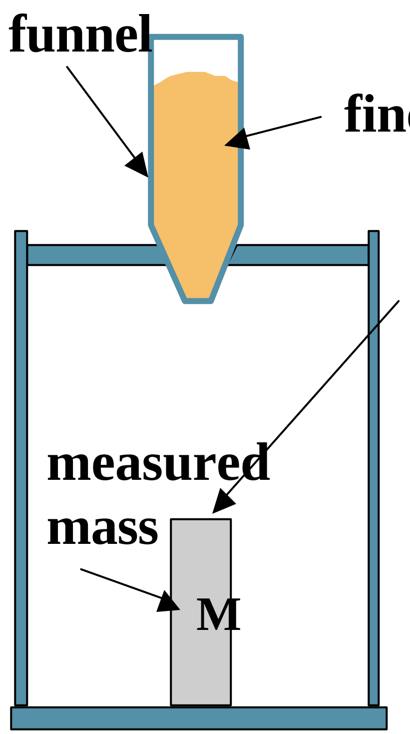
Fine Aggregate Angularity

Natural sands: typically < 45
Manufactured sands: typically > 42



Fine Aggregate Angularity, FAA





uncompacted voids =

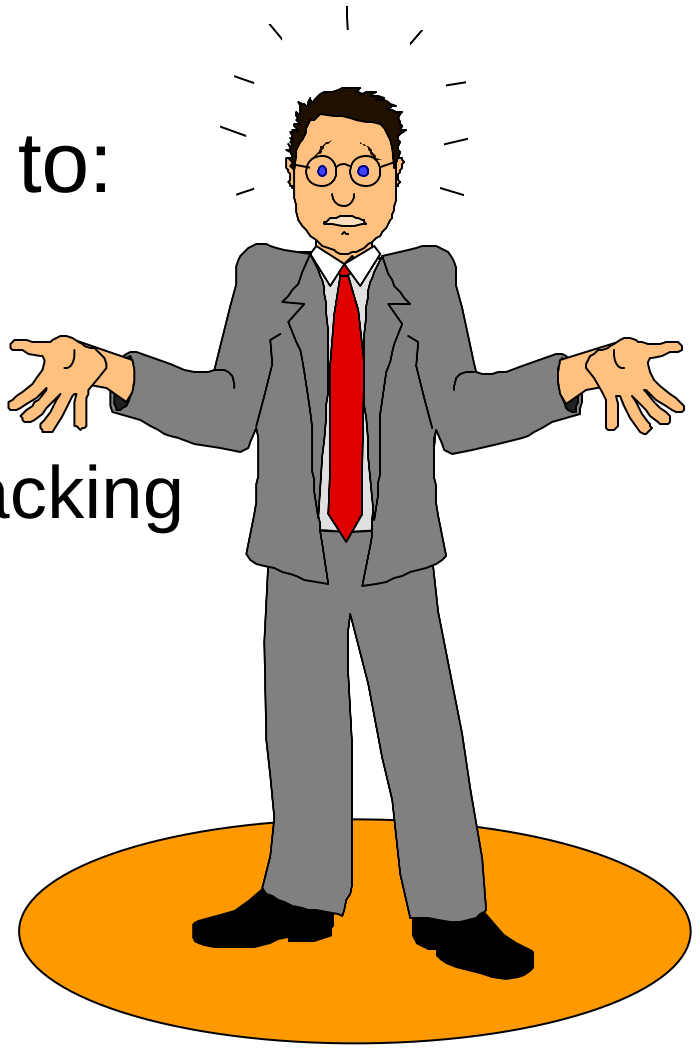
$$\frac{V - M / G_{sb}}{V} \times 100\%$$

Fine Aggregate Angularity, FAA

- Uncompacted Voids, $U = \left(\frac{V - W / G_{sb}}{V}\right) 100$

Fine Aggregate Angularity, FAA

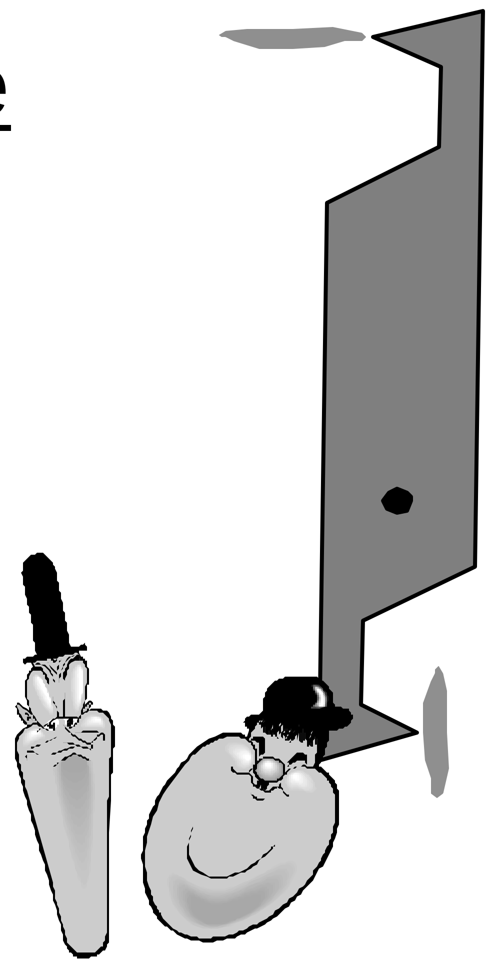
- Increase Resistance to:
  - Rutting
  - Fatigue Cracking
  - Low-temperature Cracking
- Effect:
  - Production
  - Lay-down



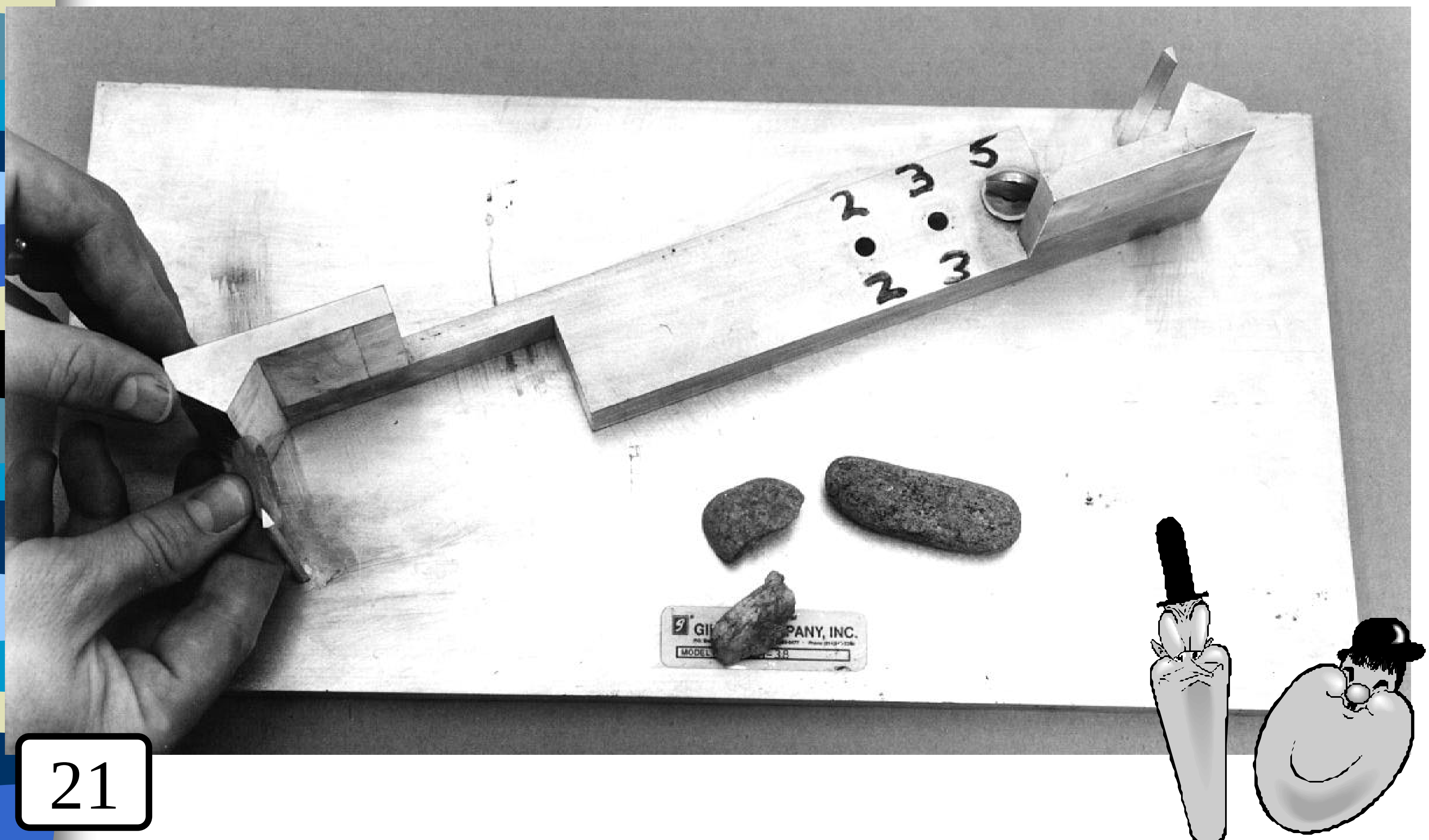
Flat & Elongated Particles, F&E

- Superpave uses a single measurement be made for flat/elongated particles.

- The 5:1 ratio refers simply to the maximum to minimum dimension.

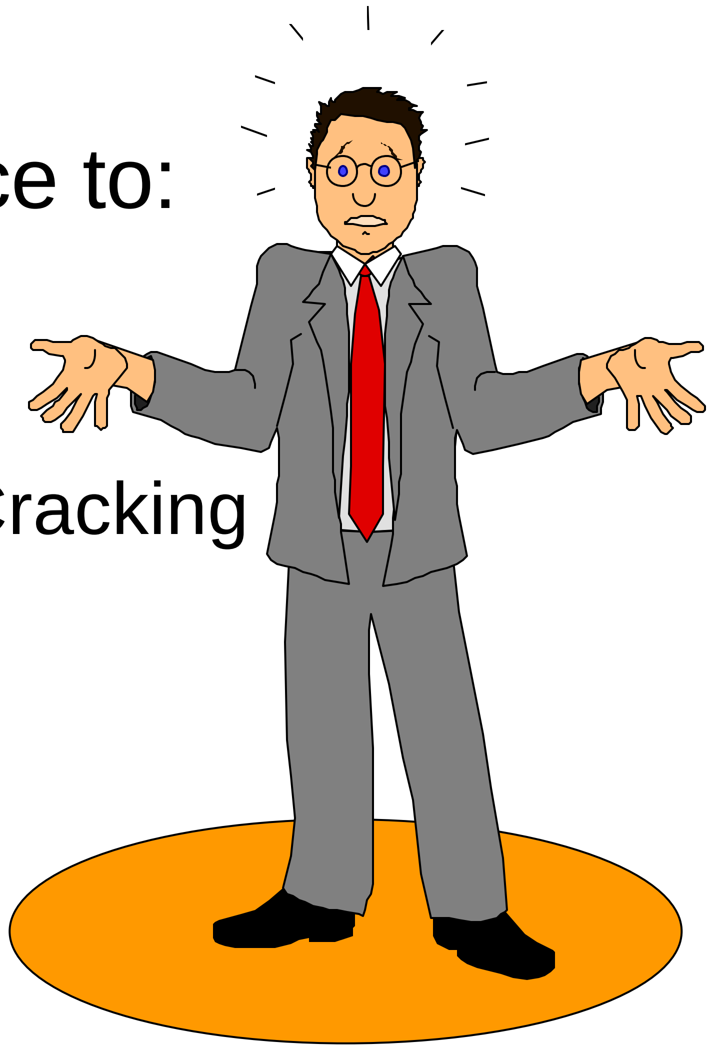


Flat & Elongated Particles, F&E



Flat & Elongated Particles, F&E

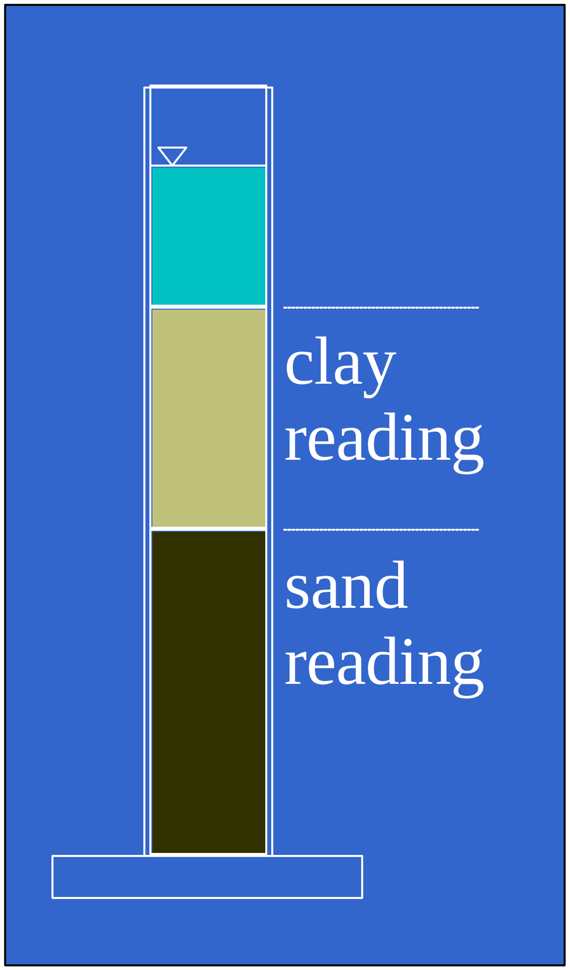
- Increase Resistance to:
  - Rutting
  - Fatigue Cracking
  - Low-temperature Cracking
- Effect:
  - Production
  - Lay-down

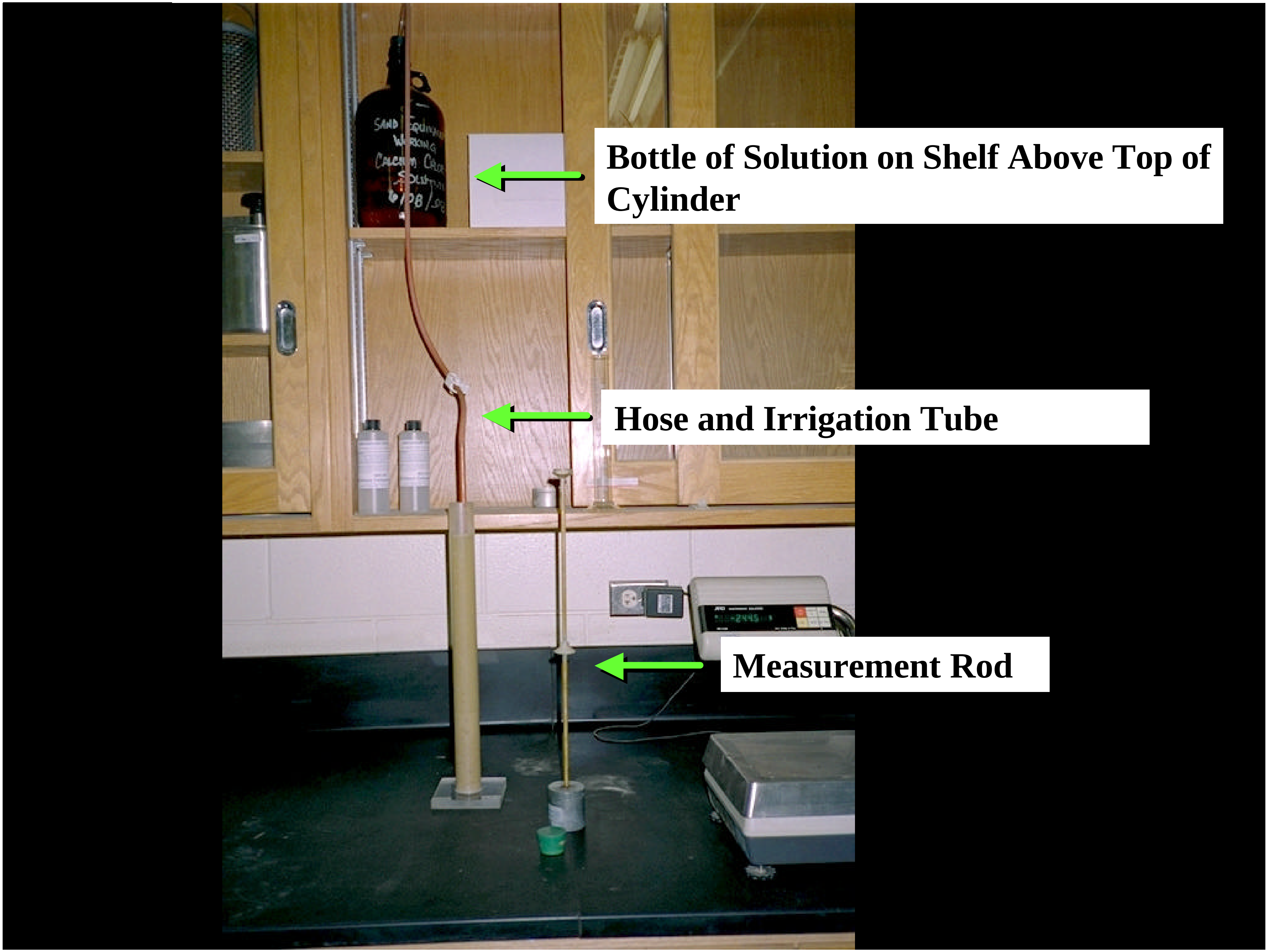


Sand Equivalent, SE

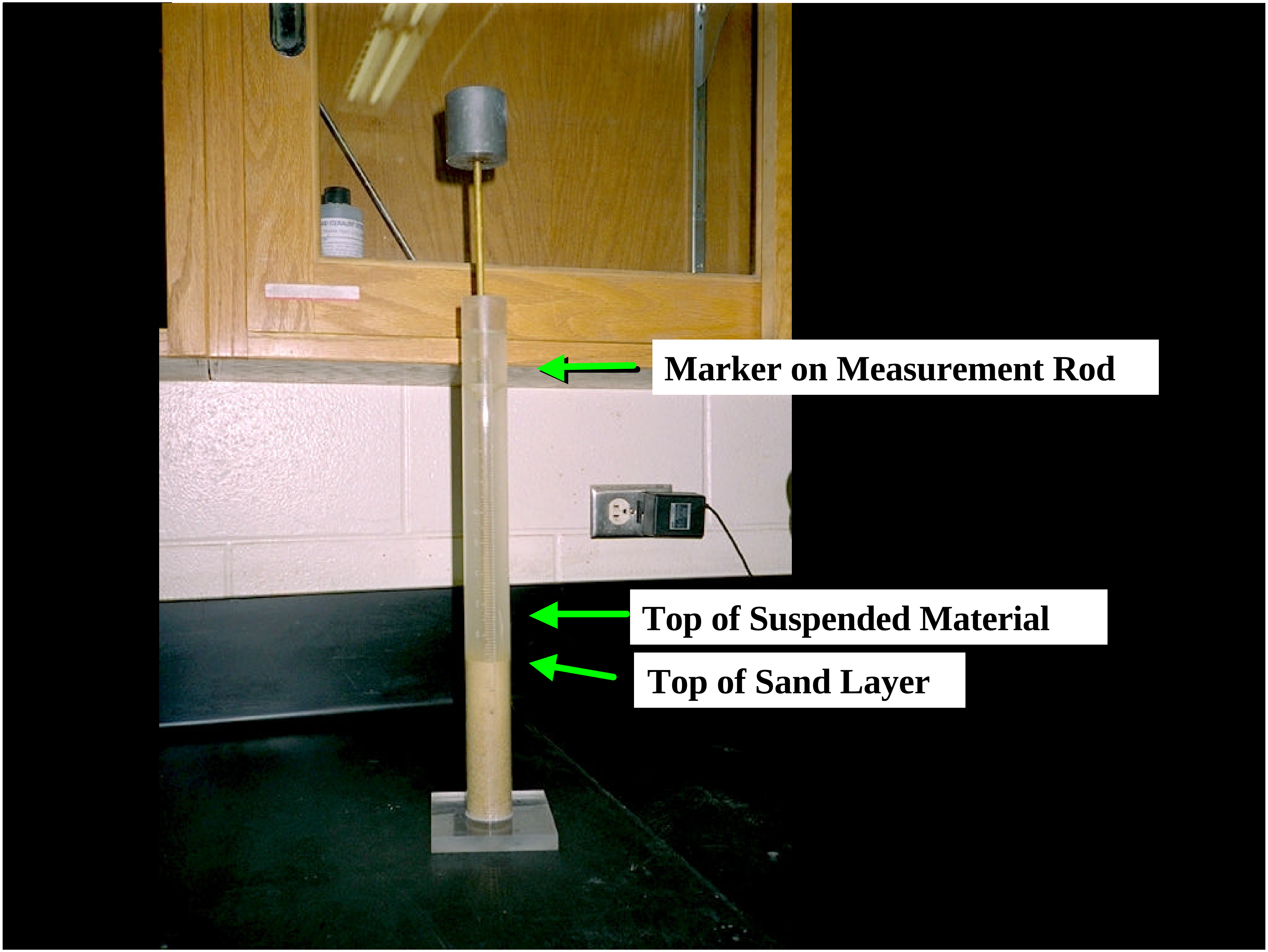
- Clay content is the percentage of clay material contained in the aggregate fraction that is finer than a 4.75 mm sieve.

- SE = 100 (SR/CR)



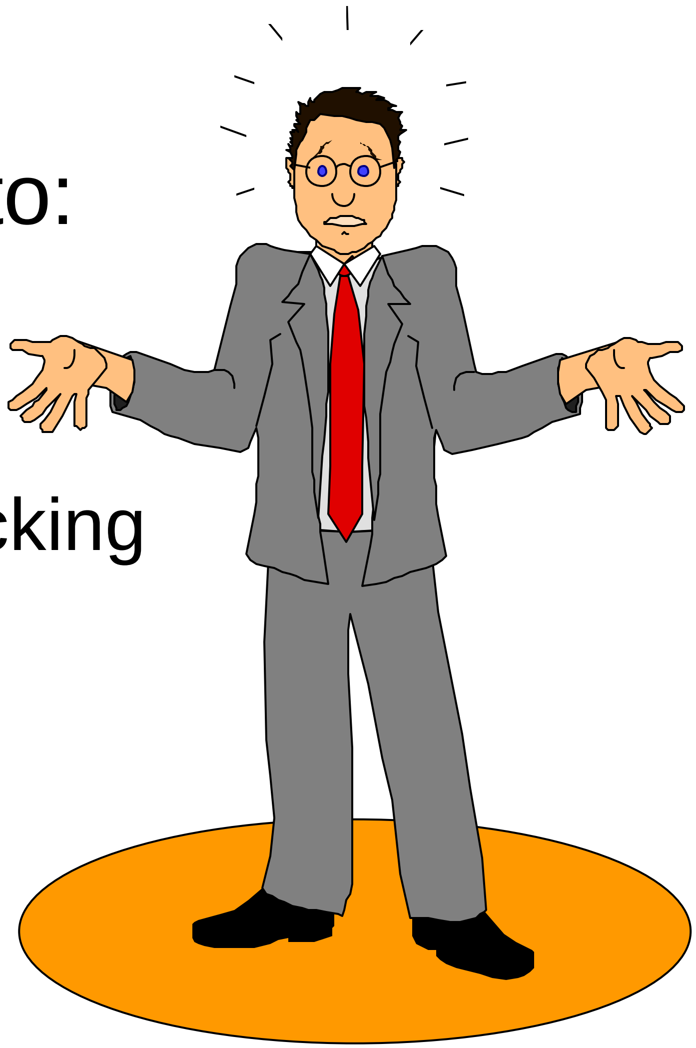


Bottle of Solution on Shelf Above Top of Cylinder
Hose and Irrigation Tube
Measurement Rod


Marker on Measurement Rod
Top of Suspended Material
Top of Sand Layer

Sand Equivalent, SE

- Increase Resistance to:
  - – Rutting
  - – Fatigue Cracking
  - – Low-temperature Cracking
- Effect:
  - – Production
  - – Lay-down



Lead States

- A consolidated table has been developed for the consensus property standards criteria.

- This new table has 5 traffic levels; to correspond to the new SGC compaction criteria.

1999 Consensus Criteria

ESAL	CAA		FAA		SE	F&E
	≤ 100	> 100	≤ 100	> 100		
< 0.3	55/-	-/-	-	-	40	-
0.3 to <3	75/-	50/-	40	40	40	10
3 to < 10	85/80	60/-	45	40	45	
10 to<30	95/90	80/75	45	40	45	
≥ 30	100	100	45	45	50	

Hot Mix, USA: CAA

Stockpile	Results	Criteria
Coarse	99 / 97	85 / 80
Intermediate	80 / 60	85 / 80

- **Q.** Do the stockpiles meet the criteria, Y/N? If the answer is "no," what does this mean?

  (a) Stockpile can not be used, or
  (b) Percentage of stockpile in blend is limited.

Hot Mix, USA: FAA

Stockpile	Results	Criterion
Man. Fines	48	45
Natural Fines	42	45

- **Q.** Do the stockpiles meet the criteria, Y/N? If the answer is “no,” what does this mean?

  (a) Stockpile can not be used, or
  (b) Percentage of stockpile in blend is limited.

Author's Note

- Fine aggregates with higher fine aggregate angularity may aid in the development of higher voids in mineral aggregate (VMA).

Hot Mix, USA: F&E

Stockpile	Results	Criterion
Coarse	9	?
Intermediate	2	

- **Q.** Do the stockpiles meet the criteria, Y/N? If the answer is "no," what does this mean?

  (a) Stockpile can not be used, or
  (b) Percentage of stockpile in blend is limited.

Hot Mix, USA: SE

Stockpile	Results	Criterion
Intermed Agg	45	?
Man. Fines	51	
Natural Fines	39	

- **Q.** Do the stockpiles meet the criteria, Y/N? If the answer is "no," what does this mean?
  (a) Stockpile can not be used, or
  (b) Percentage of stockpile in blend is limited.

Original versus 1999

- **Q.** For this project, did any of the criteria change from using the original tables versus the new standards in AASHTO MP-2?

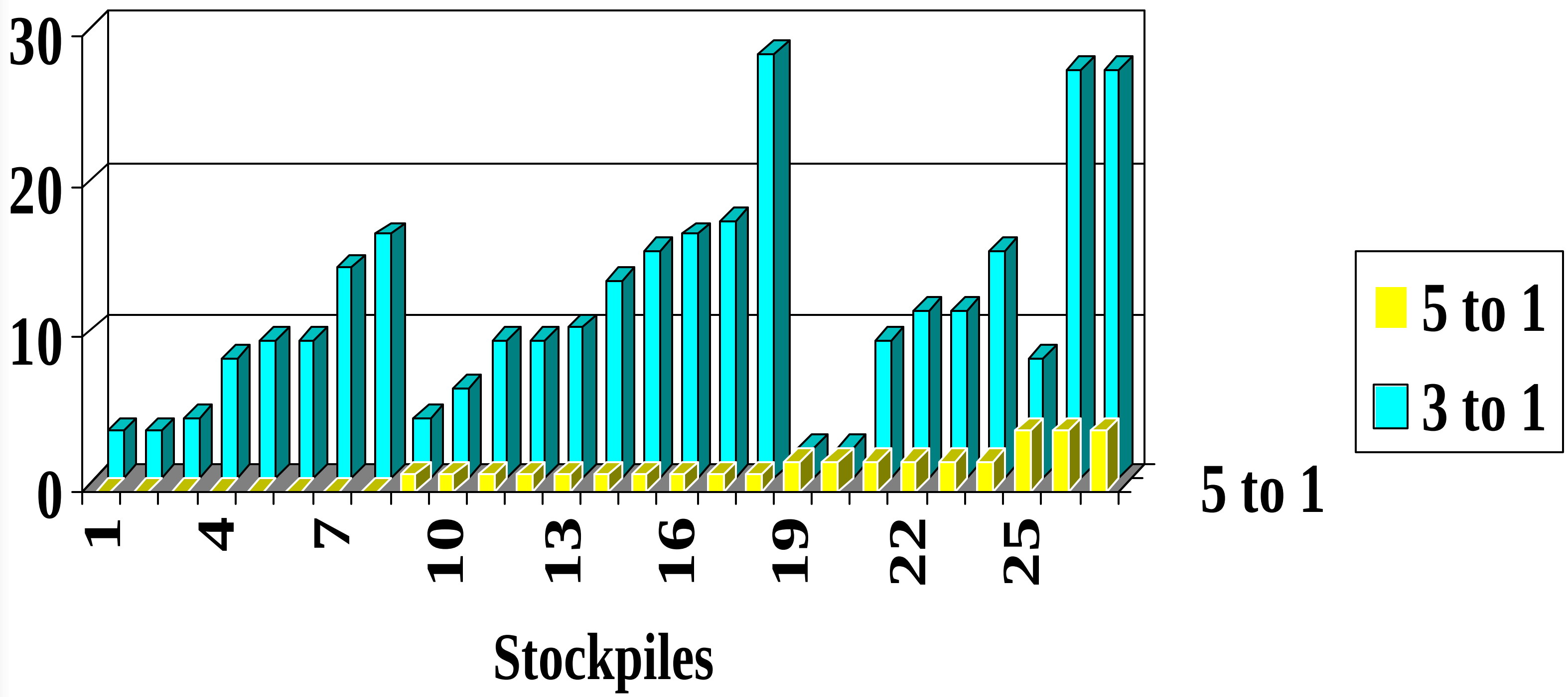
Consensus	Original	Current '99
CAA	85 /80	85 /80
FAA	45	45
F&E	10	10
SE	45	45

Mixture ETG Discussion

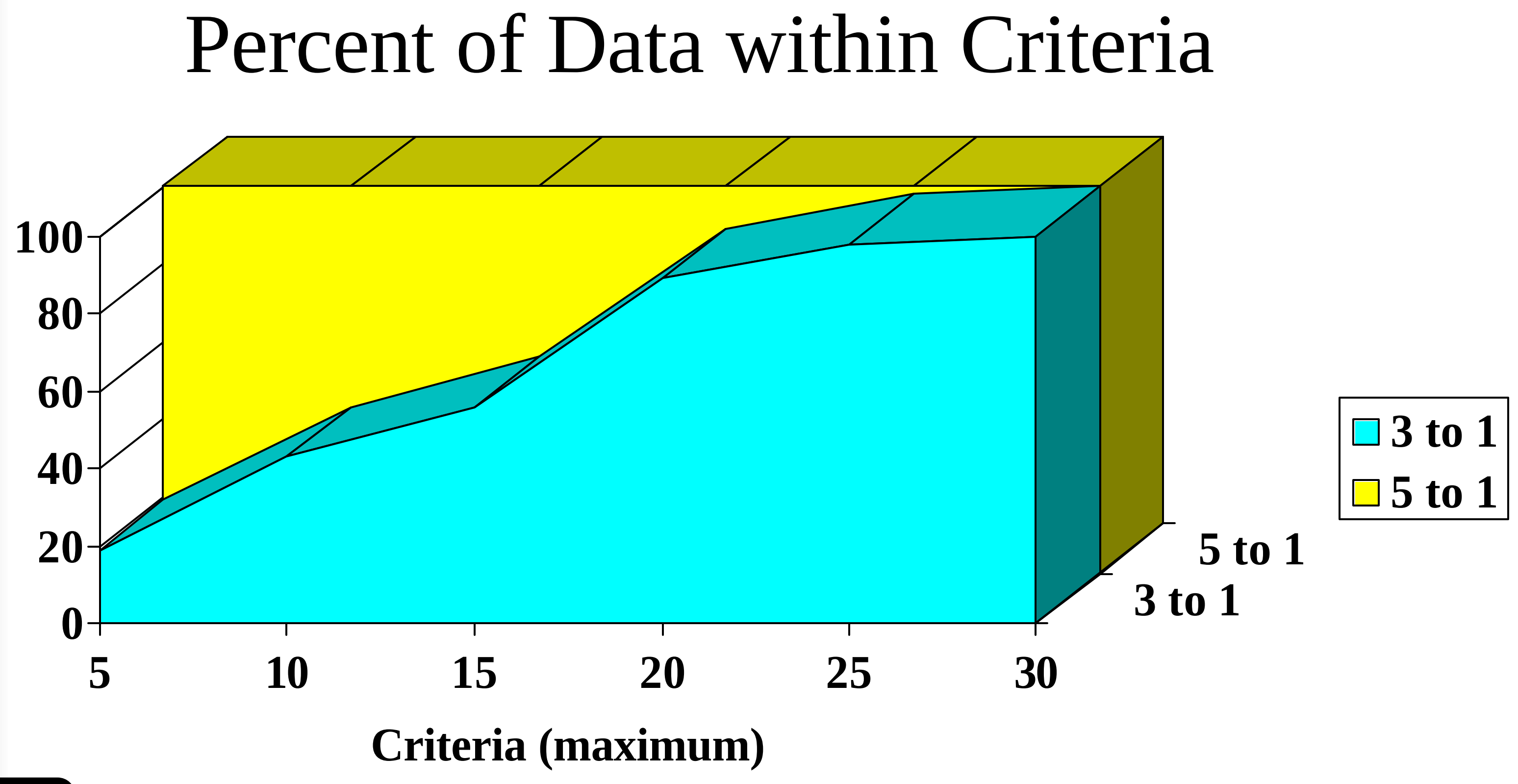
- Stockpile data collected as part of DP90 was offered for discussion of the use of the 3:1 ratio.

- 27 Stockpiles from 12 different projects sites located in:
  - California, Nevada, Alabama, Maine, Louisiana, Missouri, Illinois, South Carolina, Connecticut, Texas, Wisconsin, Minnesota, and Oklahoma.

F&E, 5:1 versus 3:1

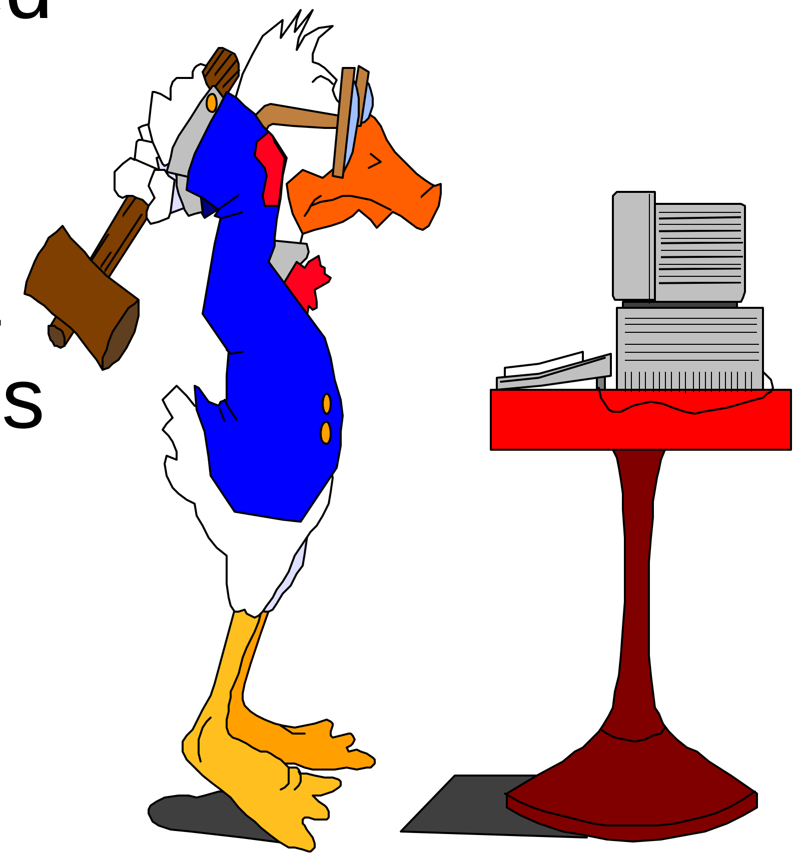


F&E, 5:1 versus 3:1



Author’s Note

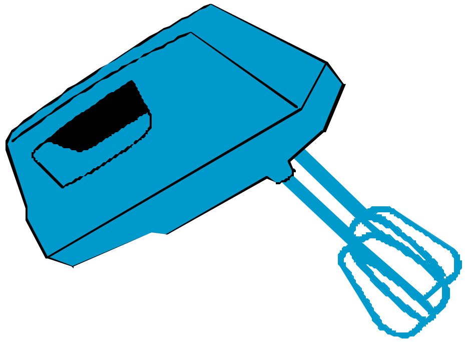
- It is recommended each specifying agency should perform a market analysis to access the impact of specifying a 3:1 source property standard.



Source Property Standards

- LA Abrasion
  - – Max loss approximately 35% to 40%
- Soundness
  - – Max loss approximately 10% to 20%
- Clay Lumps & Friable Particles
  - – Max range from 0.2% to 10%

Selection of a Design Aggregate Structure



- FHWA 0.45 Power Chart
- Control Points / Restricted Zone
- Superpave Gyratory Compactor

Design Aggregate Structure

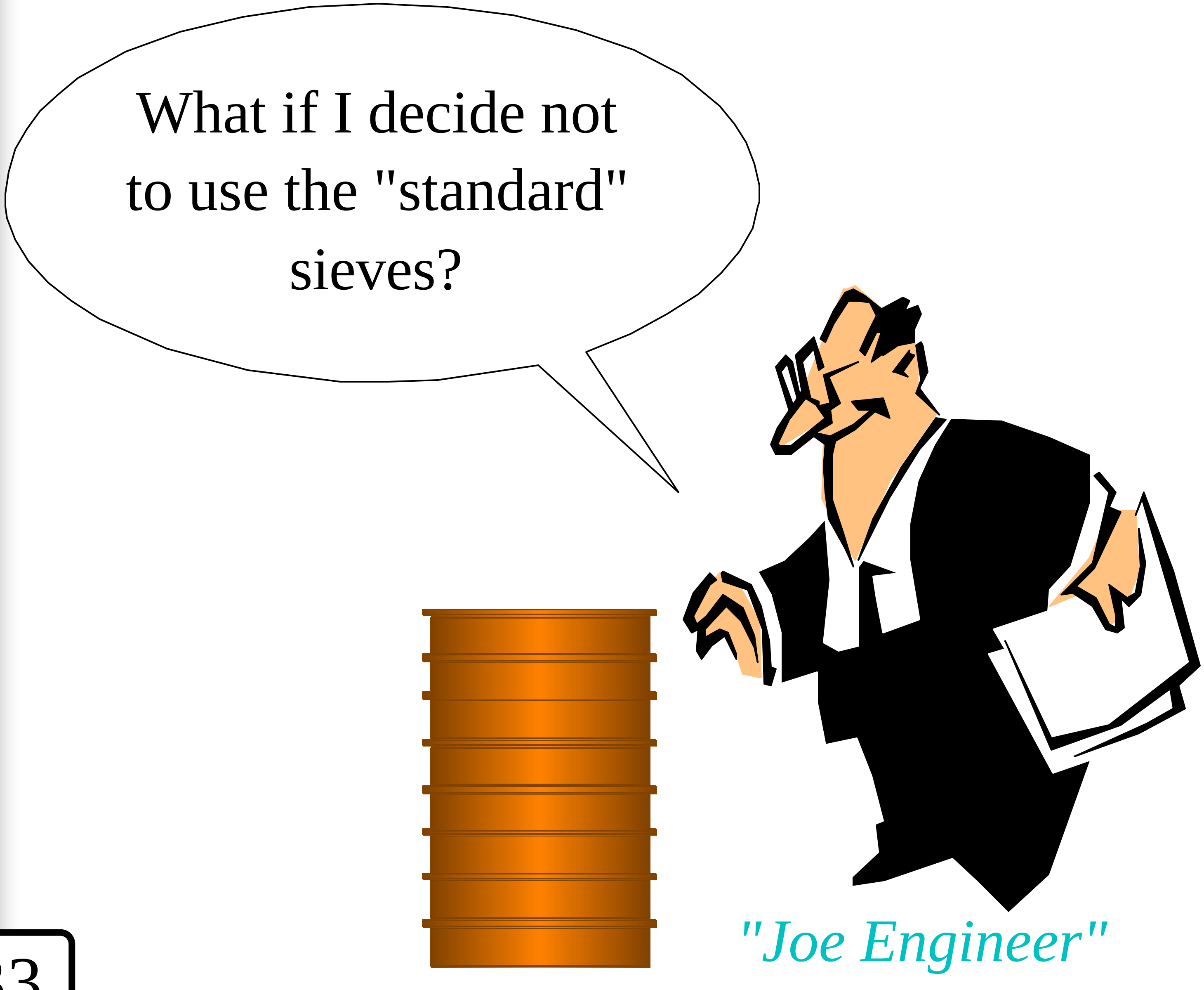
- The FHWA 0.45 Power chart is used to define permissible gradations.
  - *Nominal Maximum Sieve Size:* One standard sieve size larger than the first sieve to retain more than 10 percent.
  - *Maximum Sieve Size:* One standard sieve size larger than the nominal maximum size.

Question ?

What is a "standard" sieve ?

“Standard Sieves”

Standard Sieves, mm	
50.0	2.36
37.5	1.18
25.0	0.60
19.0	0.30
12.5	0.15
9.5	0.075
4.75	


What if I decide not to use the "standard" sieves?
"Joe Engineer"

You'll design asphalt mix, but it will NOT be Superpave !

The Match Game - Round 1

Ms. Metric meets Mr. English

No. 200 Sieve

(A) 0.15 mm
(B) 0.075 mm
(C) 19.0 mm

The Match Game - Round 1

Ms. Metric meets Mr. English

(A) 0.15 mm

No. 200 Sieve → (B) 0.075 mm

(C) 19.0 mm

The Match Game - Round 2

Ms. Metric meets Mr. English

1/2” Sieve

(A) 9.5 mm
(B) 19.0 mm
(C) 12.5 mm

The Match Game - Round 2

Ms. Metric meets Mr. English

1/2" Sieve

(A) 9.5 mm

(B) 19.0 mm

(C) 12.5 mm

The Match Game - Round 3

Ms. Metric meets Mr. English

1/4" Sieve

(A) 4.75 mm
(B) 9.5 mm
(C) 2.36 mm

The Match Game - Round 3

Ms. Metric meets Mr. English

1/4” Sieve

(A) 4.75 mm
(B) 9.5 mm
(C) 2.36 mm
(D) None of the above!

Gradation Criteria

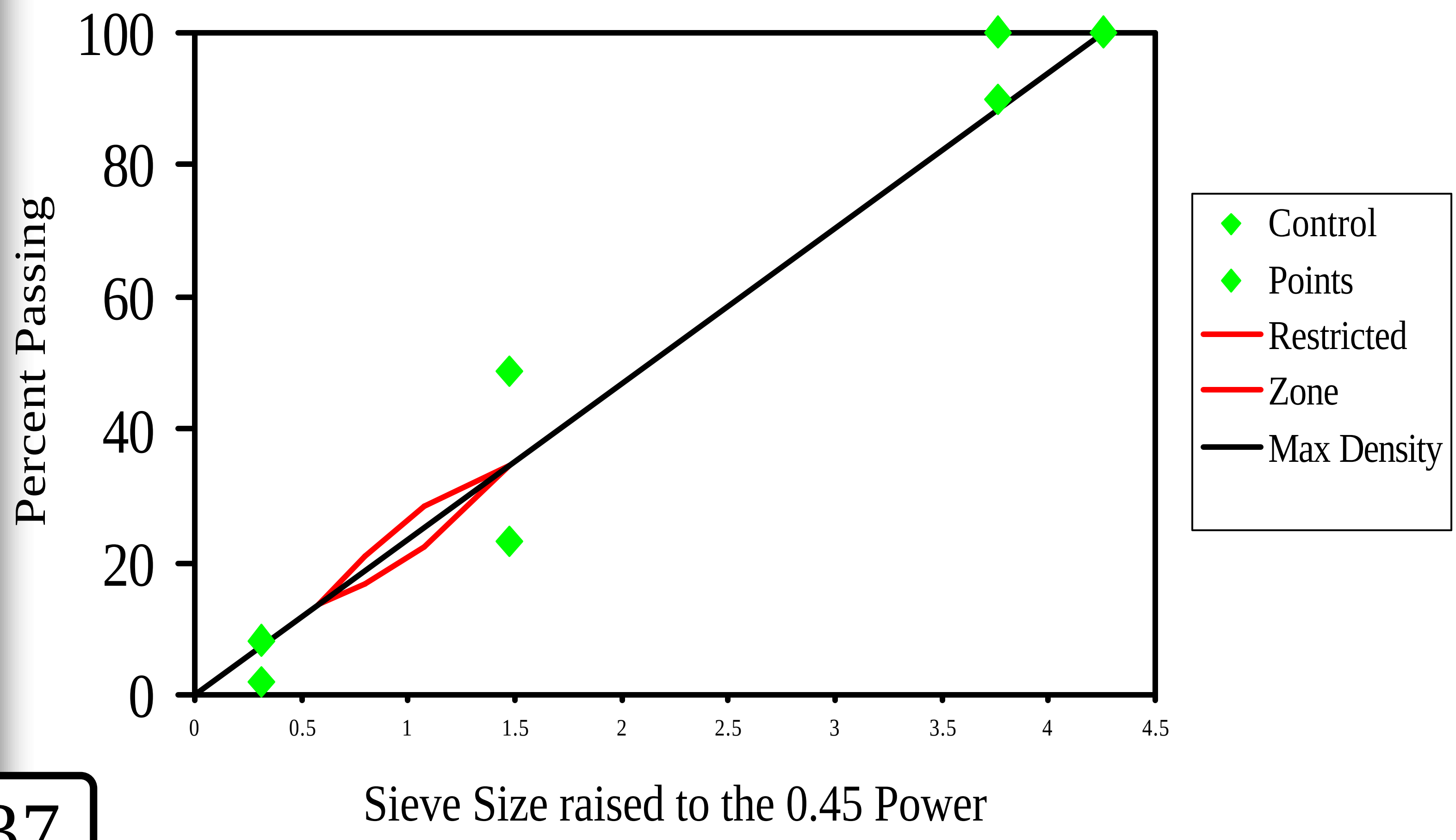
- Control Points
  - – Maximum Size
  - – Nominal Maximum Size
  - – Key Sieves: 0.075 and 2.36 mm

- Recommended Restricted Zone
  - – Starting from 0.30 to 2.36 or 4.75 mm

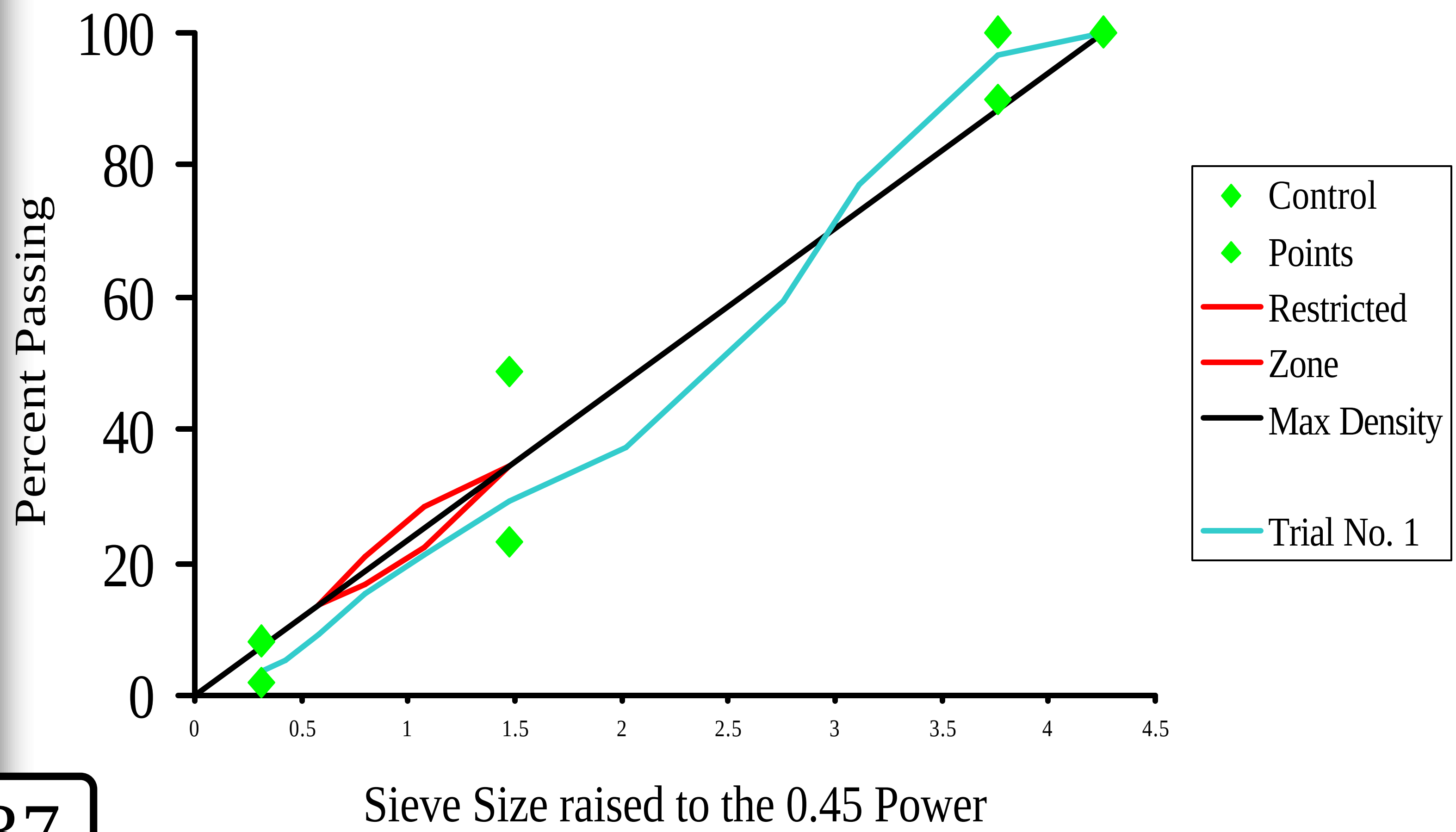
Gradation Criteria - 19 mm Mix

Sieve, mm	Minimum	Maximum
25.0	100	100
19.0	90	100
2.36	23	49
0.075	2	8
Recommended Restricted Zone		
2.36	34.6	34.6
1.18	28.3	22.3
0.60	20.7	16.7
0.30	13.7	13.7

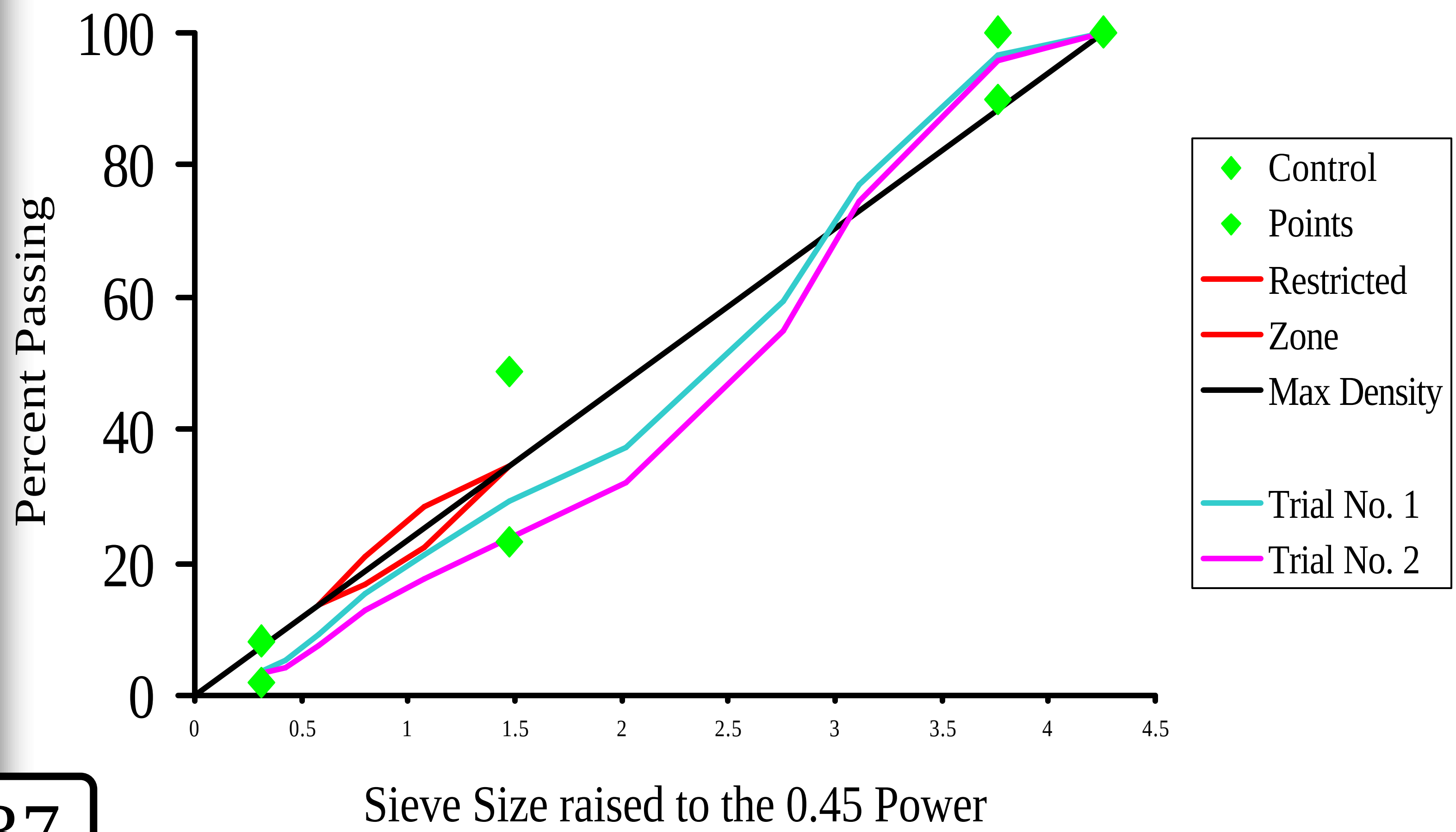
FHWA 0.45 Power Chart



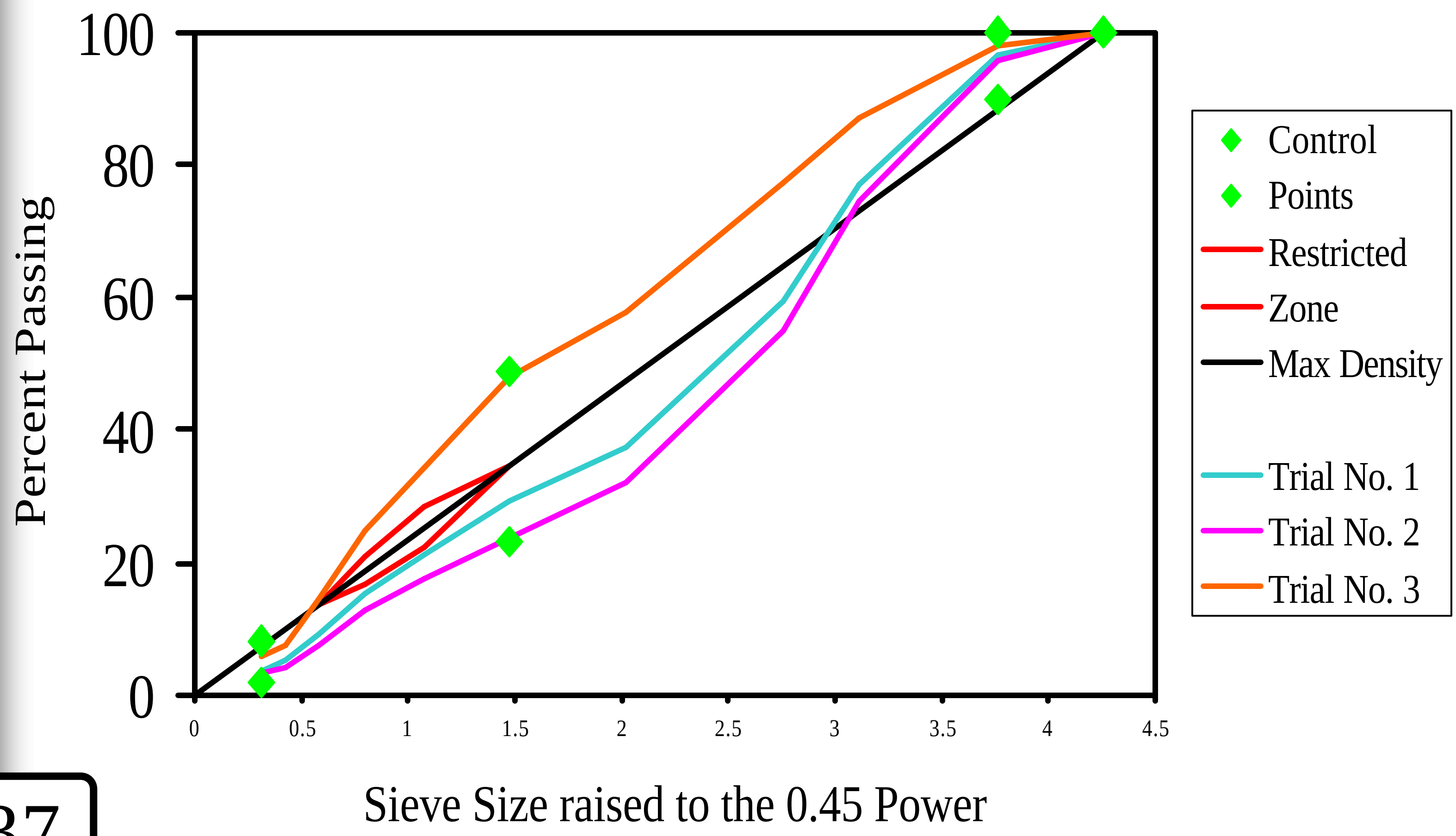
FHWA 0.45 Power Chart



FHWA 0.45 Power Chart



FHWA 0.45 Power Chart



Estimated Trial Blend Properties Huber's Method

- Determine what portion of the stockpiles apply to consensus property standard for each trial blend.

- Example: CAA for 1 fractured face for Trial Blend No. 1

Estimated Trial Blend Properties Huber's Method

Stockpile	CAA	(A) Trial Blend #1	(B) % of +4.75mm	(AxB) % App to CAA
Coarse	99/97	46 %	97 %	44.6 %
Inter.	80/60	24 %	75 %	18 %
Man. Fines	/	15 %	0 %	0
Natural Fines	/	15 %	0 %	0

Portion of the stockpiles that apply to consensus property.

Huber's Method

- C = Test result, and
- D = Portion of the stockpile that applies to consensus property standard,
- n = Stockpile number.

$$\text{Est. Property} = \frac{[(CxD)1 + (CxD)2 \ldots n]}{[(D)1 + (D)2 \ldots n]}$$

Estimated Trial Blend Properties Huber's Method

Stockpile	**(C) CAA +1**	**(D) % App to CAA**	**(CxD)**
Coarse	99	44.6 %	44.2 %
Inter.	80	18 %	14.4 %

- Est. Property = $\dfrac{[(CxD)1 + (CxD)2 \ldots n]}{[(D)1 + (D)2 \ldots n]}$

Estimated Trial Blend Properties Huber's Method

Stockpile	(C) CAA +1	(D) % App to CAA	(CxD)
Coarse	99	44.6 %	44.2 %
Inter.	80	18 %	14.4 %

- $CAA_{+1} = \frac{[(99x44.2) +(80x14.4)]}{[(44.2) + (14.4)]}$

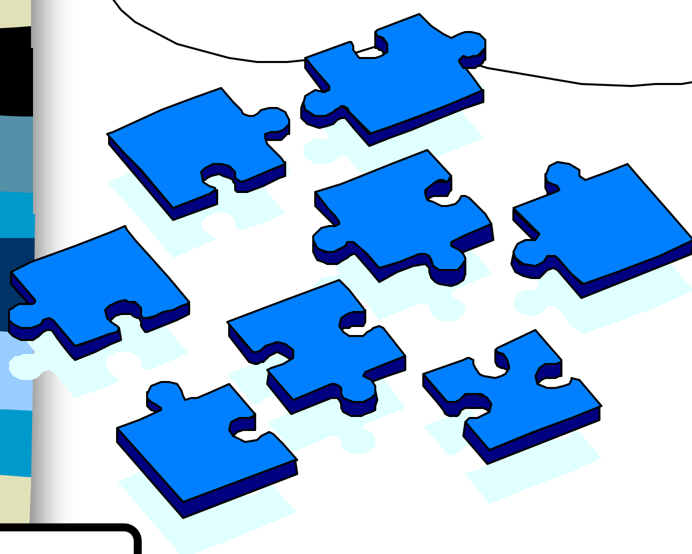
Estimated Trial Blend Properties Huber's Method

Stockpile	(C) CAA +1	(D) % App to CAA	(CxD)
Coarse	99	44.6 %	44.2 %
Inter.	80	18 %	14.4 %

- $CAA_{+1} = \dfrac{[(4375.8) + (1152)]}{[(58.6)]} = 94\ \%$

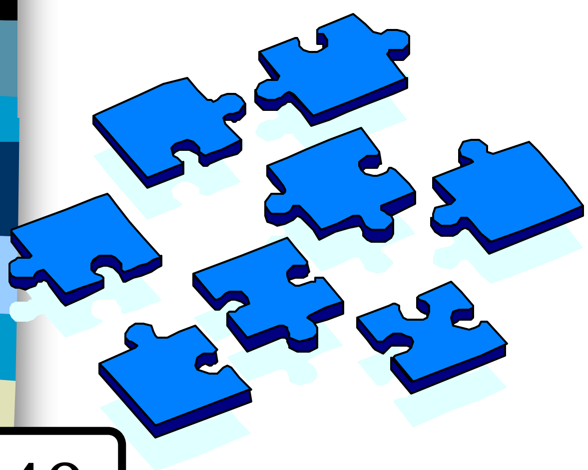
Estimating Trial Blend Properties

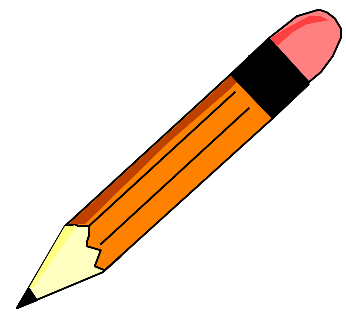
Q. What is CAA 2+ and SE for Trial Blend No.3 ?



Answers.

- CAA 2+ = 81
- SE = 44.47 = 44



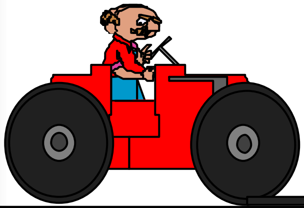


What's Next ?

- Based upon project environment and traffic we have selected a PG binder, PG 58-22.
- Based upon traffic and layer location we have set consensus criteria and accessed our stockpiles.
- Using the FHWA 0.45 power chart we have developed trial blends. . .

Next we need to. . .

- Estimated asphalt binder contents for the trial blends,
- Mix and compact the trial blends in the Superpave gyratory compactor *(SGC)*,
- Evaluate the trial blends volumetrically, and
- Select the Design Aggregate Structure.

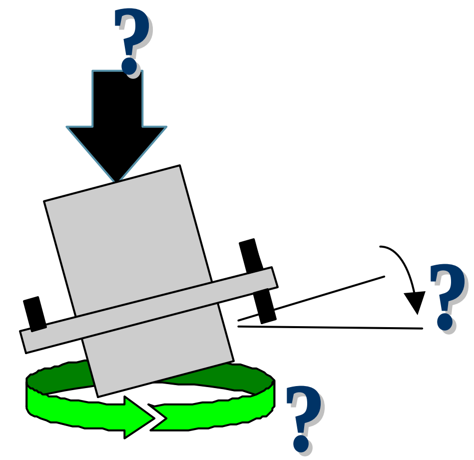


Goals of Compaction

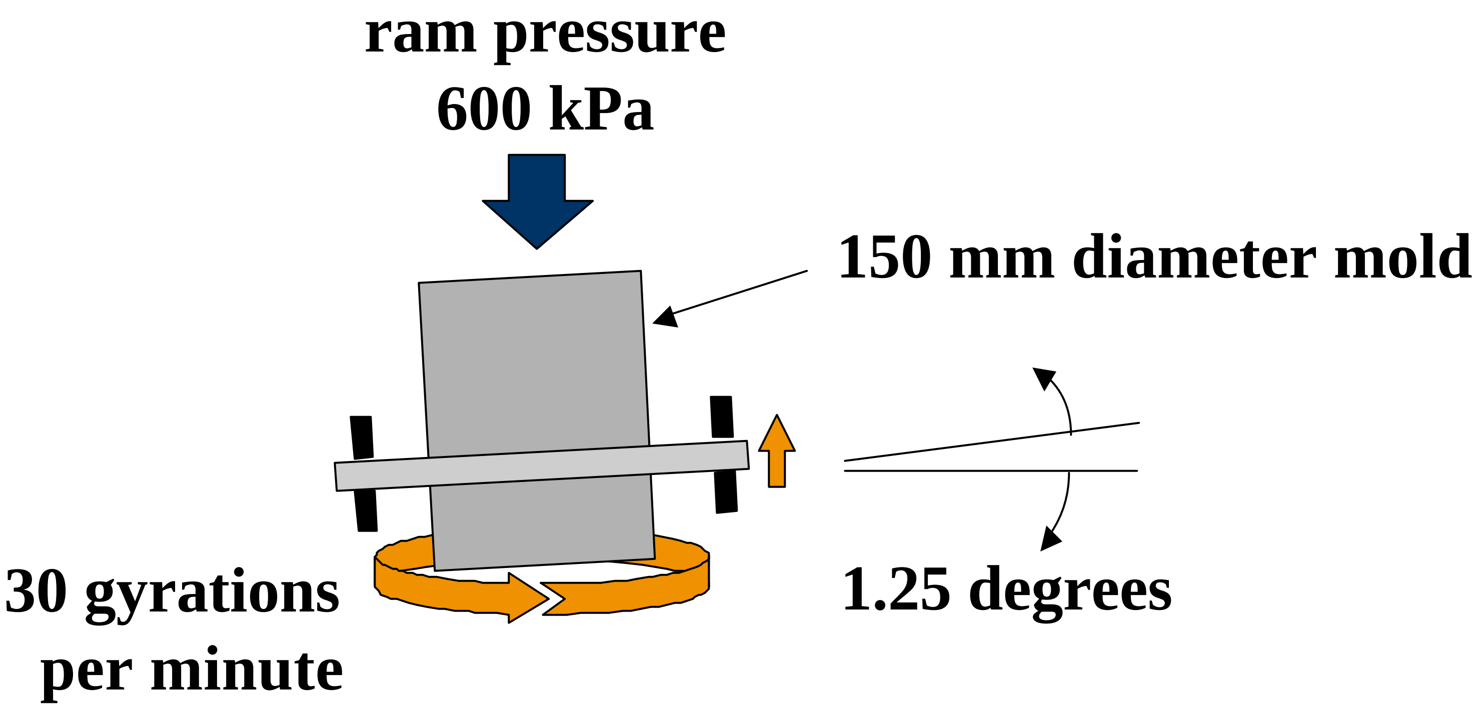
- Simulate field densification
  - –traffic
  - –climate
- Accommodate large aggregates
- Measure compact-ability
- Conducive to QC

Superpave Gyratory Compactor

- Basis
  - Texas equipment
  - French operational characteristics
- 150 mm diameter
  - up to 37.5 mm nominal size
- Height Recordation



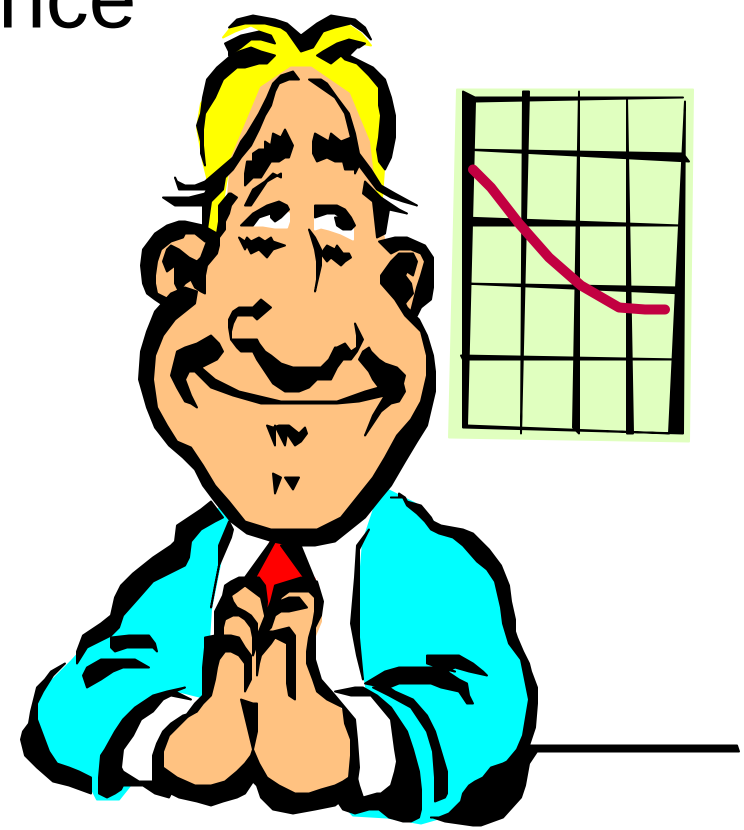
Superpave Gyratory Compactor



FHWA Pooled Fund Purchase
Superpave Gyratory Compactor

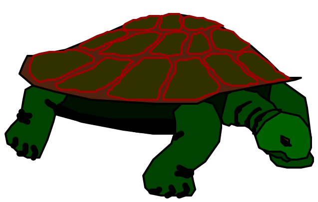
Estimating Trial Binder Contents

- Based on experience for a 19.0 mm nominal, surface mix, the asphalt binder content should be. . ?

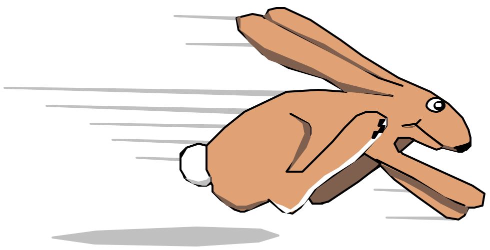


The Calculations

- Step 1: Estimate Gse
- Step 2: Estimate Vba
- Step 3: Estimate Vbe
- Step 4: Estimate Pbi, (binder - initial)



"by hand"



"by computer"

Step 1: Estimate Gse

- Gse = Gsb + 0.8 (Gsa - Gsb)
  - 0.8 factor accounts for absorption, for high absorption aggregates use 0.6 or 0.5
- Trial Blend No. 1, TB#1
- Gse = 2.566 +0.6(2.685 -2.566) = 2.637

Step 2: Estimate Vba

- Vba = f(Va, Pb, Ps, Gb, Gsb, Gse)
  - Va = 0.04, 4% voids
  - Pb = 0.05, (approximately 5% binder)
  - Ps = 1 - Pb = 0.95
- TB#1: Vba = 0.0233

Step 3: Estimate Vbe

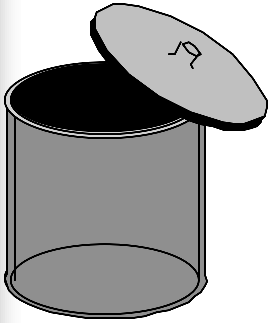
- Vbe = 0.176 - 0.0675 Ln (Sn)
  - – Sn = Nominal maximum size in mm
- Vbe = 0.176 - 0.0675 Ln(19) = 0.090
  - – This value is true for **all** blends.

Step 4: Estimate Pbi

- Pbi = f(Va, Gb, Gse, Vbe, Vba)
- TB#1: Pbi = 4.95 %
- Author's Note: The equations can not replace experience.

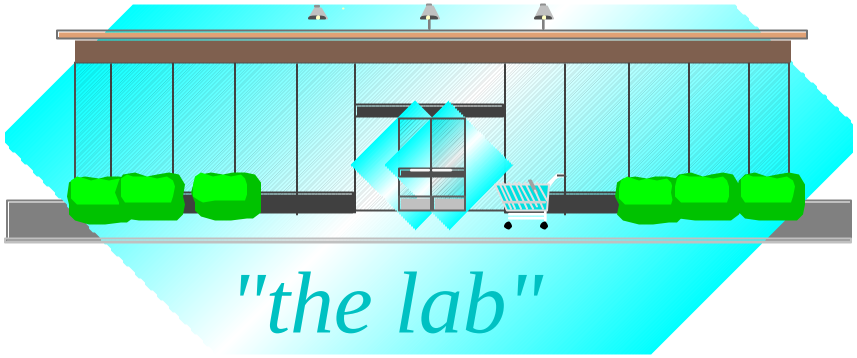
Summary of Estimated Pbi

Trial Blend	P*bi*	Use
1	4.95	5.0
2	4.98	5.0
3	4.95	5.0



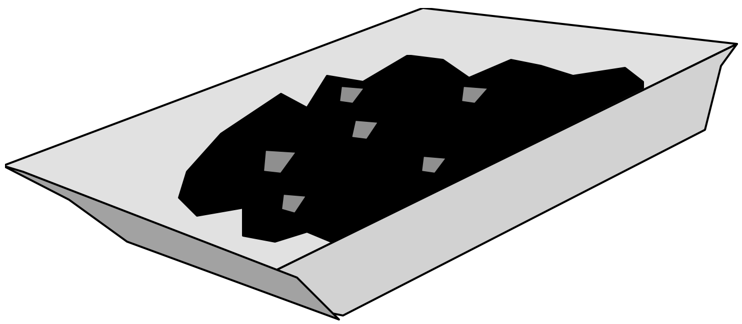
Required Testing

Trial Blend	SGC	Rice, G_{mm}
1	3 (4800 g/ea)	2 (2000 g/ea)
2	3	2
3	3	2
Total 55.2 kg	43.2 kg	12.0 kg

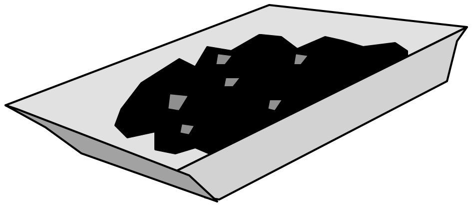


Required Aging

- Original Specification:
  - Aging of both gyratory and G_{mm} samples,
  - 4 hours at 135°C in a forced-draft oven,
  - Mixing samples every hour.



Required Aging '99



- Specimens are mixed at the equiviscous mixing temperature.
- Specimens are short term aged for 2-hours at the equiviscous compaction temperature in a forced-draft oven.
- **This is only for volumetric design.**

Aging

History Lesson on Compaction

- SHRP researcher evaluated 9 GPS sites to develop the original SGC compaction table.
- Mixture ETG conducted the “N-design II” study using data for State projects, TFHRC, and WesTrack.
- NCHRP 9-9 investigated the sensitivity of the original compaction table

History continued. . .

- September 23, 1998, a date which changed SGC compaction forever.
  - – Mixture ETG, Baltimore, Maryland

Compaction

SGC Criteria

- N ini - “Tenderness Check” represents the mix during construction. Mixes that compact too quickly in the SGC may have tenderness problems during construction.
- N des - . . .
- N max - . . .

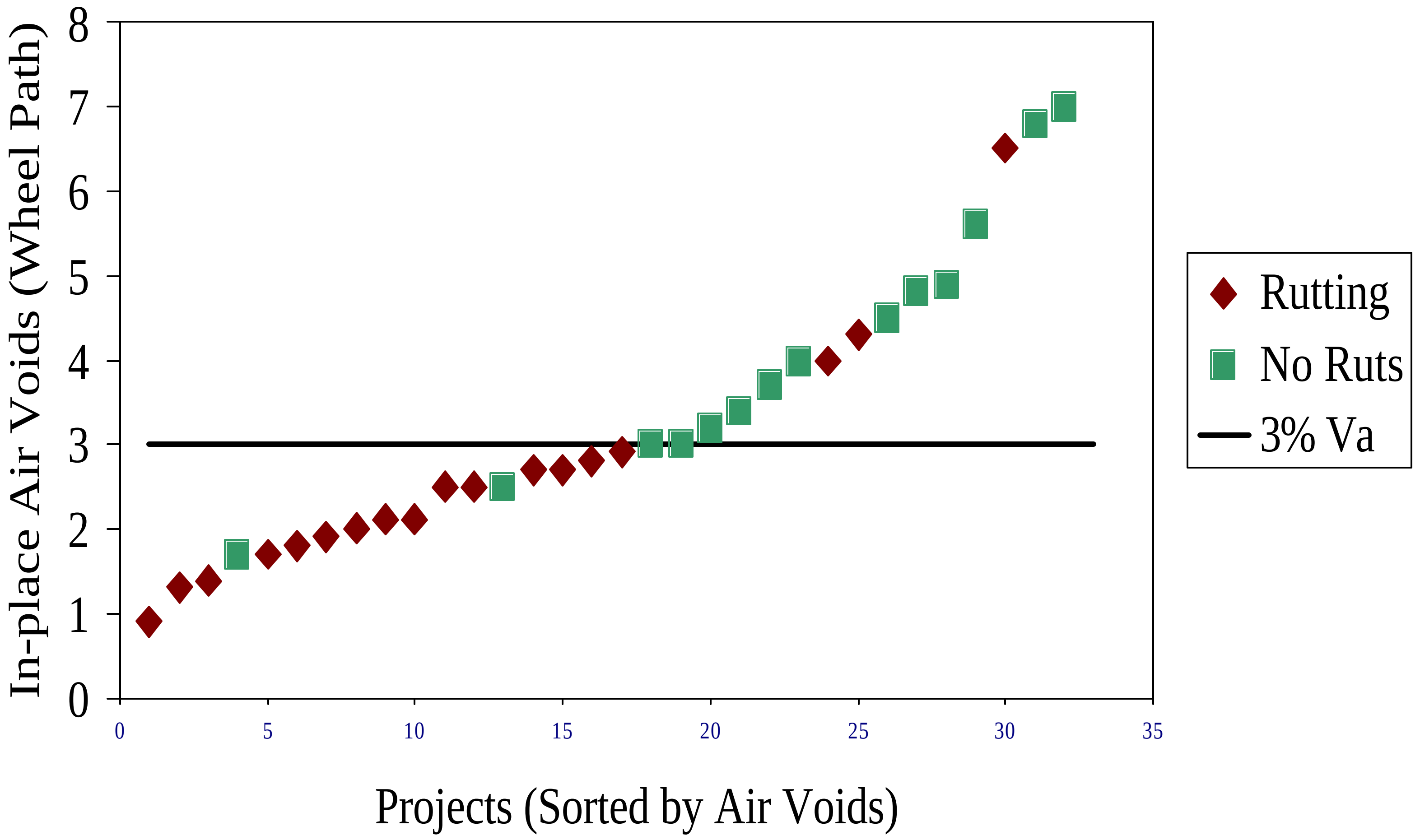
SGC Criteria

- N ini
- N des - “Volumetric Check” Represents the mix after construction and initial trafficking. Mix volumetrics, (Va, VMA, and VFA), are compared to empirically based criteria.
- N max - . . .

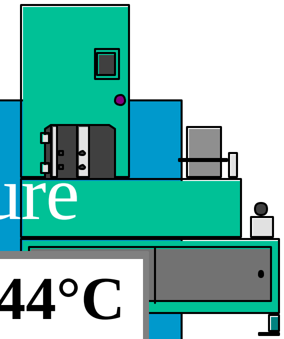
SGC Criteria

- N ini
- N des
- N max - **Optional** "Rutting Check" Mixes that commonly rut have been compacted below 2% air voids under traffic. Mixes compacting below 2% air voids in the SGC may have rutting problems.

Why Volumetrics ?
Colorado Study



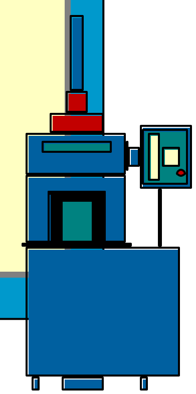
Original SGC Compaction Effort



7 Day Average Design High Air Temperature

Estimated Traffic	< 39°C	39°-40°C	41°-42°C	43°-44°C
< 0.3	68			
< 1				
< 3				
< 10				
< 30				
< 100				
≥ 100				172

28 Compaction Levels



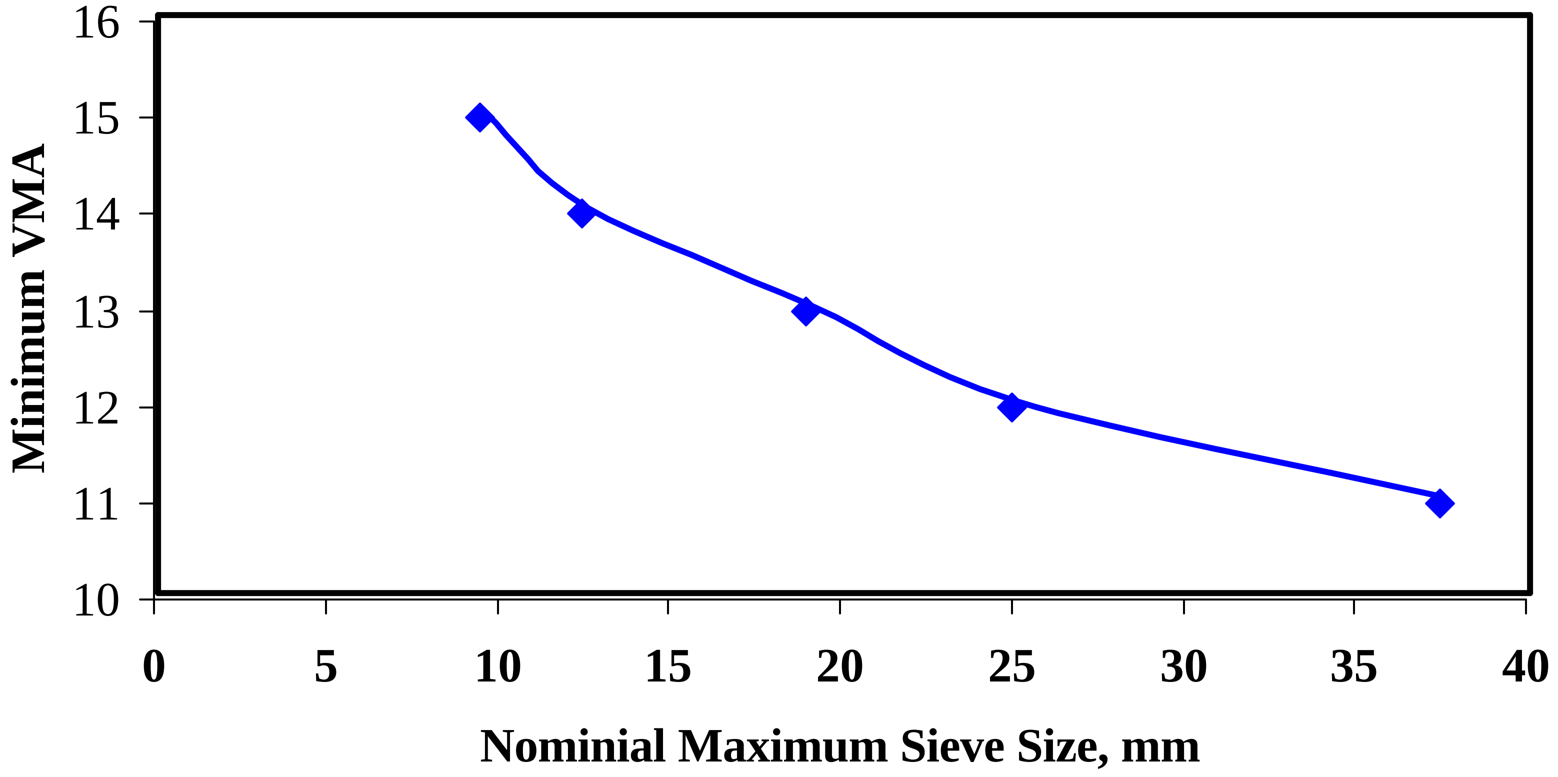
SGC Compaction Effort '99

ESAL's	N_{ini}	N_{des}	N_{max}	App
< 0.3	6	50	75	Light
0.3 to < 3	7	75	115	Medium
3 to < 30	8	100*	160	High
10 to <30	8	100	160	High
≥ 30	9	125	205	Heavy

Base mix *(< 100 mm)* option to drop one level, unless the mix will be exposed to traffic during construction.

Q. What should VMA criteria be a function of ?

Voids in Mineral Aggregate, VMA



Volumetric Design Criteria ‘99

Traffic ESAL	SGC Criteria			VMA	VFA	$\frac{\text{Fines}}{P_{be}}$
	N_{ini}	N_{des}	N_{max}			
< 0.3	$\le$91.5				70-80	
< 3	$\le$90.5				65-78	0.6
< 10	$\le$89.0	=96.0	$\le$98.0	n/a		-to-
< 30	$\le$89.0				65-75	1.2
> 30	$\le$89.0					

Hot Mix, USA

Est. 20-year design traffic is 6.3M ESAL's

Property	Criteria
N_{ini} / $\%G_{mm}$	
N_{des} / $\%G_{mm}$	
N_{max} / $\%G_{mm}$	
VMA	
VFA	
Dust-to-Binder	

Hot Mix, USA

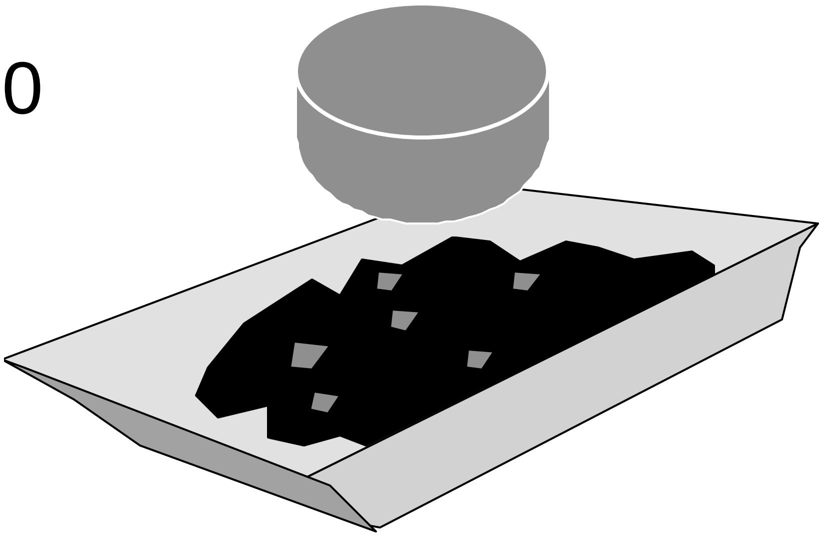
Est. 20-year design traffic is 6.3M ESAL's

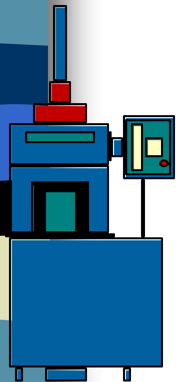
Property	Criteria
N_{ini} / $\%G_{mm}$	8 gyr $\leq$ 89%
N_{des} / $\%G_{mm}$	100 gyr = 96%
N_{max} / $\%G_{mm}$	160 gyr $\leq$ 98%
VMA	13.0 min
VFA	65 to 75
Dust-to-Binder	0.6 to 1.2

SGC Compaction Curve

- % G_{mm} vs Log (No. of Gyrations)
  - Height is monitored during compaction and is used to calculate the densification of the specimen, expressed as % G_{mm}.

$$\%G_{mm\ des} = \frac{Gmb}{Gmm} * 100$$

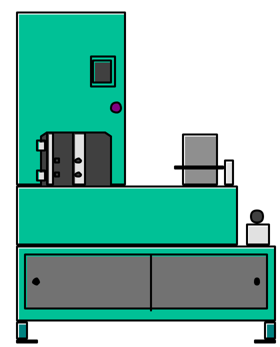




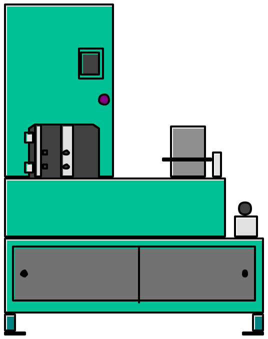
SGC Compaction Curve

- % G_{mm} vs Log (No. of Gyrations)
  - – Height data, h ini, h des

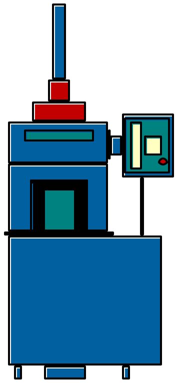
$$\%G_{mm}\ ini = \%\ G_{mm}\ des * \frac{h\ des}{h\ ini}$$



SGC Compaction Calculations



- Trail Blend No. 1
- G_{mm} = **2.475**
  - Specimen 1, Gmb = 2.351
  - Specimen 1, Gmb = 2.348
  - Specimen 1, Gmb = 2.353



SGC Calc's for Trial Blend No. 1

- Specimen 1

- %Gmm des = $\frac{Gmb}{Gmm}$ * 100 = $\frac{2.351}{2.475}$ * 100

- %Gmm des = 95.0 % = 96.0% Criterion

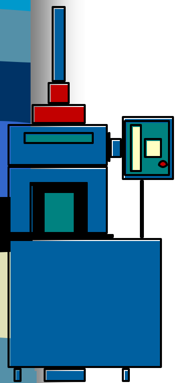
SGC Calc's for Trial Blend No. 1

- **Q.** What are they for specimens 2 & 3 ?

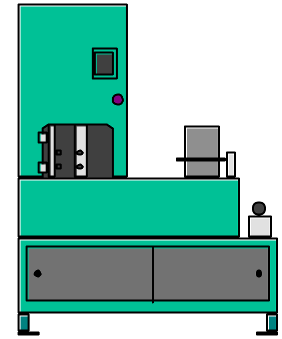
- $\%Gmm_{des} = \frac{Gmb}{Gmm} * 100 = ?$

SGC Calc's for Trial Blend No. 1

- %Gmm max for specimens 2 & 3:
- 2, %Gmm des = 94.9 %
- 3, %Gmm des = 95.1 %



SGC Height Data



- Trail Blend No. 1

TB 1 Specimen	H_{ini}	H_{des}	% G_{mm} at N_{des}
1	129.6	117.4	95.0 %
2	129.8	117.4	94.9 %
3	129.9	117.8	95.1%

- %Gmm ini = 95.0*(117.4/129.6) = 86.1%

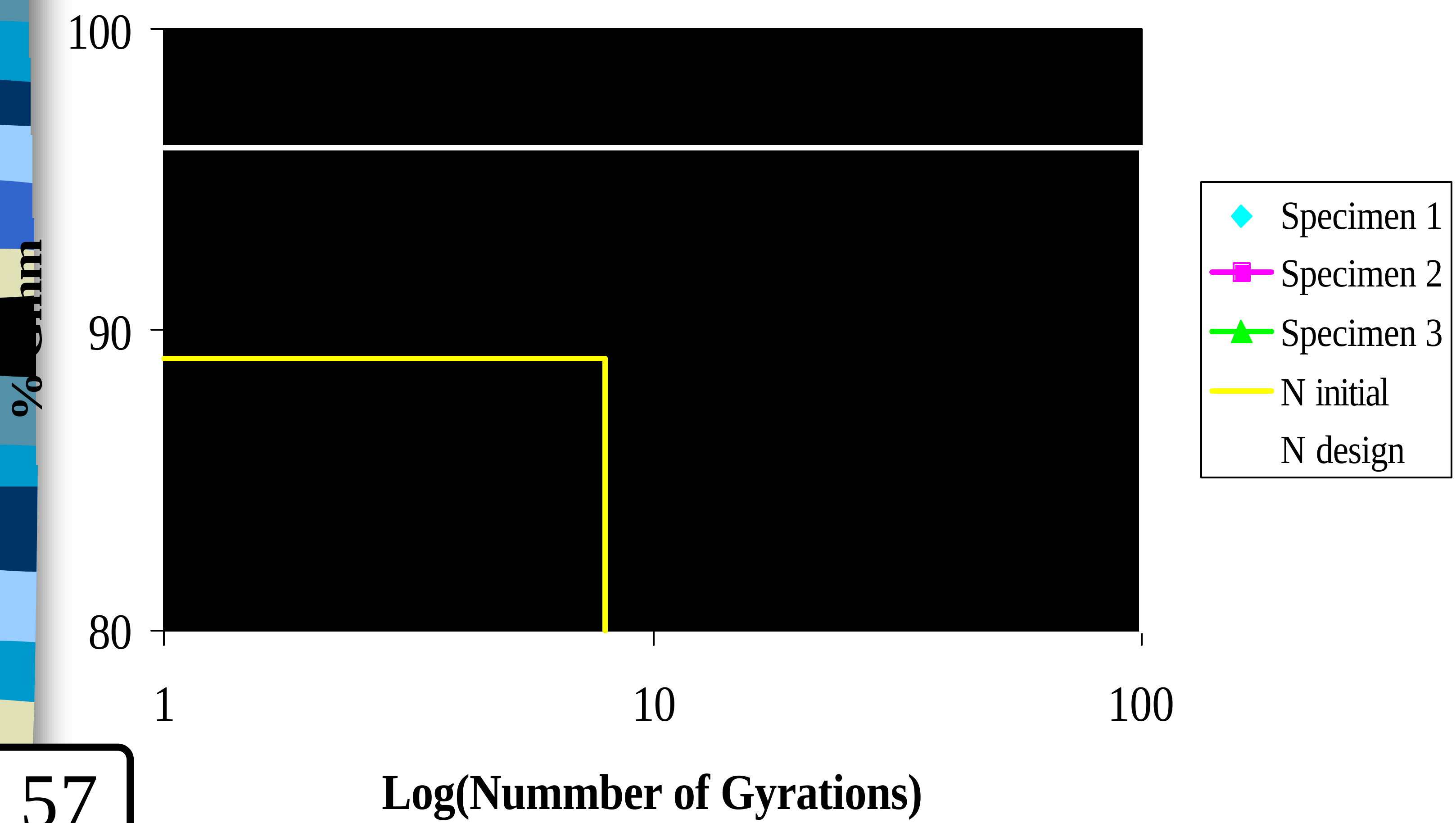
%Gmm ini

What is %Gmm ini
for specimens 2 & 3 ?

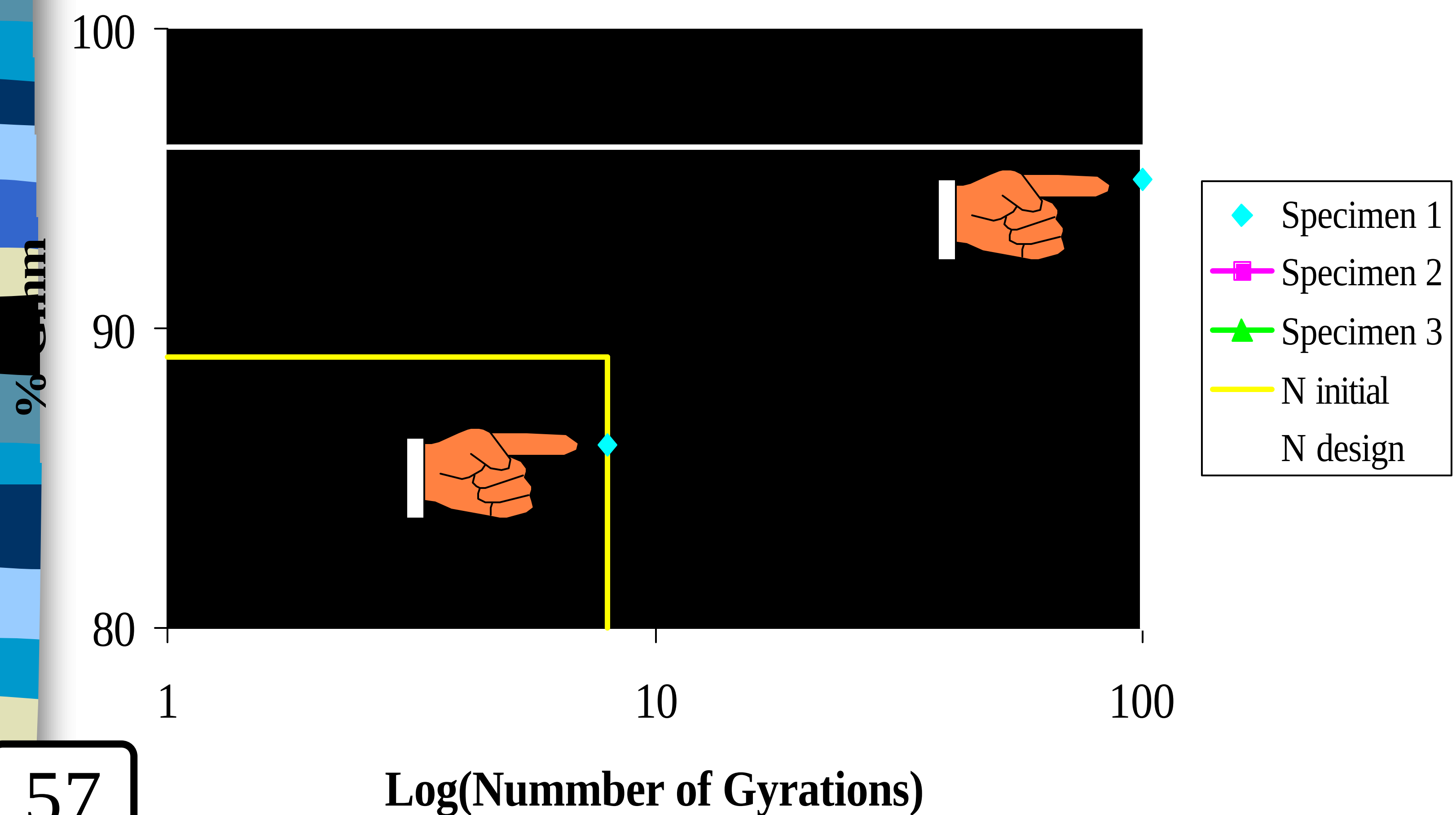
%Gmm ini

- 2: %Gmm ini = 85.8 %
- 3: %Gmm ini = 86.2 %

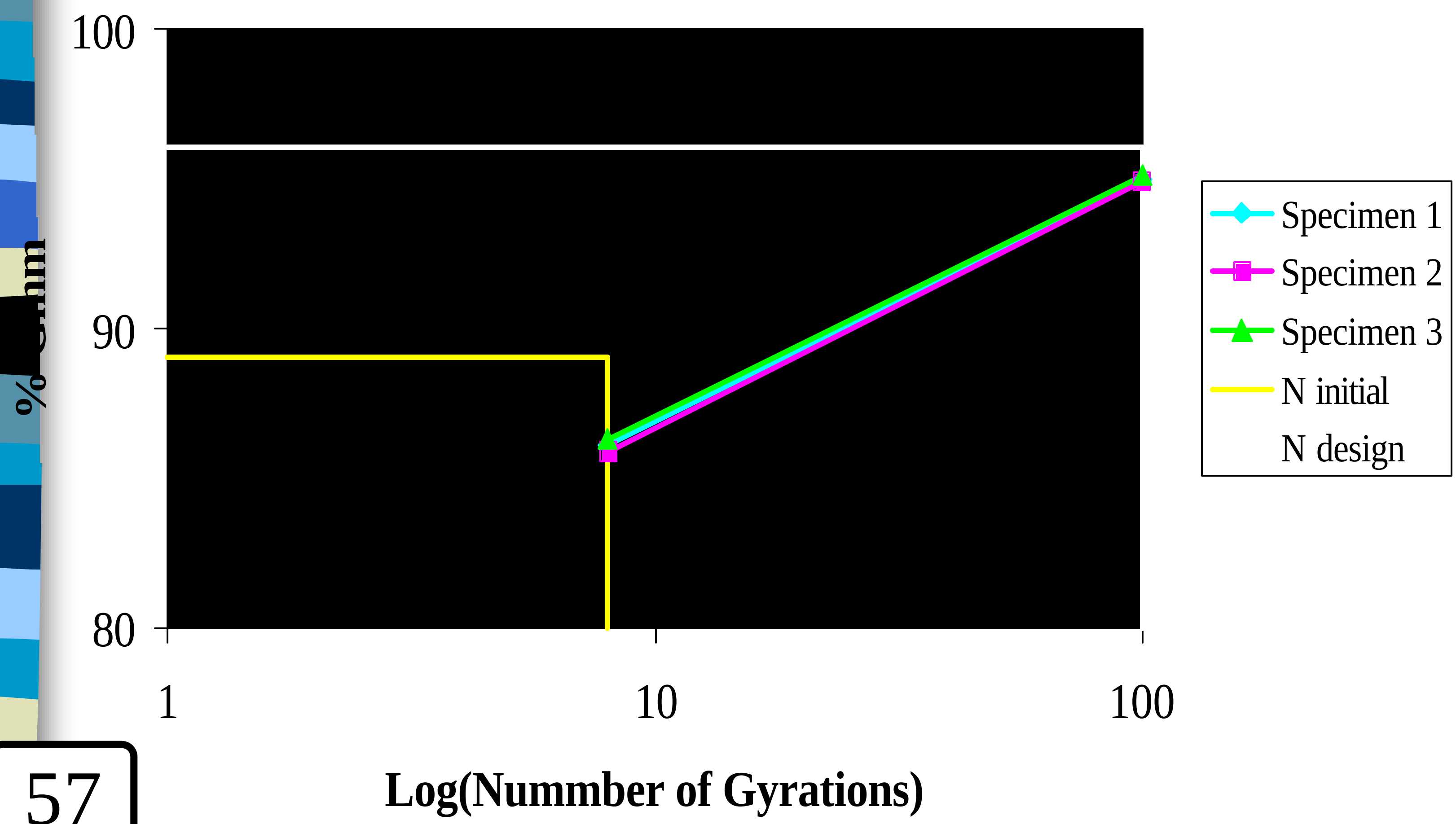
SGC Compaction Chart



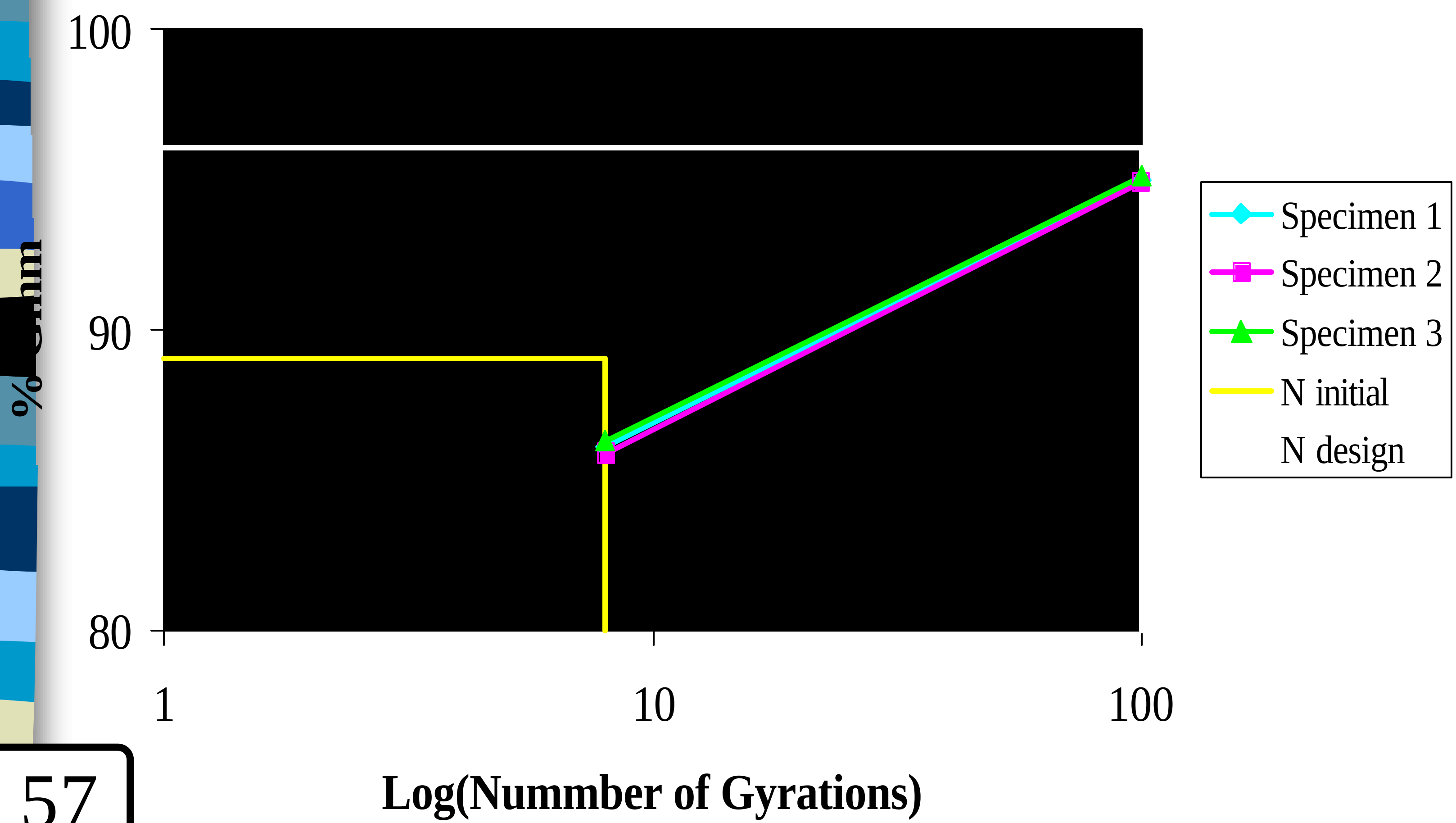
SGC Compaction Chart



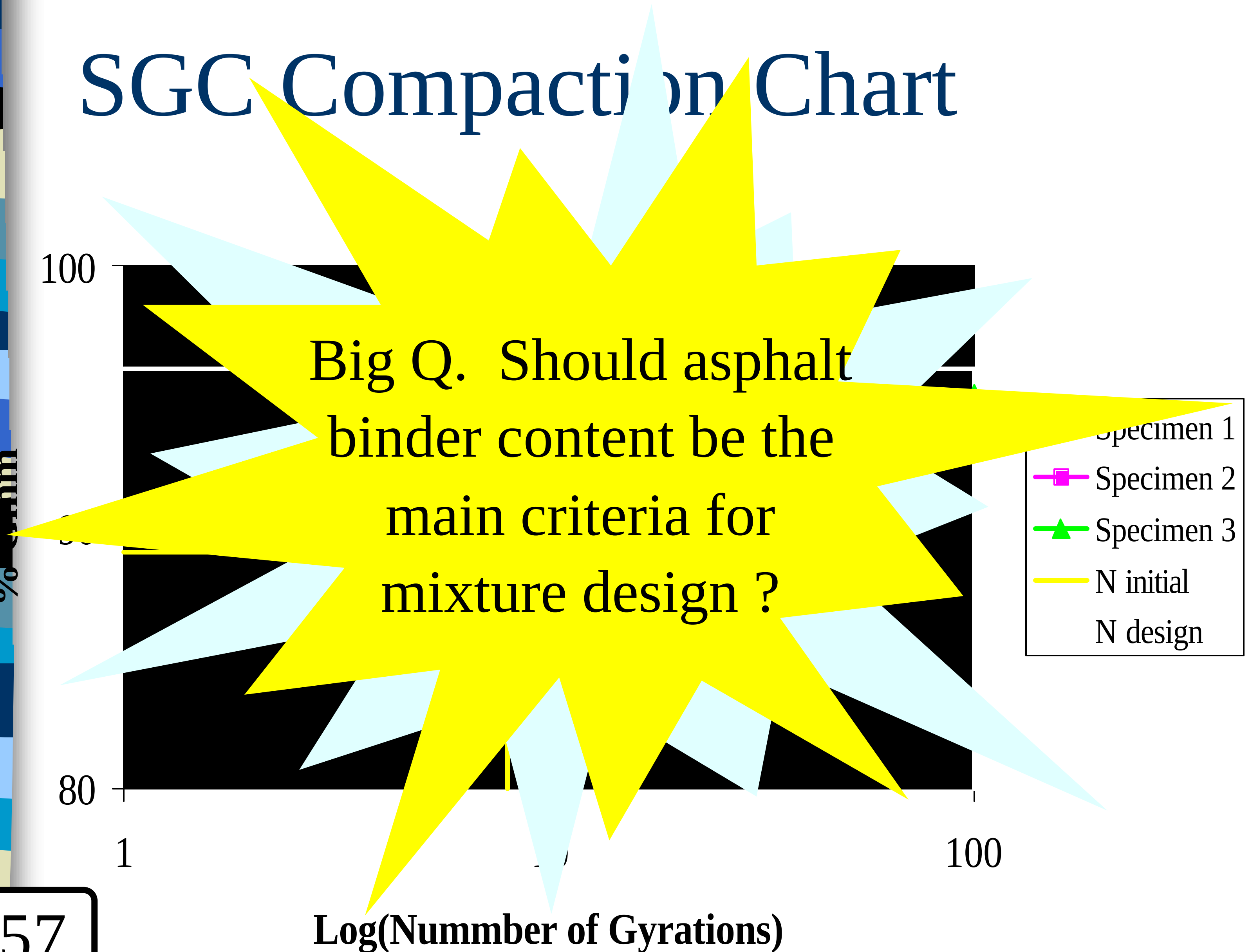
SGC Compaction Chart



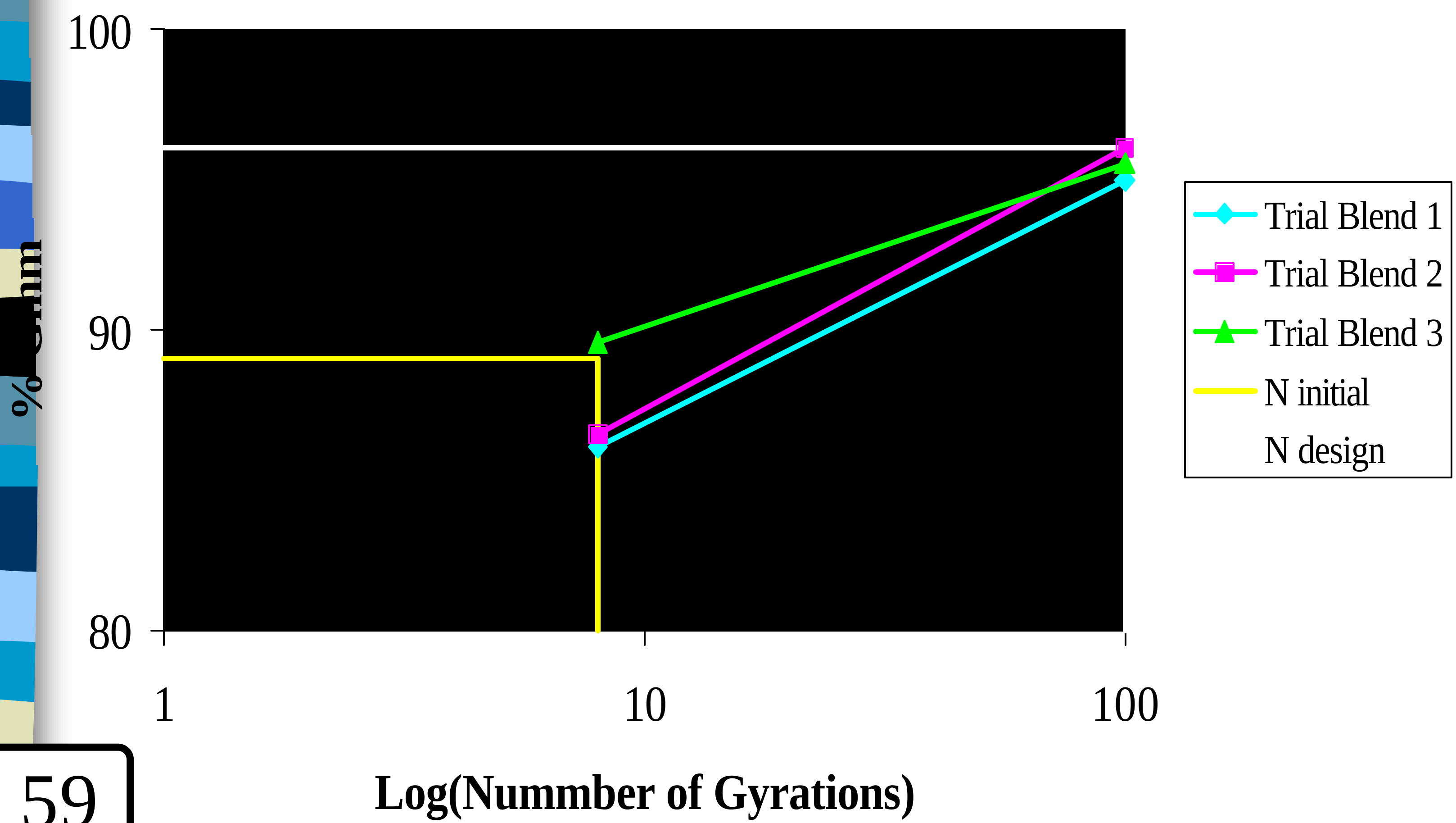
Q. Is binder content high or low?



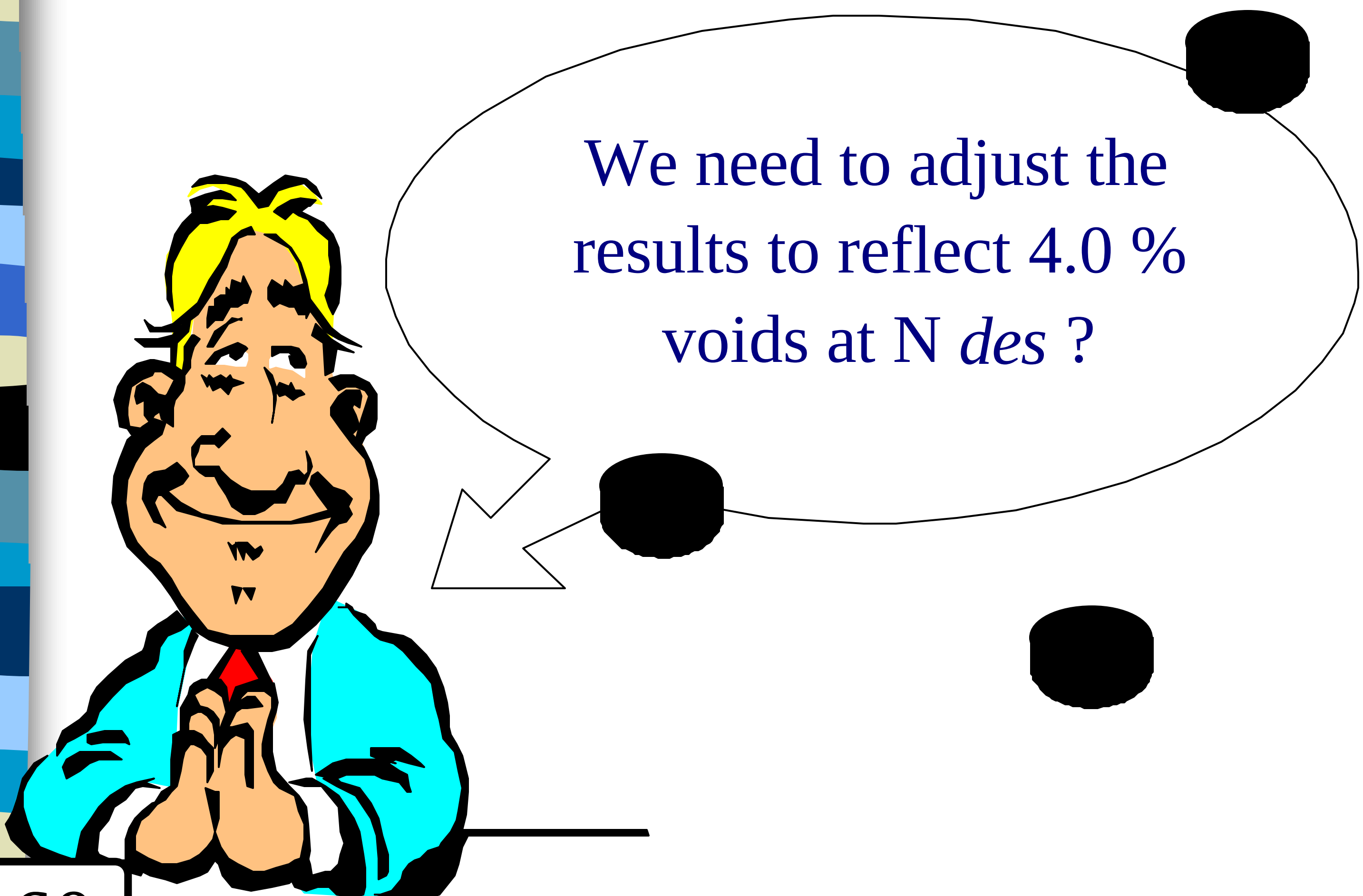
SGC Compaction Chart



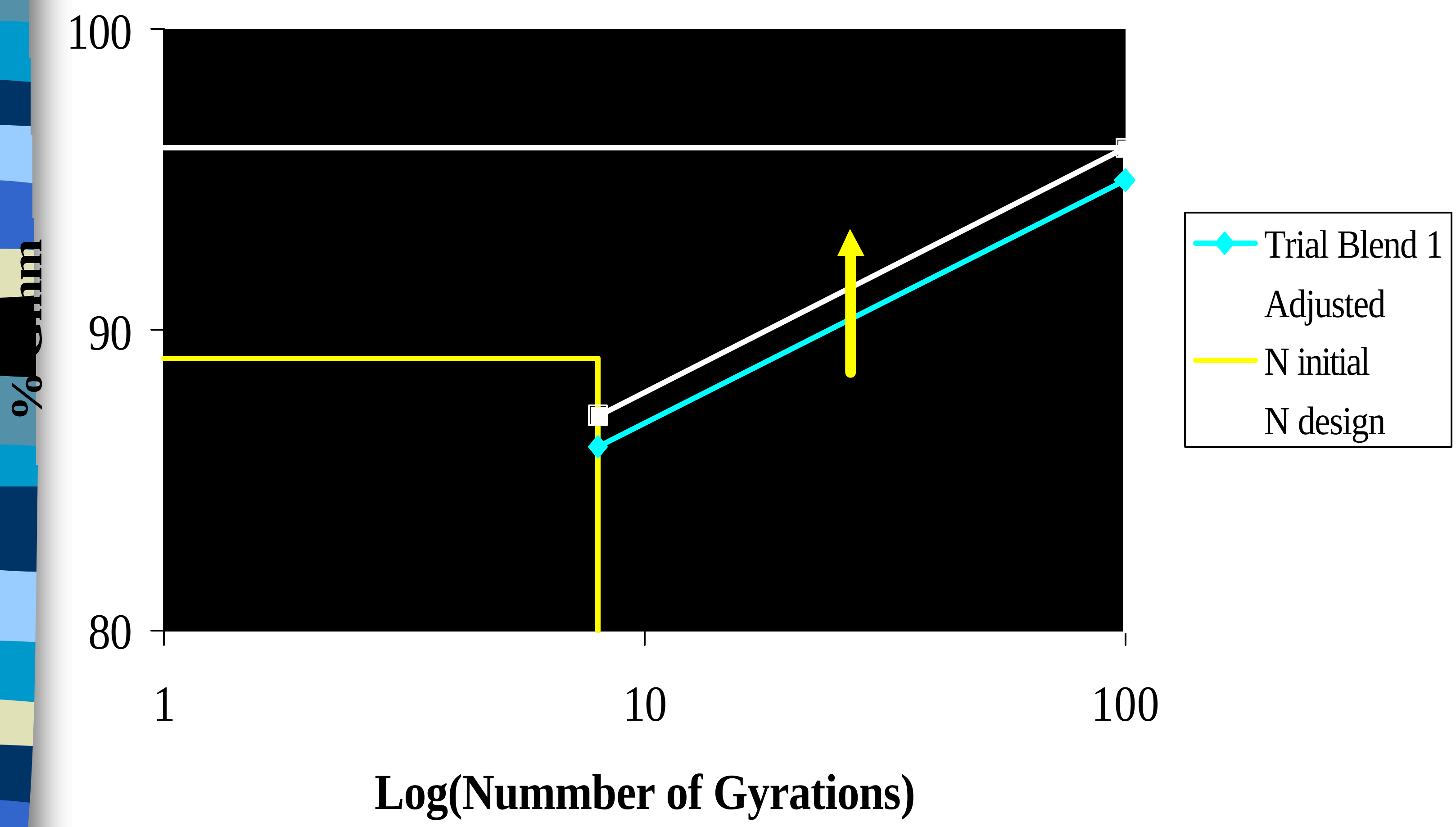
Trial Blends



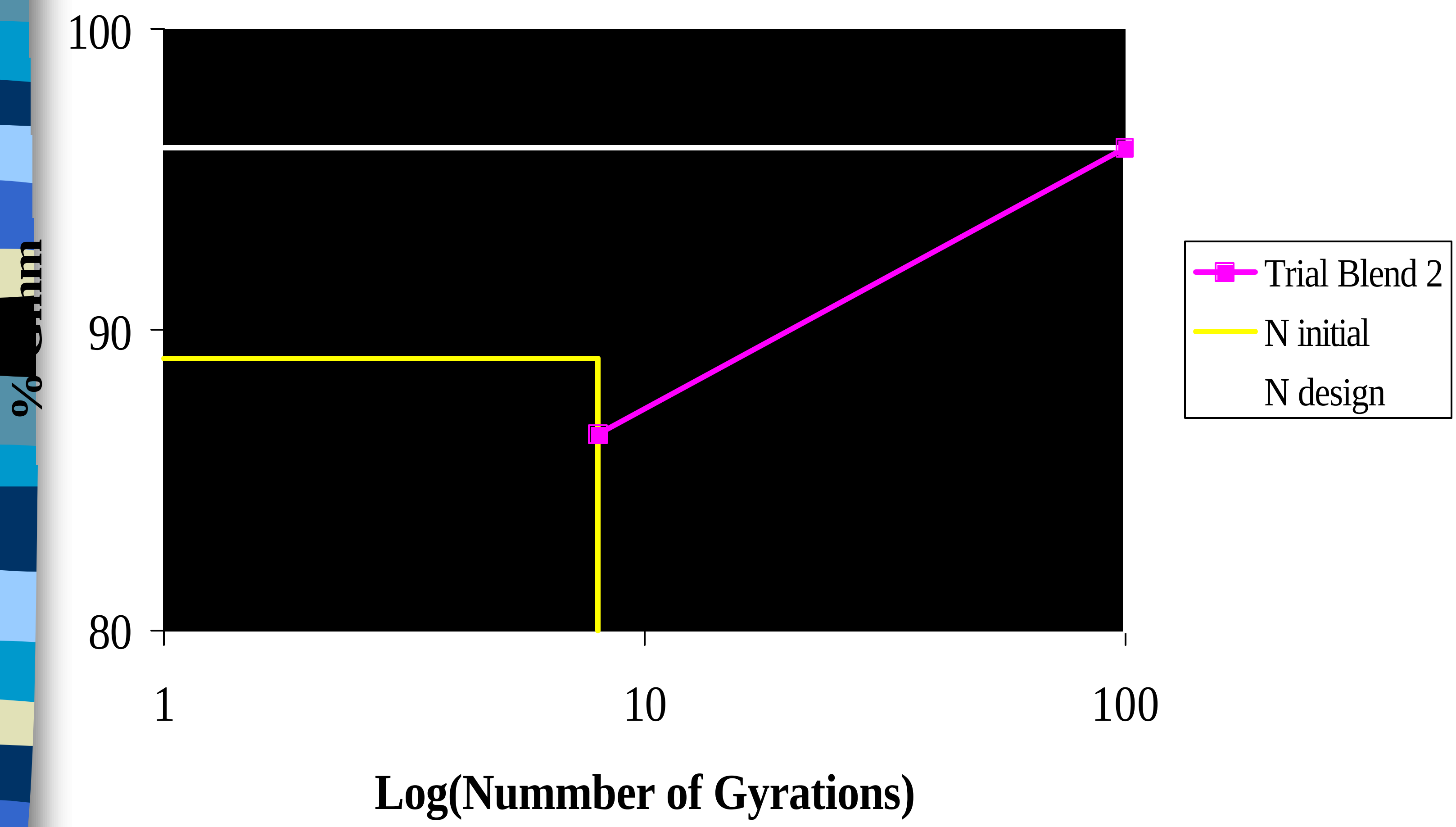
How do we choose ?



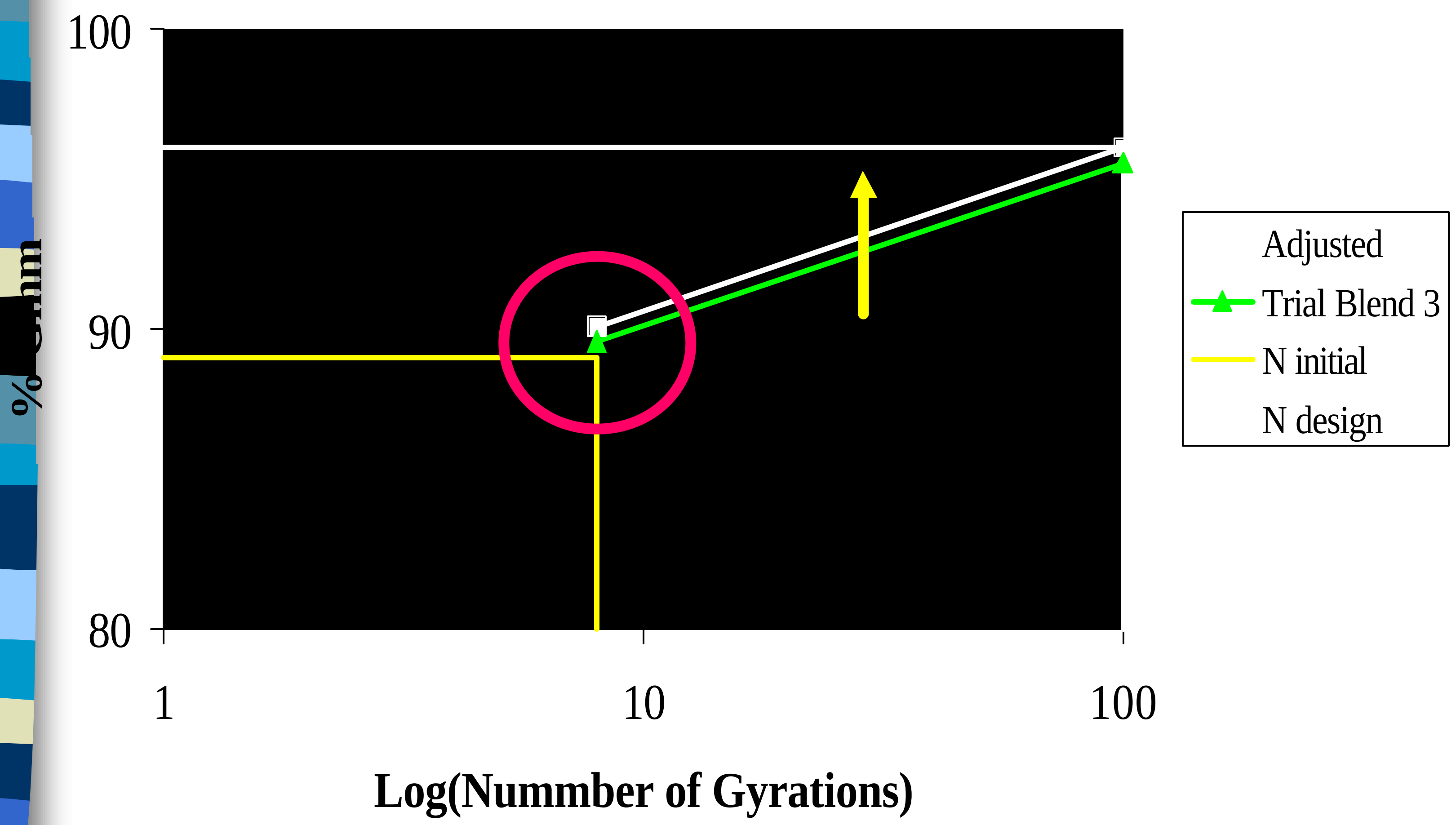
Trial Blend No. 1



Trial Blend No. 2

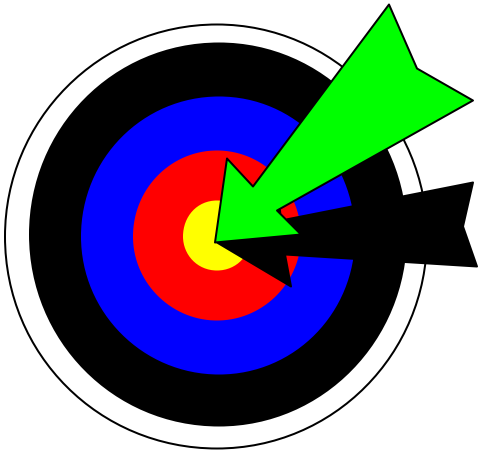


Trial Blend No. 3



Estimating the Properties at 4% Va

- 1) Estimate binder content
- 2) Estimate VMA
- 3) Estimate VFA
- 4) Estimate %Gmm ini
- 5) Estimate Dust-to-Binder ratio

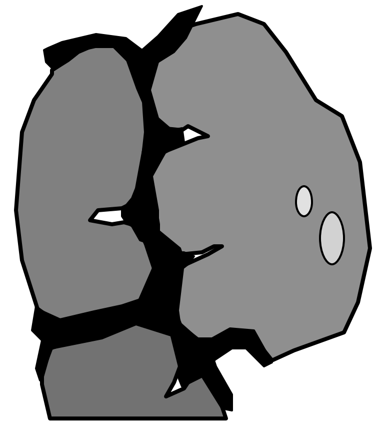


Estimate Pb with 4% Va

- Pb, est = Pbi - [0.4 *(4 - Va at N des)]
- Rule: 1 % Air Voids = 0.4 % Binder

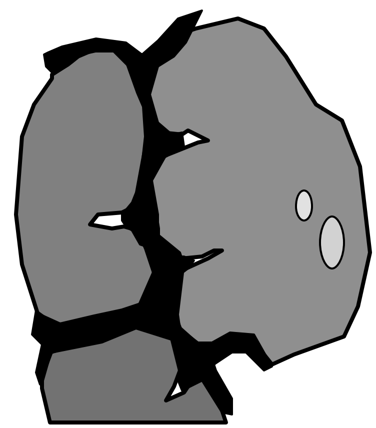
Estimate VMA at N_{des} w/ 4% Va

- VMA, est = VMA + C (4 - Va at N des)
  - – C = constant (either 0.1 or 0.2)
  - – C = 0.1, when Va is less than 4.0%
  - – C = 0.2, when Va is 4.0% or g



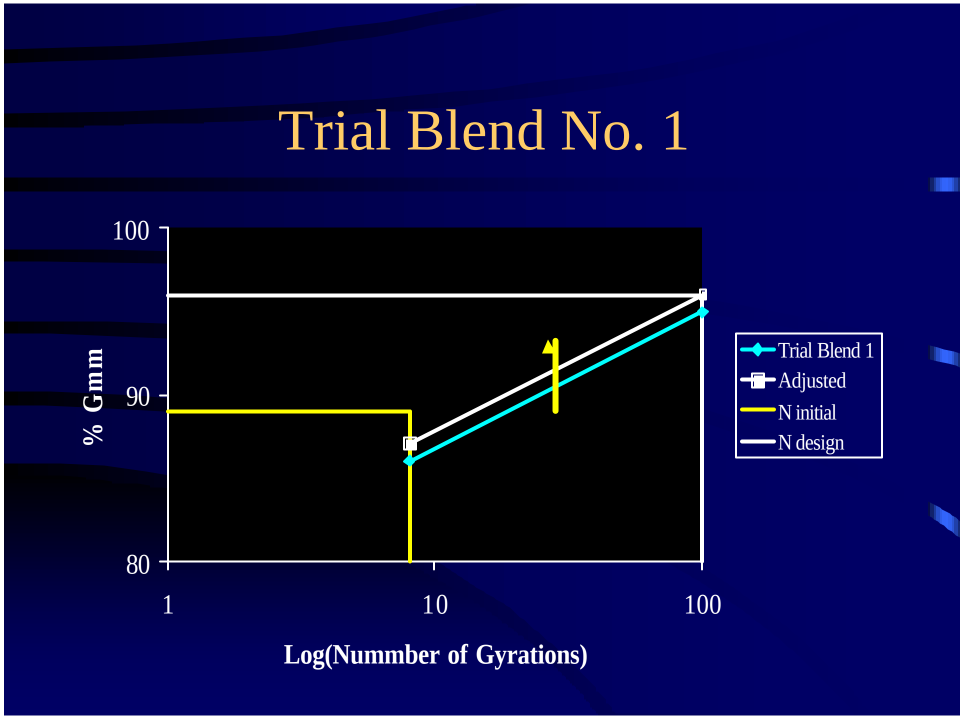
Estimate VFA at N_{des} w/ 4% Va

- $$VFA, est = 100 \frac{(VMA, est - 4)}{VMA, est}$$



Estimate %Gmm ini & %Gmm max

- %Gmm ini, est = %Gmm ini -(4 - Va at N des)



Estimate F/Pbe w/ 4% Va

- Pbe, est = f(Gb, Gse, Gsb, Pb est)
- Author's Note: The Dust-to-Binder ratio in Superpave is based upon the effective asphalt binder content, NOT the total.

Compare Estimated Properties to Volumetric Criteria

Property	**Criteria**
N_{ini} / % G_{mm}	8 gyr ≤ 89%
N_{des} / % G_{mm}	100 gyr = 96%
VMA	13.0 min
VFA	65 to 75
Dust-to-Binder	0.6 to 1.2

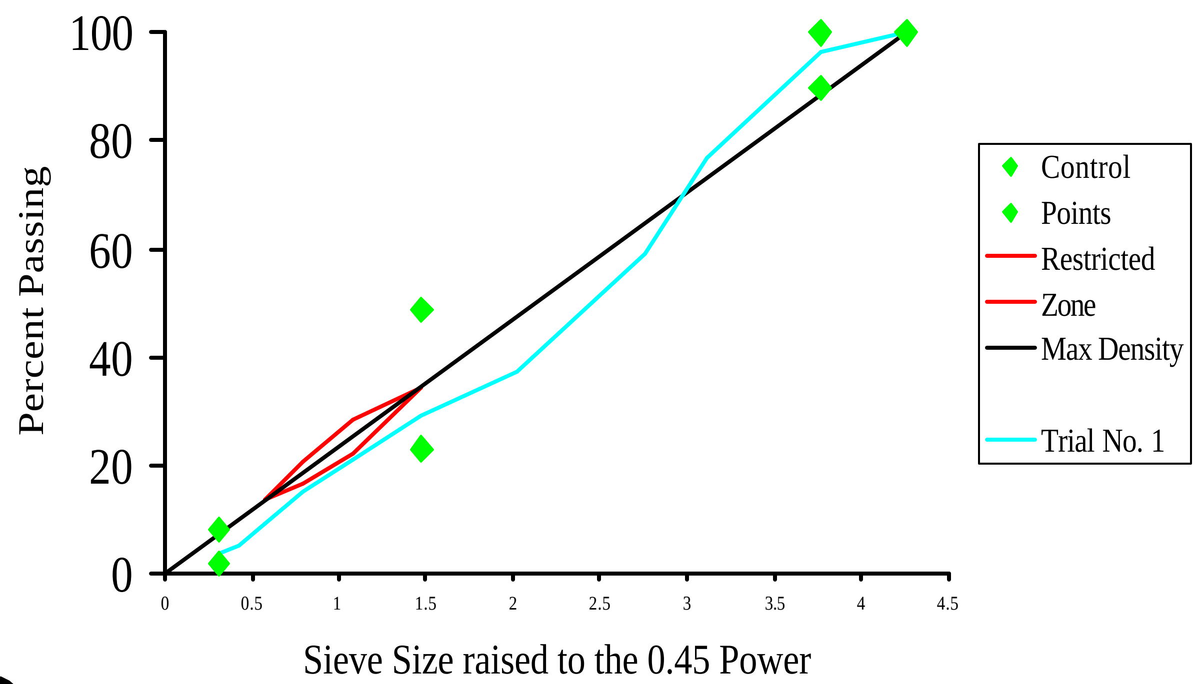
Summary of Estimated Properties

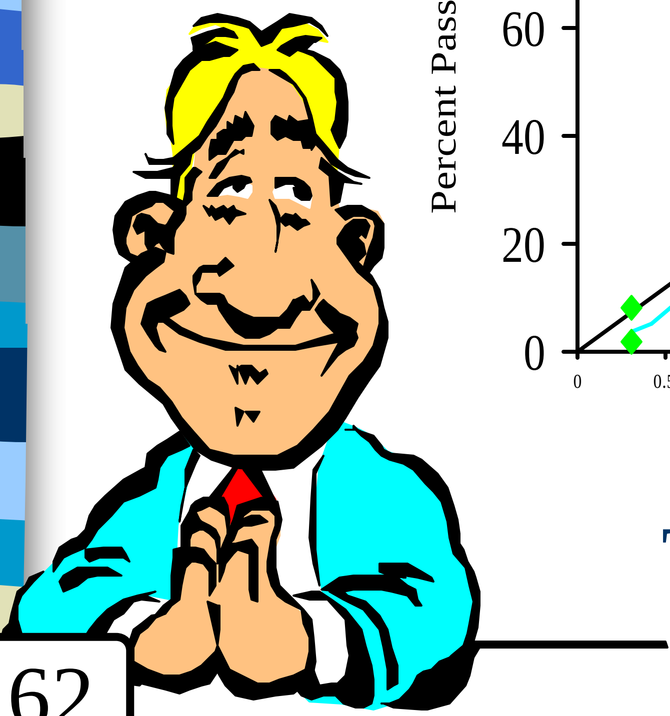
Trial Blends	P_b	VMA at N_{des}	VFA at N_{des}	$\underline{\text{Fines}}$ P_{be}	$\%G_{mm}$ at N_{ini}
1	5.4	13.8	71	0.82	87.1
2	5.0	13.0	69	0.81	86.5
3	5.2	13.4	70	1.15	90.1
Criteria		13 min	65-75	0.6-1.2	89 max

Summary of Estimated Properties

Trial Blends	P_b	VMA at N_{des}	VFA at N_{des}	Fines / P_{be}	$\%G_{mm}$ at N_{ini}
1	5.4	13.8	71	0.82	87.1
2	5.0	13.0	69	0.81	86.5
3	5.2	13.4	70	1.15	90.1
Criteria		13 min	65-75	0.6-1.2	89 max

Design Aggregate Structure





Trial Blend No. 1

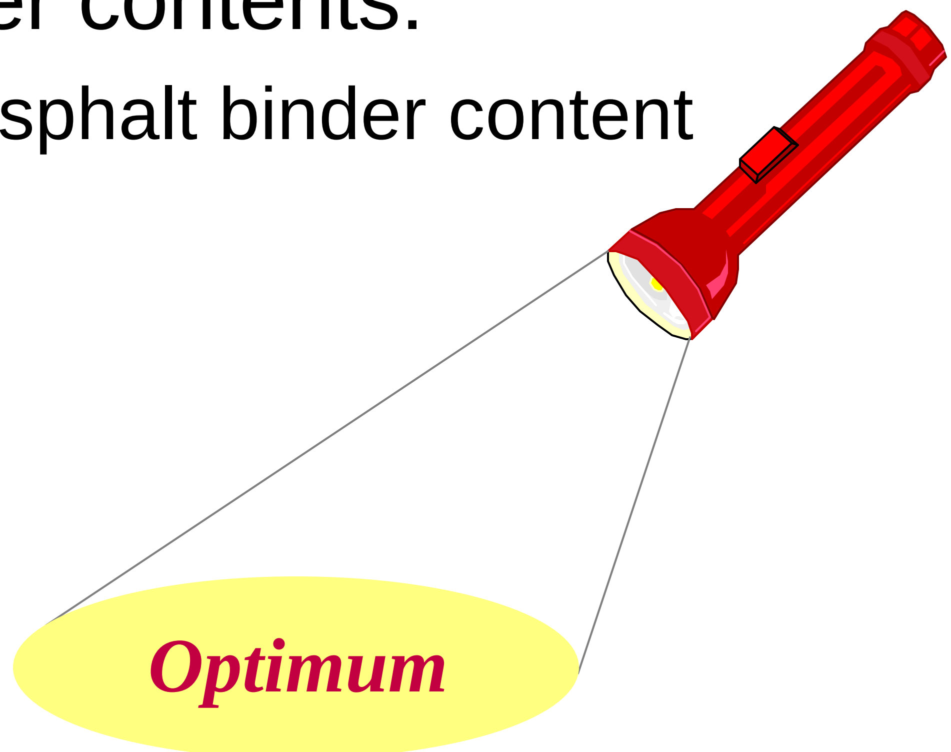
Q. What if all three Trial Blends meet the design requirement ?

Selection of the Design Asphalt Binder Content

Optimum P_b

Design Asphalt Binder Content

- Specimens are compacted at varying asphalt binder contents:
  - Estimated asphalt binder content
  - ± 0.5 %
  - + 1.0 %



Lead States

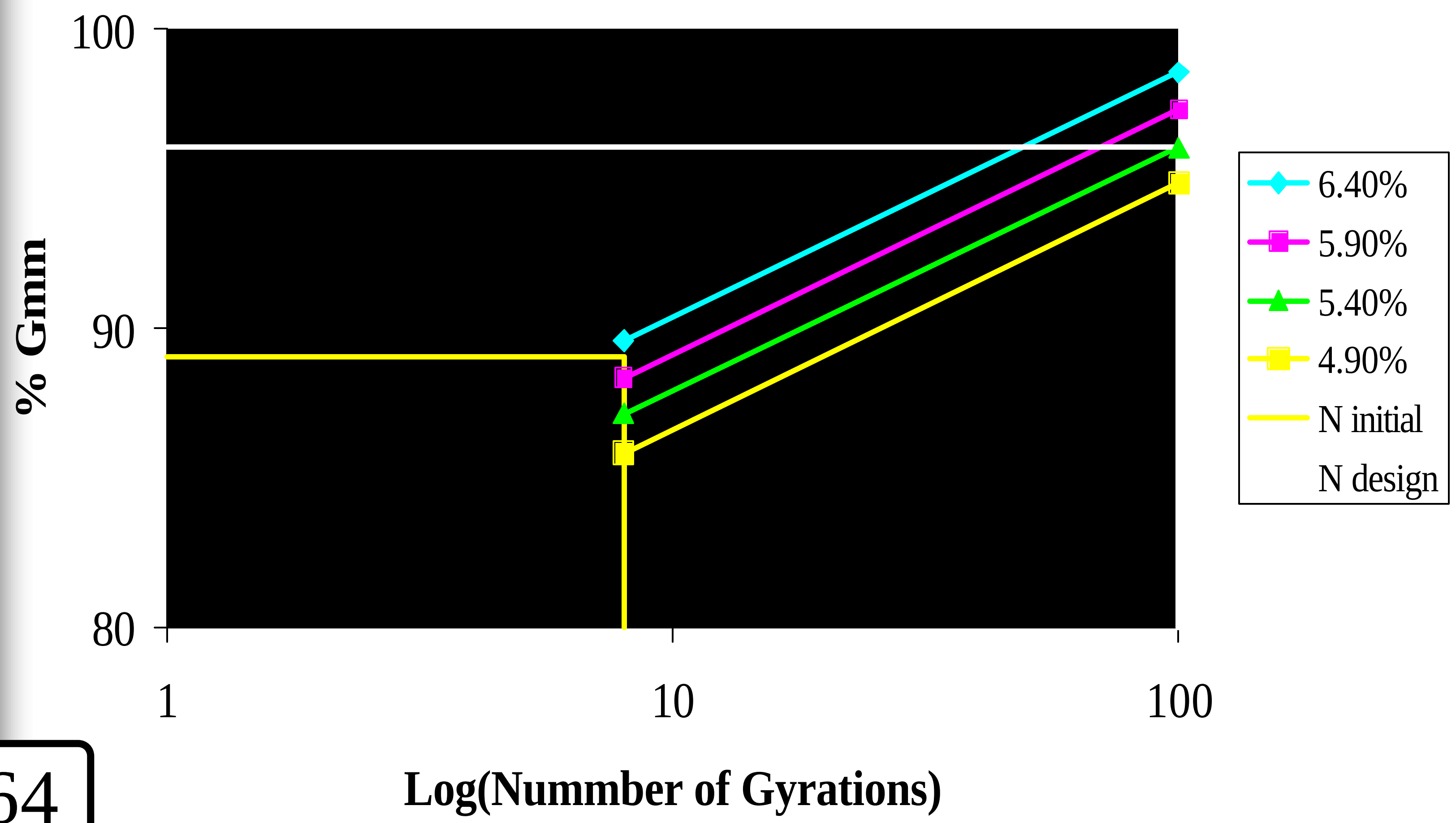
- Based upon the recommendations of NCHRP 9-9,
- Optimization of the design aggregate blend is only compacted to N_{des}

- Check the design aggregate blend at the optimum asphalt compacted to N_{max}

Required Tests

Batched Pb	SGC Specimens	Gmm Rice
4.9 (- ½ %)	3 (4800 g/ea)	2 (2000 g/ea)
5.4 (Target)	3	2
5.9 (+ ½ %)	3	2
6.4 (+ 1 %)	3	2
Total	57,600 g	16,000 g

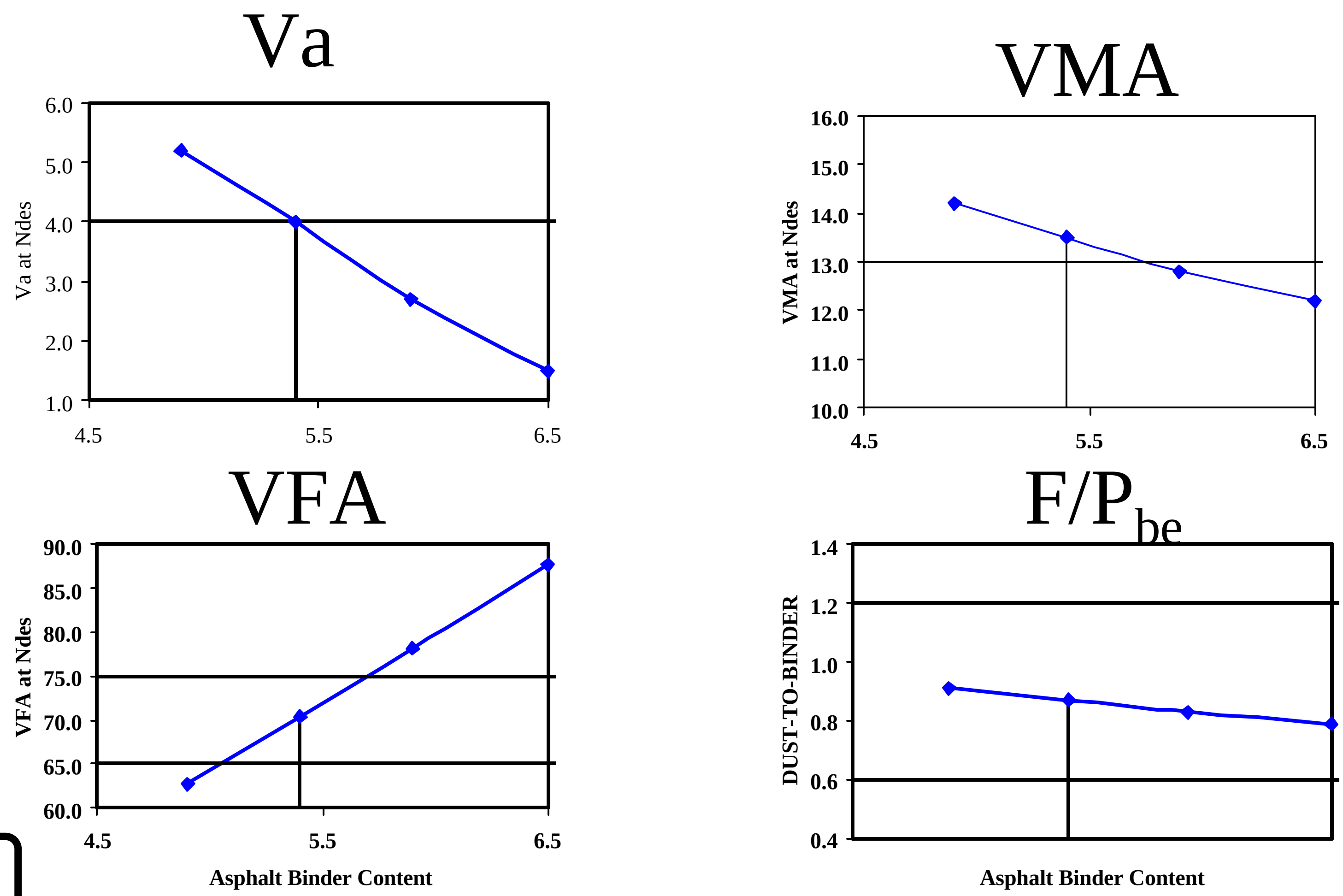
SGC Compaction Chart



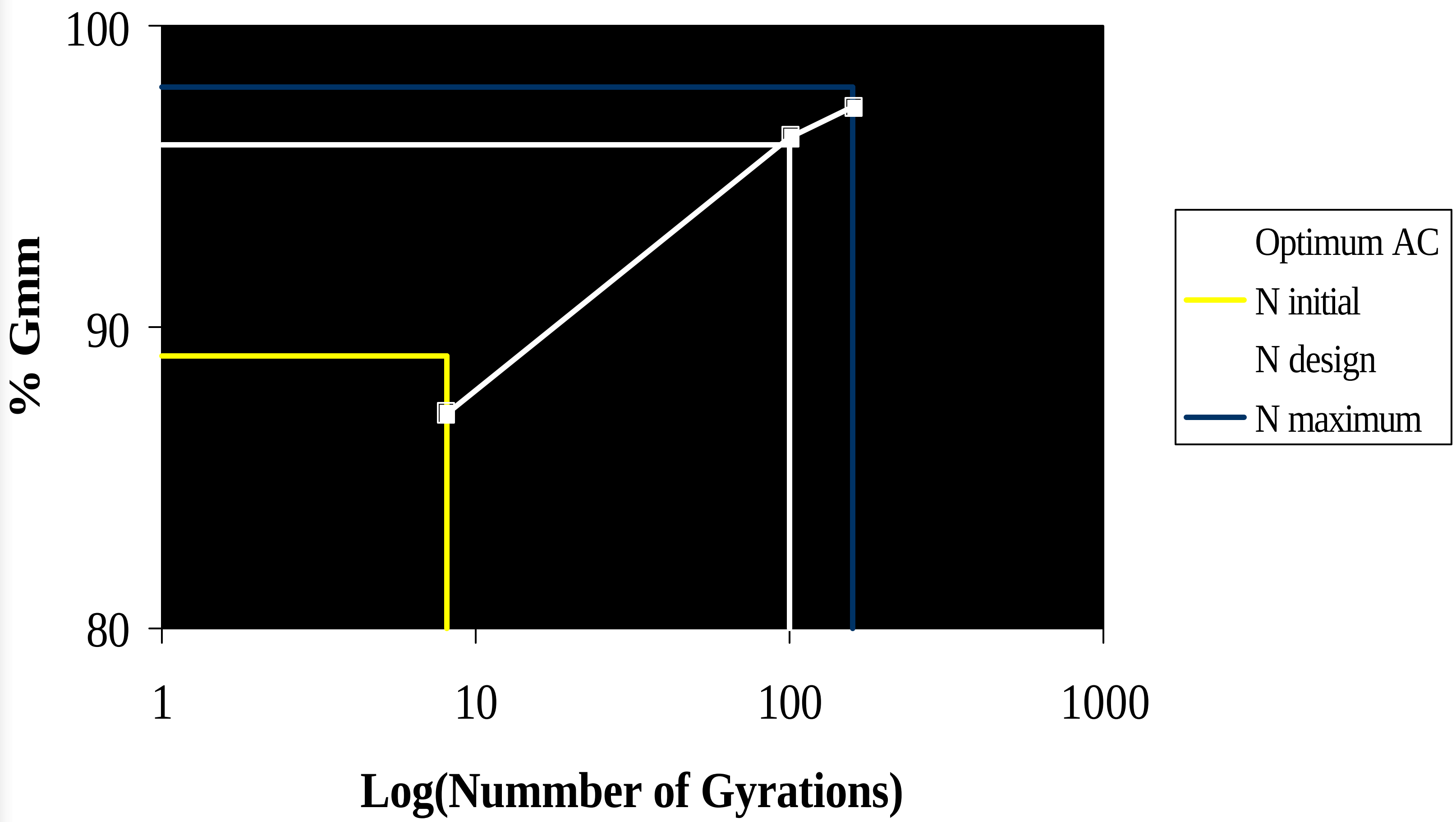
Summary of Optimization

Property	Results	Criteria
Va at N_{des}	4.0	4.0
VMA at N_{des}	13.5	13.0 min
VFA at N_{des}	70	65 to 75
F / P_{be} ratio	0.87	0.6 to 1.2
%$G_{mm\ ini}$	86.9	$\leq$ 89
%$G_{mm\ max}$	n/a	$\leq$ 98

Summary of Optimization



Design Blend at Optimum Rutting Check



Author's Note

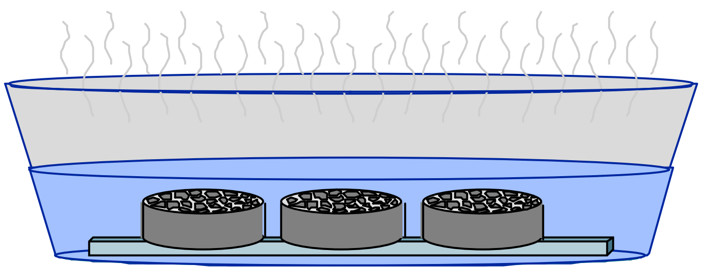
- If you have limited experience with the trial gradations. It is recommended during the selection of the design aggregate structure that you compact at least one specimen to N_{max} to assess the blends ability to resist rutting.

Evaluation of Moisture Sensitivity

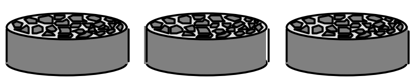
AASHTO T-283

Evaluation of Moisture Sensitivity

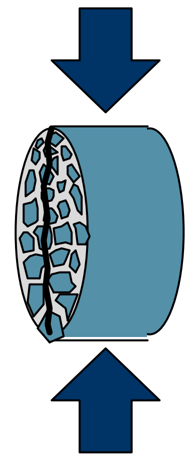
Measured on Proposed Aggregate Blend and Asphalt Content



3 Conditioned Specimens



3 Dry Specimens



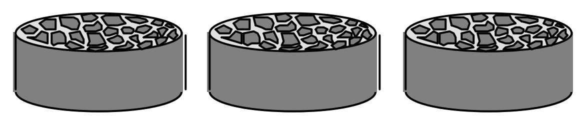
80 % minimum

Tensile Strength Ratio

Evaluation of Moisture Sensitivity

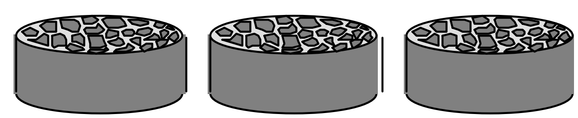
- **Short term aging:**
  - loose mix 16 hrs @ 60 ºC
  - comp mix 72-96 hrs @ 25 ºC
- **Two subsets with equal voids**
  - one - “dry”
  - one - saturated

6 to 8 % air



Dry

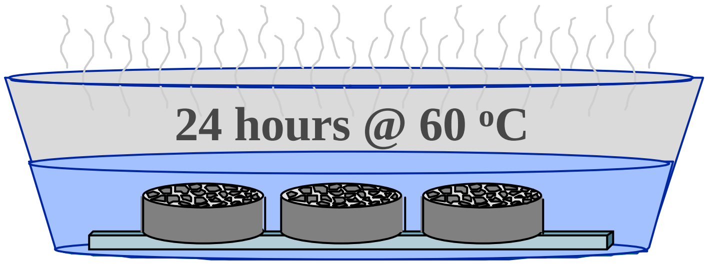
6 to 8 % air



55 to 80 % saturation

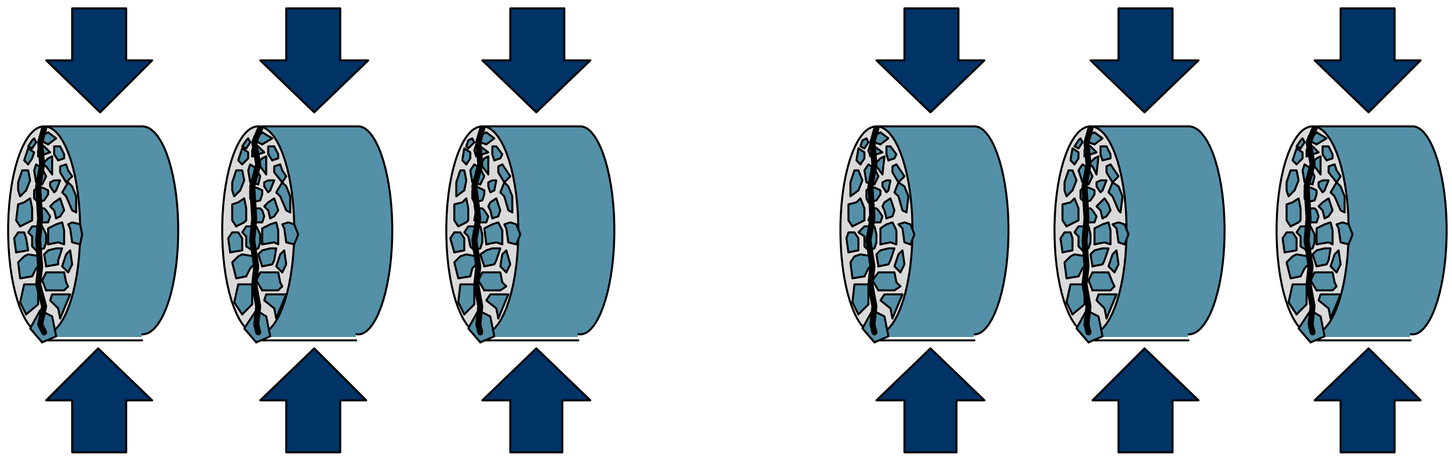
Evaluation of Moisture Sensitivity

- **optional freeze cycle**
- **hot water soak**



Evaluation of Moisture Sensitivity

51 mm / min @ 25 °C



Avg Dry Tensile Strength **Avg Wet Tensile Strength**

$$TSR = \frac{Wet}{Dry} \geq 80\ \%$$

Evaluation of Moisture Sensitivity

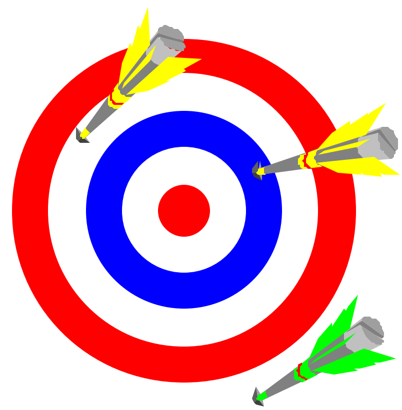
AASHTO T-283

Samples	SGC	ITS
Unconditioned Dry	3 Specimens 7 % Va	872 kPa
Conditioned Wet	3 Specimens 7 % Va	721 kPa
	TSR	82.7 %
	Superpave Criteria	**80 % min**

Question ?

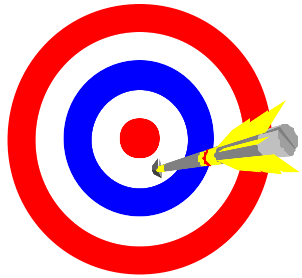
What if the TSR fails ?

Author's Note



- SHRP gave us the ECS
- Superpave calls for AASHTO T-283
  - 4" Marshall Specimens
- NCHRP 9-13 ties T-283 + gyratory
  - Jon Epps (University of Nevada at Reno)

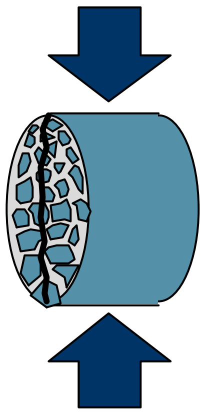
Author's Note



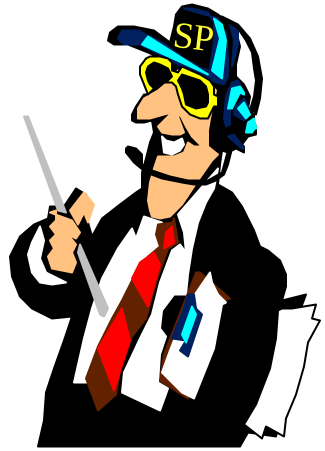
- In the interim agencies are. . .
  - Using Modified Lottman / Root-Tunnicliff
    - 150 & 100 mm SGC, 4" Marshall Specimens
    - 100% Saturation
  - Proof Tests
    - Asphalt Pavement Analyzer (Georgia LWT)
    - Hamburg Loaded Wheel Tester
  - Pull-off Test (Binder/Mastic only)

Better moisture sensitivity test

- July 28, 1999 -- NCHRP hosted "Moisture Sensitivity Focus Group"
- Outcome: NCHRP project to develop a new test for moisture sensitivity



Major Steps in Superpave

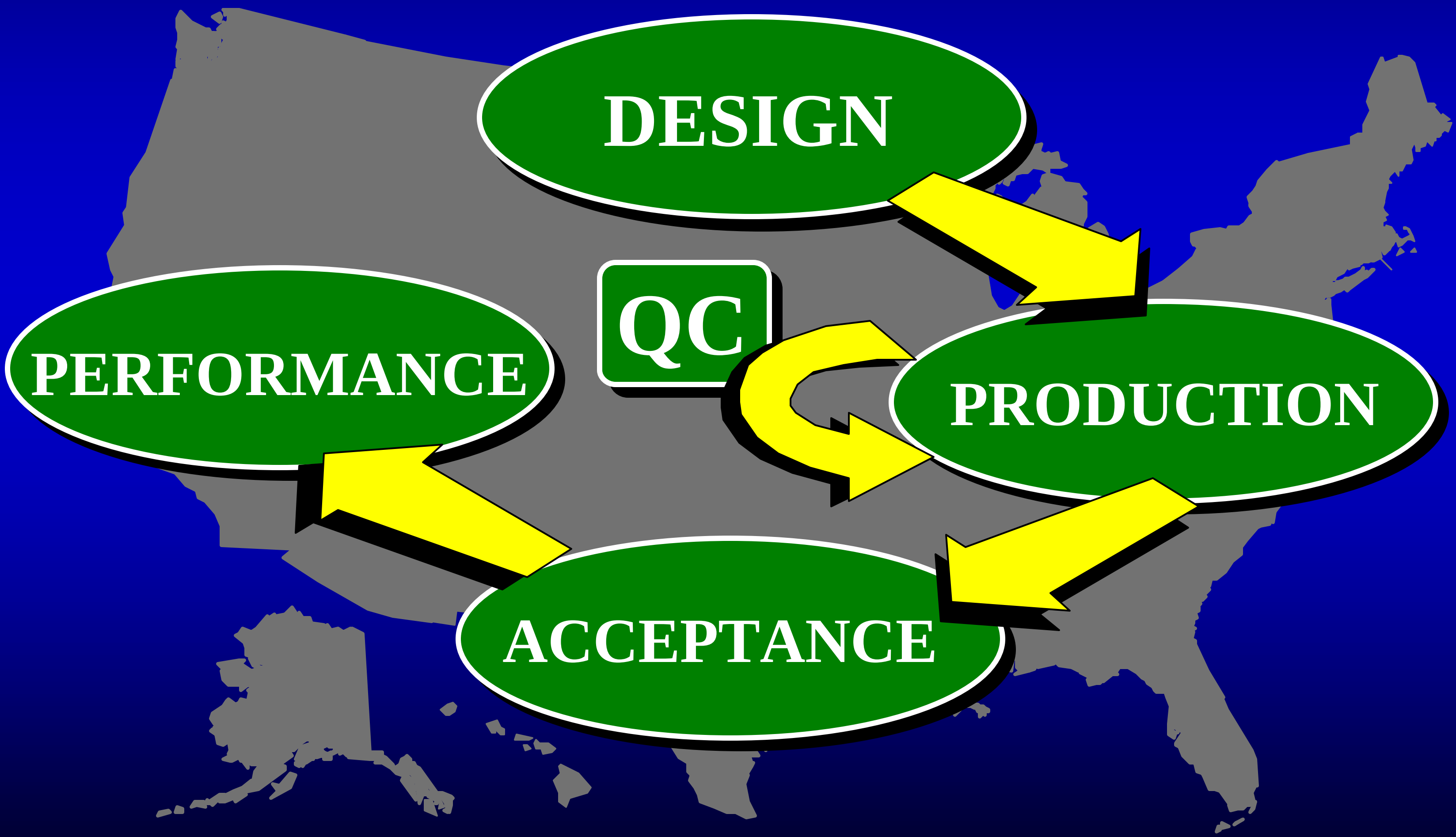


- Selection of Materials,
- Selections of a Design Aggregate Structure,
- Selection of the Design Binder Content, and
- Evaluation of Moisture Sensitivity.
  – Mixture/Aggregate & Binder ETG
  – Lead States

Guidelines for the use of RAP

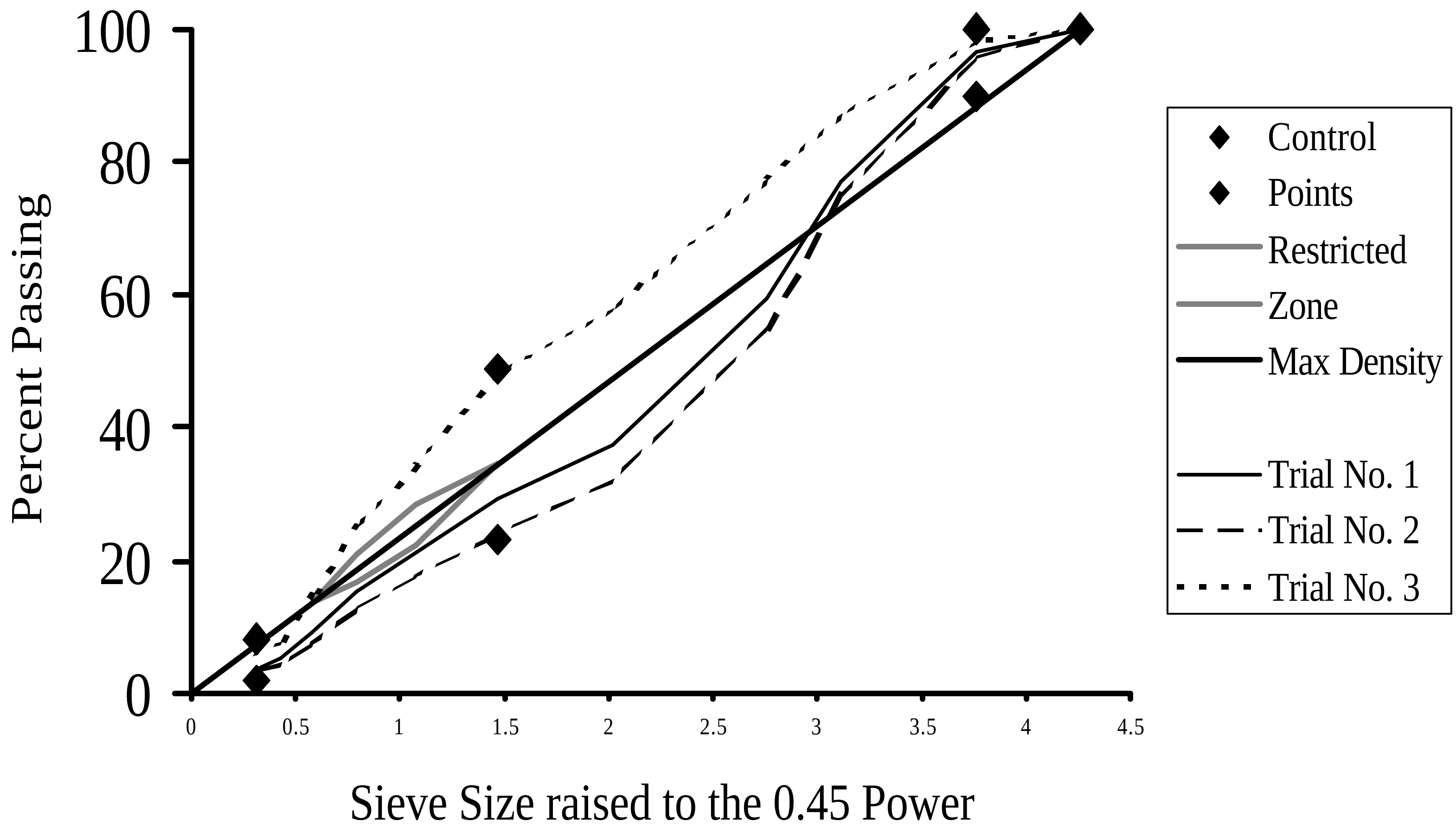
- FHWA Mix ETG developed guidelines based upon consensus and limited testing (<15%, 15-25, 25%+).
- NCHRP 9-12, “Incorporation of RAP in the Superpave System”
  - Rebecca McDaniel (NC Superpave Center)

Superpave Field Management

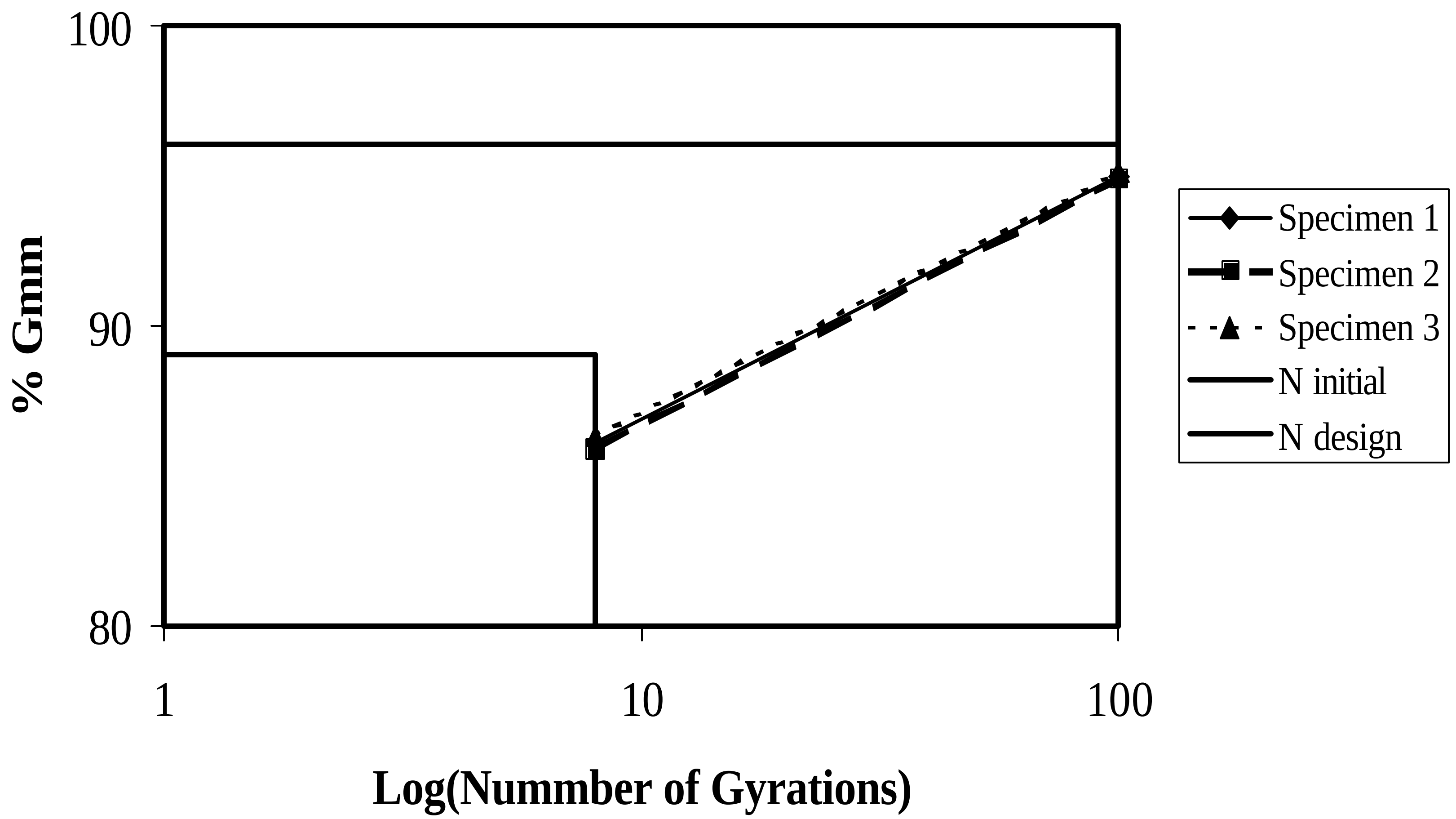



Thank you.

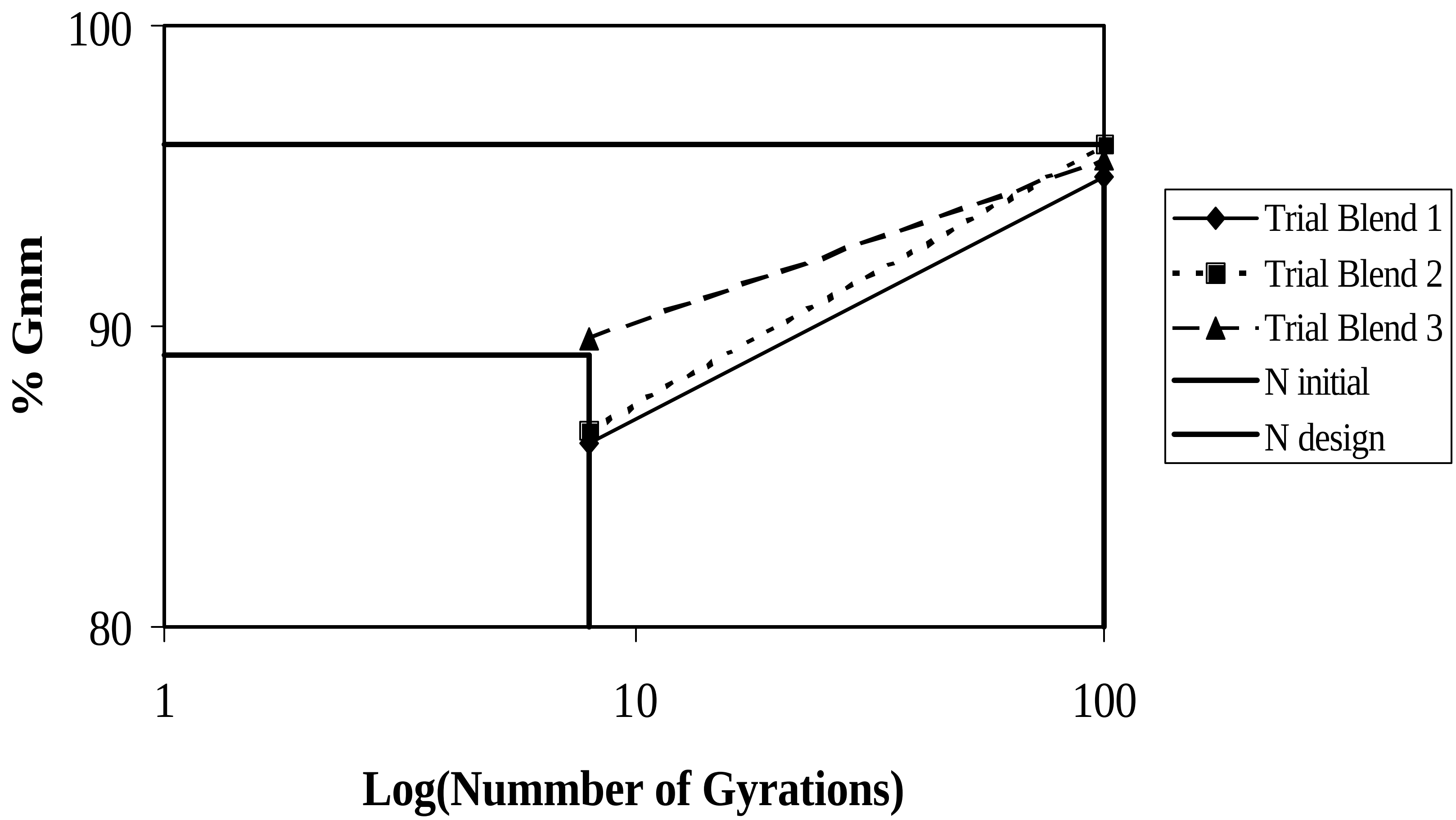
FHWA 0.45 Power Chart



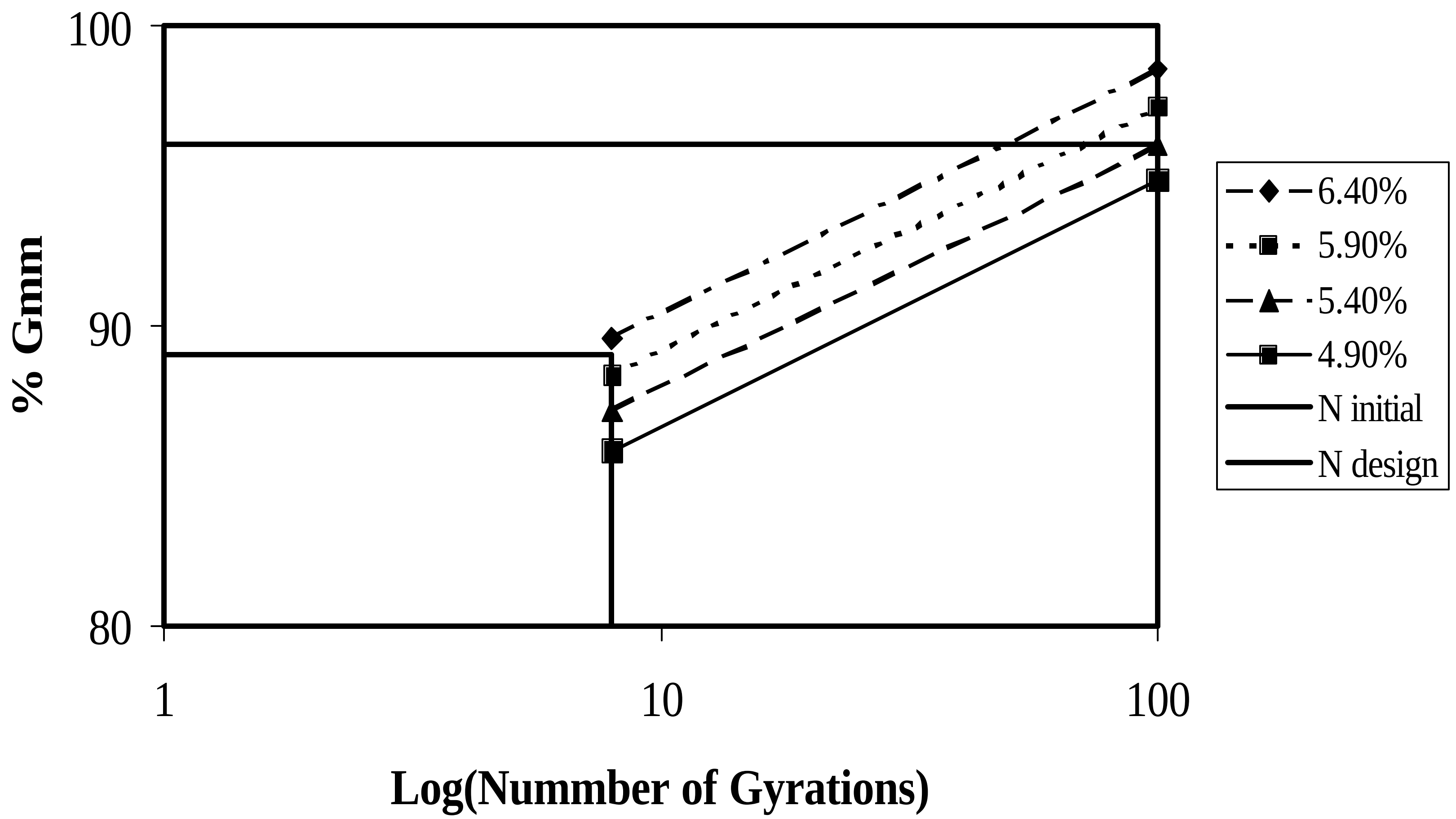
SGC Compaction Chart



Trial Blends

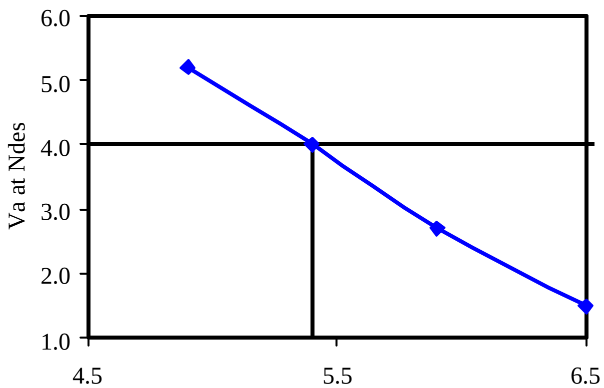


SGC Compaction Chart

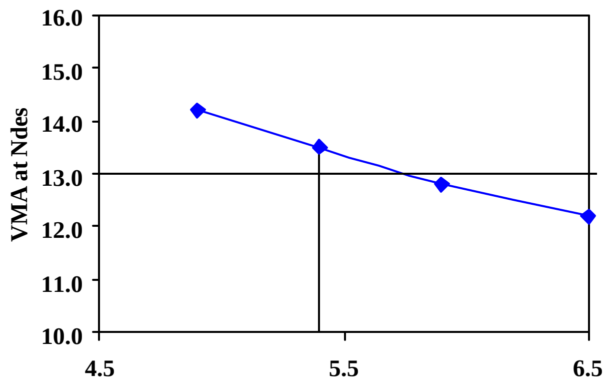


Summary of Optimization

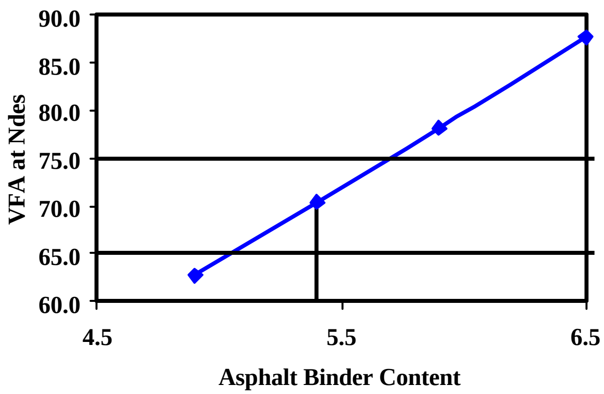
V_a



VMA



VFA



F/P_{be}