Superpave^{TM} Mix Design

Marshall Mix Design

1. Select suitable aggregates
2. Select a suitable asphalt binder
3. Select appropriate mixing and compaction temps
4. Select a suitable aggregate structure
5. Mix and compact samples in the lab
6. Analyze mix volumetrics (air voids, etc.)
7. Select the optimum asphalt content
8. Evaluate moisture susceptibility

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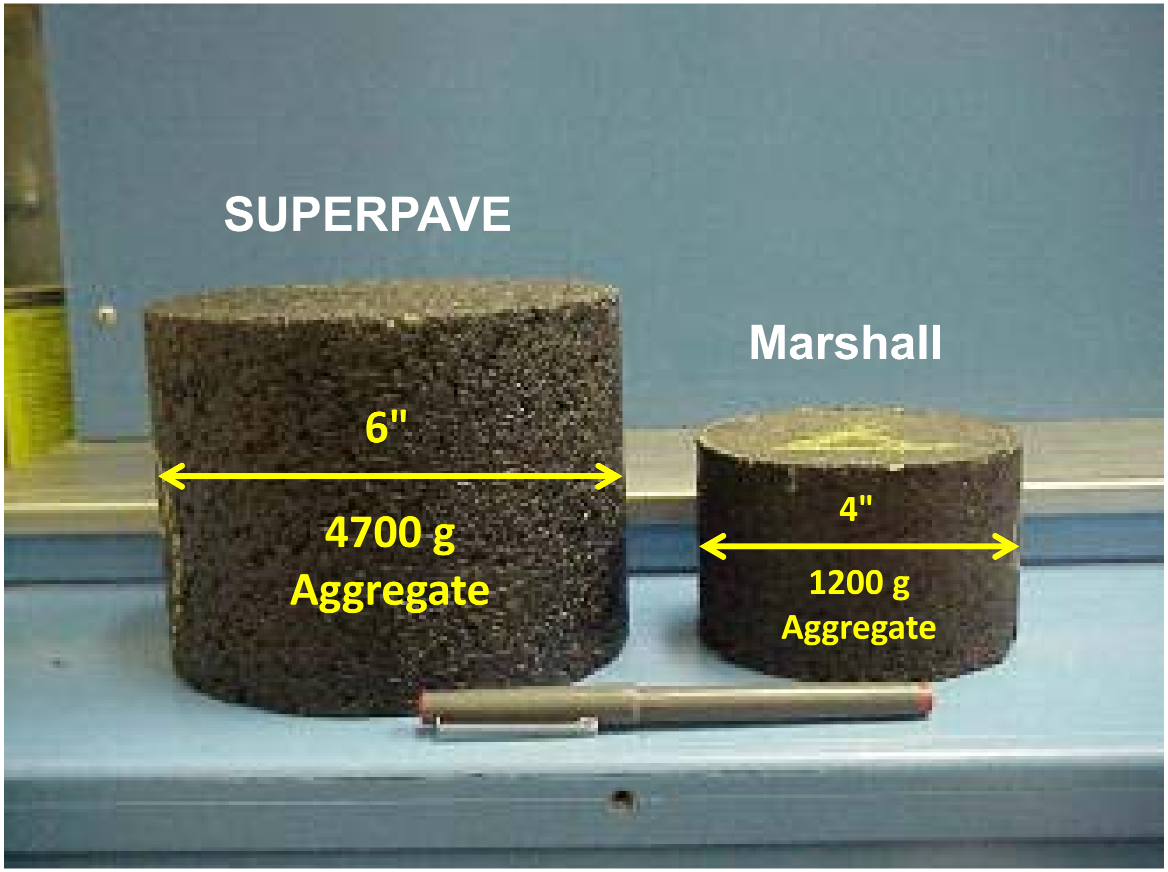
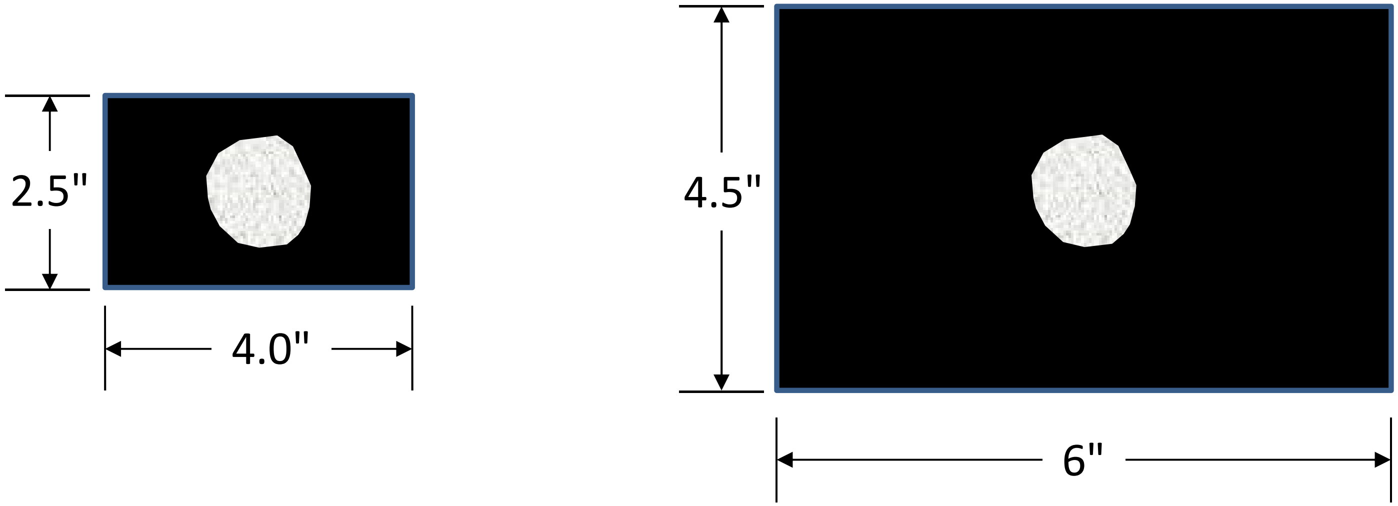
Superpave Specimens



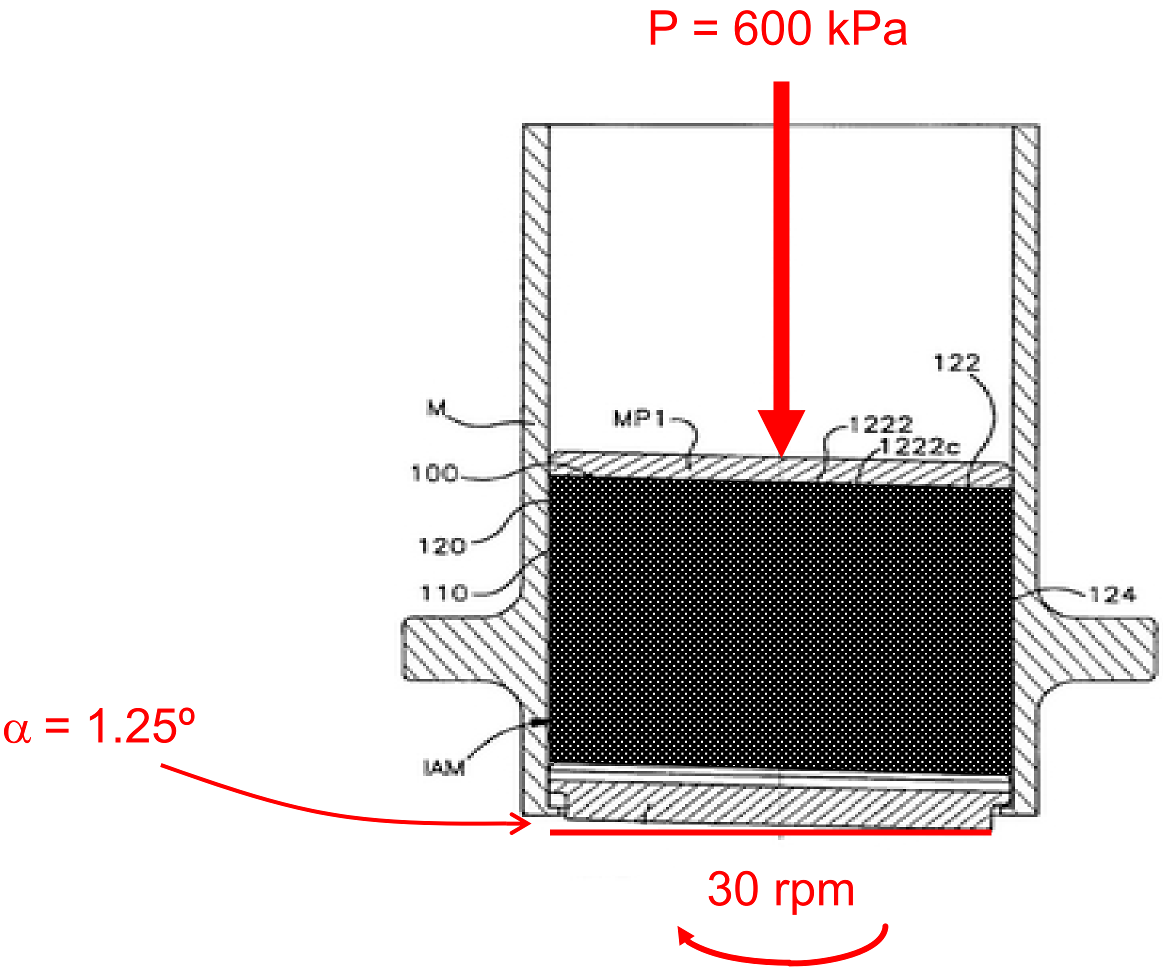
Why 4700-g Specimens?

- The larger specimens better accommodate larger NMAS mixes (up to 1½ inches). Marshall specimens 2½ inches high can be dominated by a single large aggregate particle.



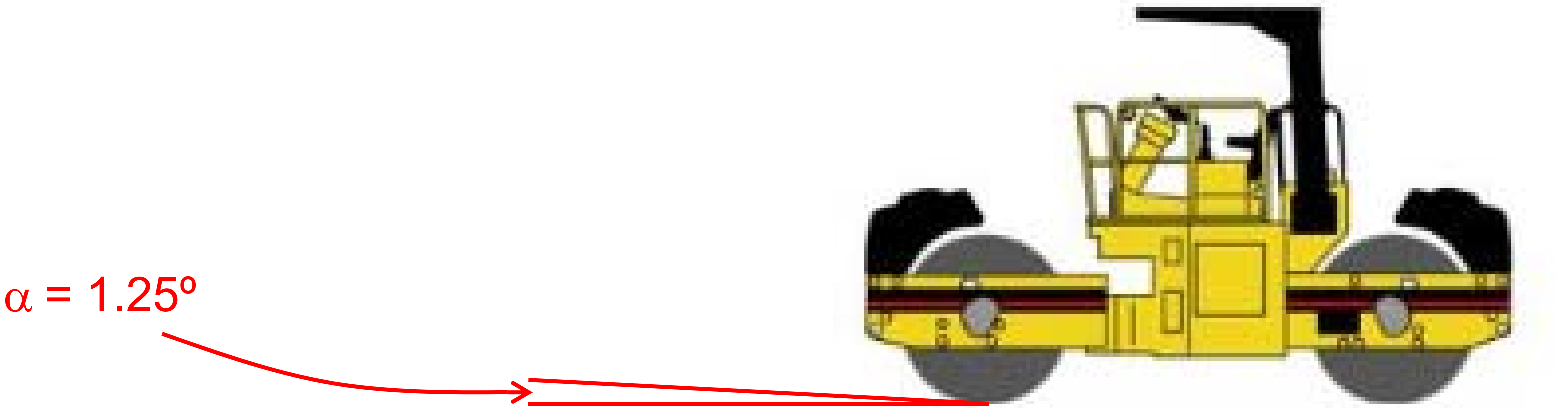
Gyratory Compactor

Gyratory Compaction



Why Gyratory Compaction?

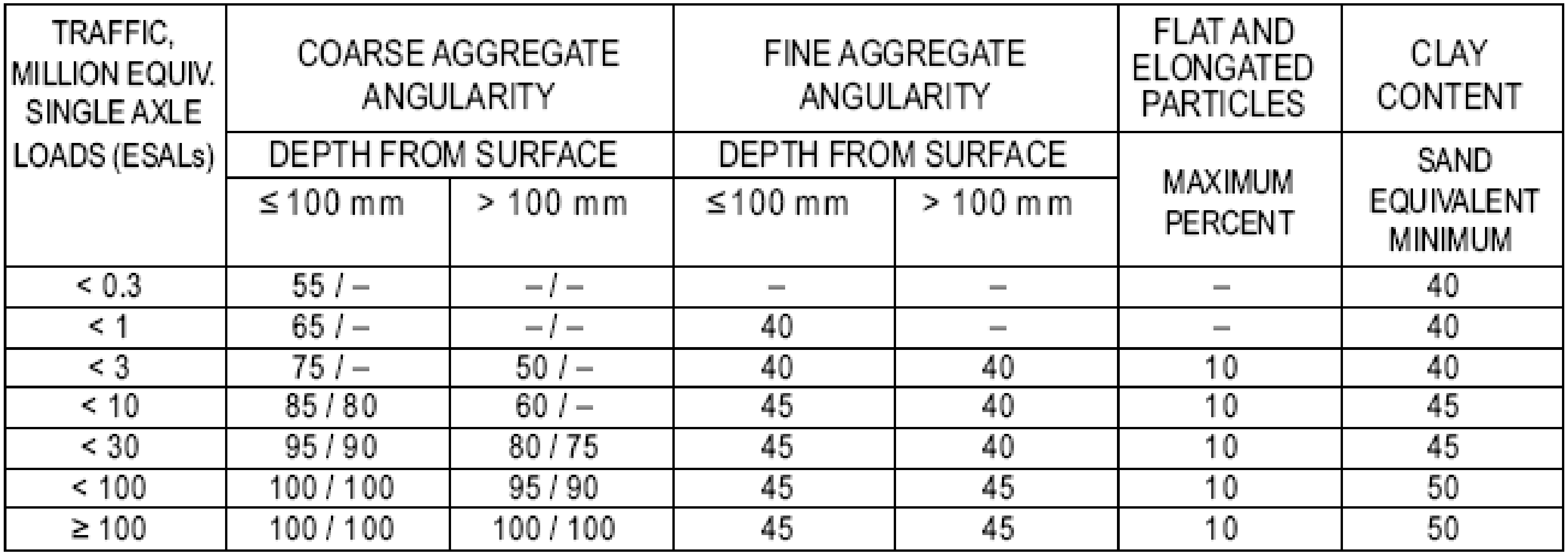
- Gyratory compaction produces a kneading motion that better replicates what happens beneath the rollers during compaction on the road surface.



Superpave Mix Design Approach

- Select suitable materials and determine the proper mixing and compacting temperatures.
- Determine the best aggregate blend from among several trial blends using specimens compacted at one trial asphalt content.
- Estimate the correct asphalt content for the best blend using the results from that one trial.
- Determine the optimum asphalt content using specimens compacted at four different asphalt contents around the estimate.

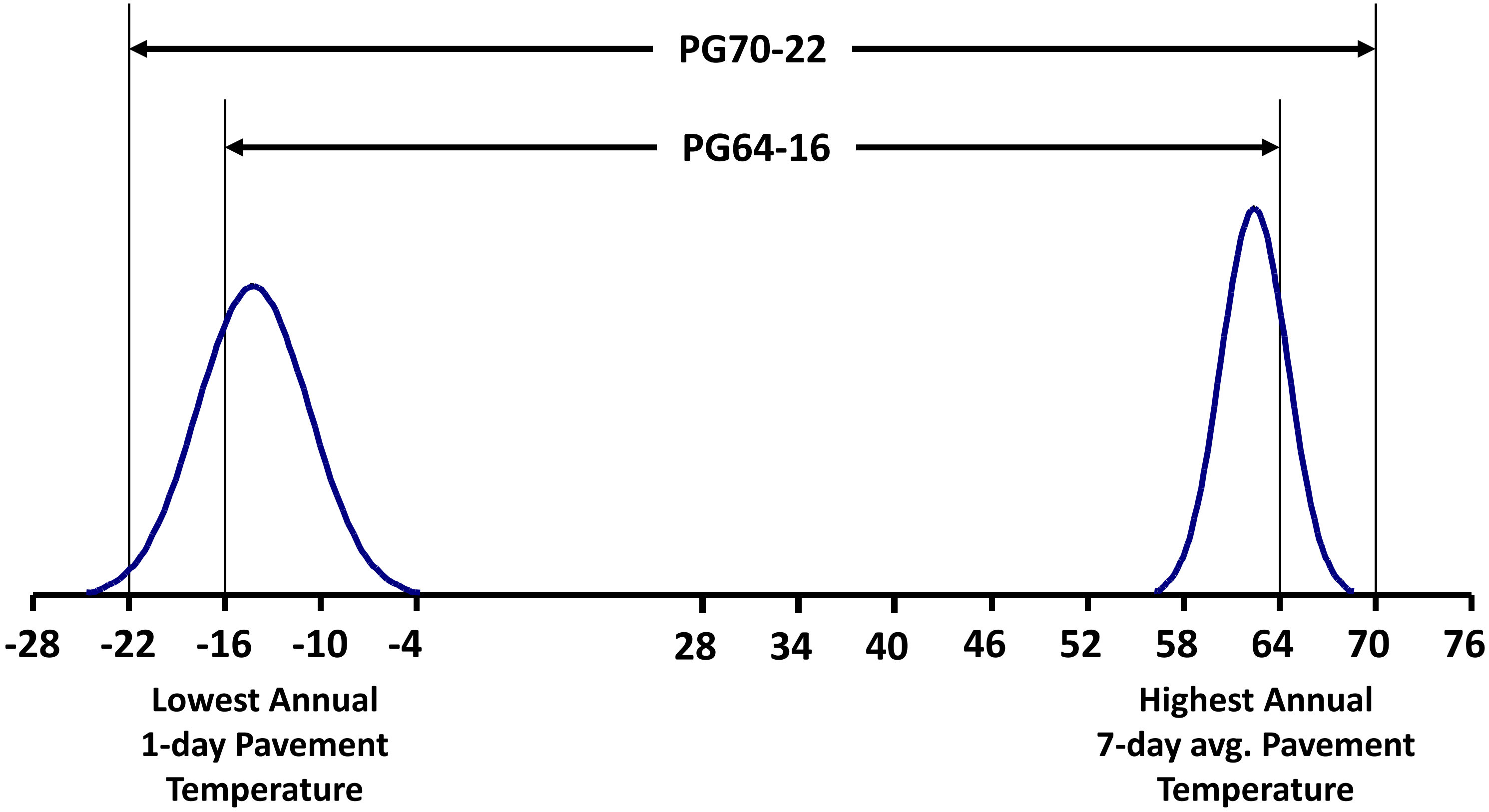
1. Select suitable aggregates



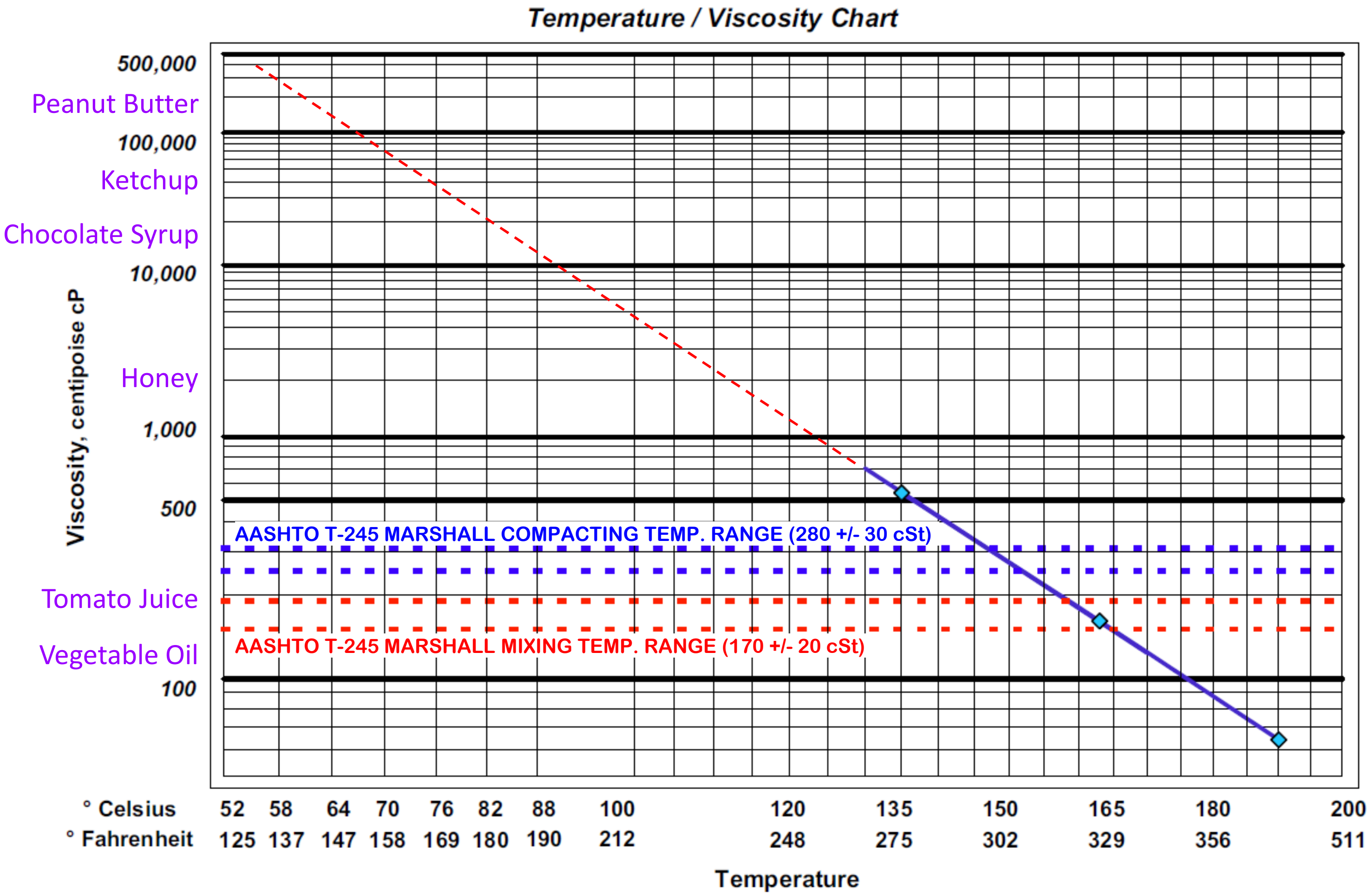
TRAFFIC, MILLION EQUIV. SINGLE AXLE LOADS (ESALs)	COARSE AGGREGATE ANGULARITY		FINE AGGREGATE ANGULARITY		FLAT AND ELONGATED PARTICLES	CLAY CONTENT
	DEPTH FROM SURFACE		DEPTH FROM SURFACE		MAXIMUM PERCENT	SAND EQUIVALENT MINIMUM
	≤ 100 mm	> 100 mm	≤100 mm	> 100 mm		
< 0.3	55 / –	– / –	–	–	–	40
< 1	65 / –	– / –	40	–	–	40
< 3	75 / –	50 / –	40	40	10	40
< 10	85 / 80	60 / –	45	40	10	45
< 30	95 / 90	80 / 75	45	40	10	45
< 100	100 / 100	95 / 90	45	45	10	50
≥ 100	100 / 100	100 / 100	45	45	10	50

Source: NCEES *FE Supplied Reference Handbook*

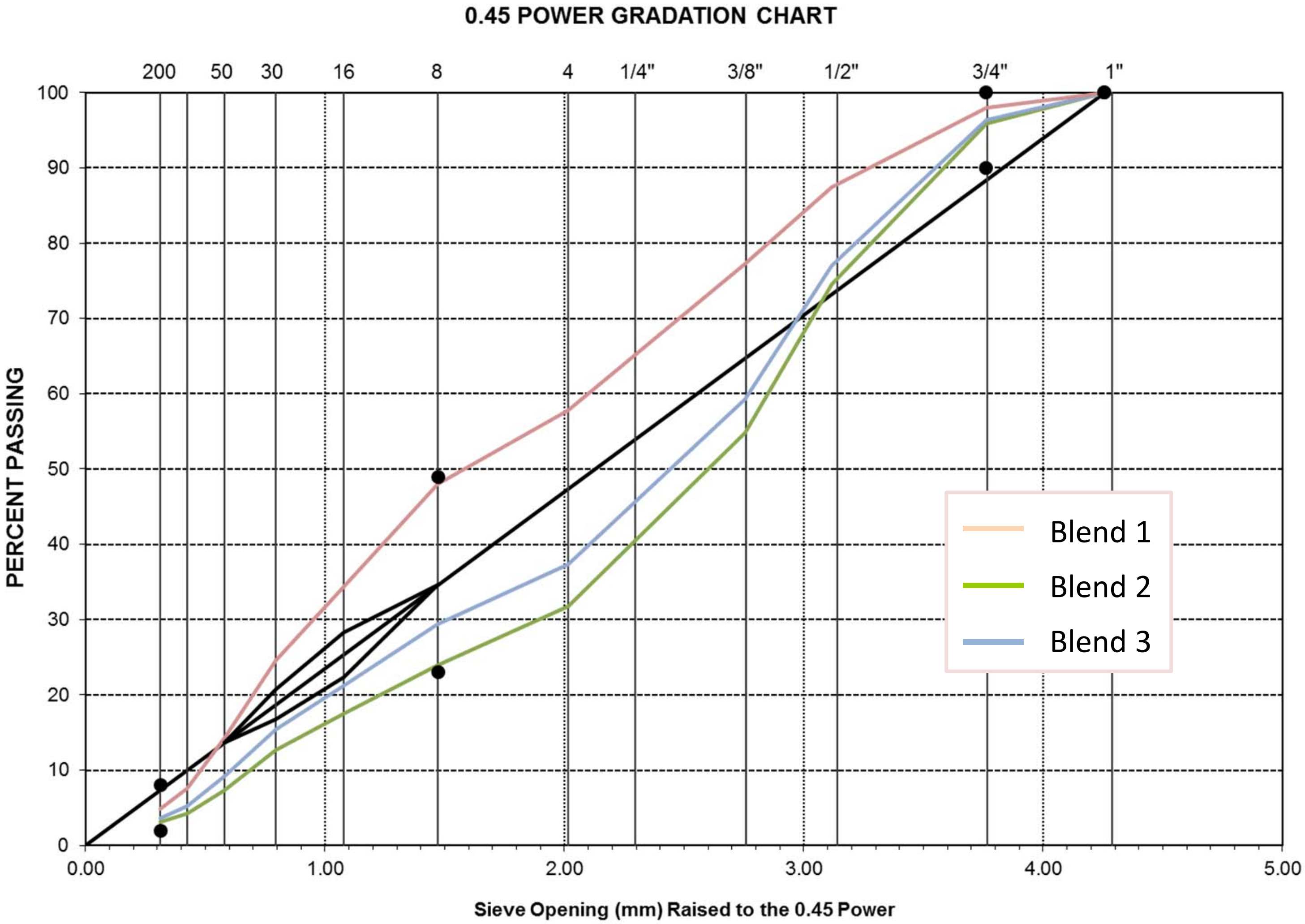
2. Select a suitable asphalt binder



3. Determine relevant temperatures



4. Create several aggregate blends



5. Select a Trial Binder Content

NMAS (mm)	Aggregate Relative Density and Absorption			
	2.65 / 0.8%	2.65 / 1.6%	2.70 / 0.8%	2.70 / 1.6%
9.5	8.3	8.9	8.1	8.7
12.5	5.0	5.6	4.9	5.5
19	4.4	5.0	4.3	5.0
25	4.1	4.7	4.0	4.6

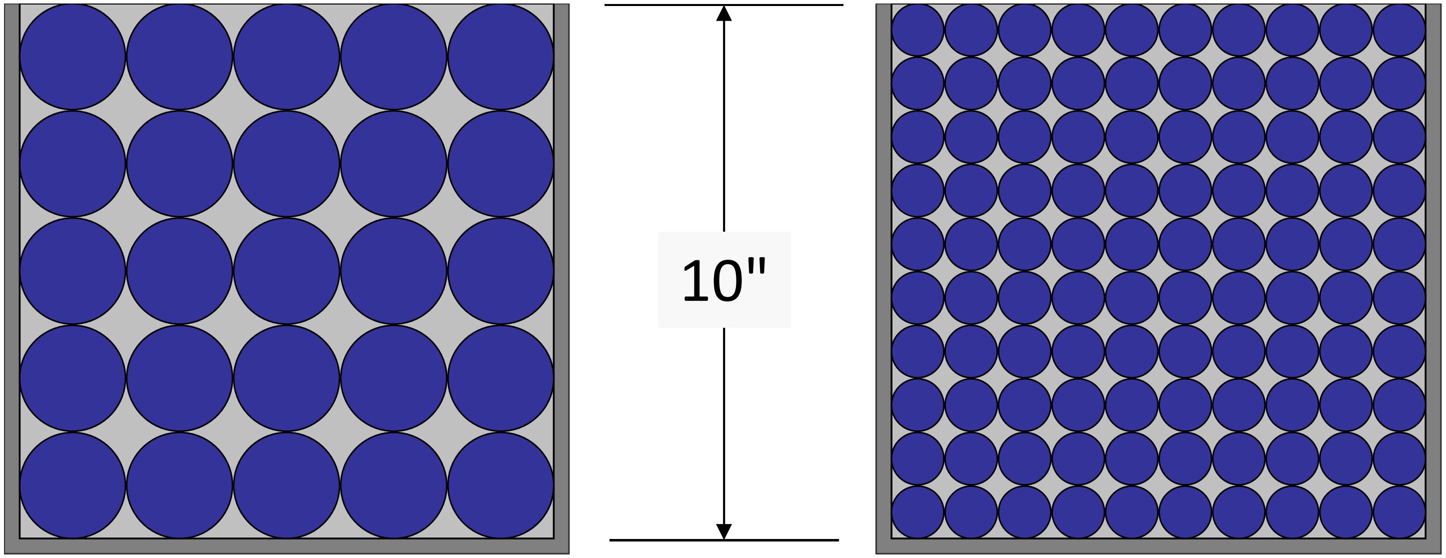
A Question to Ponder

- Why does the trial binder content drop with increasing NMAS?

NMAS (mm)	Aggregate Relative Density and Absorption			
	2.65 / 0.8%	2.65 / 1.6%	2.70 / 0.8%	2.70 / 1.6%
9.5	8.3	8.9	8.1	8.7
12.5	5.0	5.6	4.9	5.5
19	4.4	5.0	4.3	5.0
25	4.1	4.7	4.0	4.6

Effect of NMAS on Surface Area

effective asphalt volume ∝ aggregate surface area



surface area = 11 ft^2

surface area = 22 ft^2

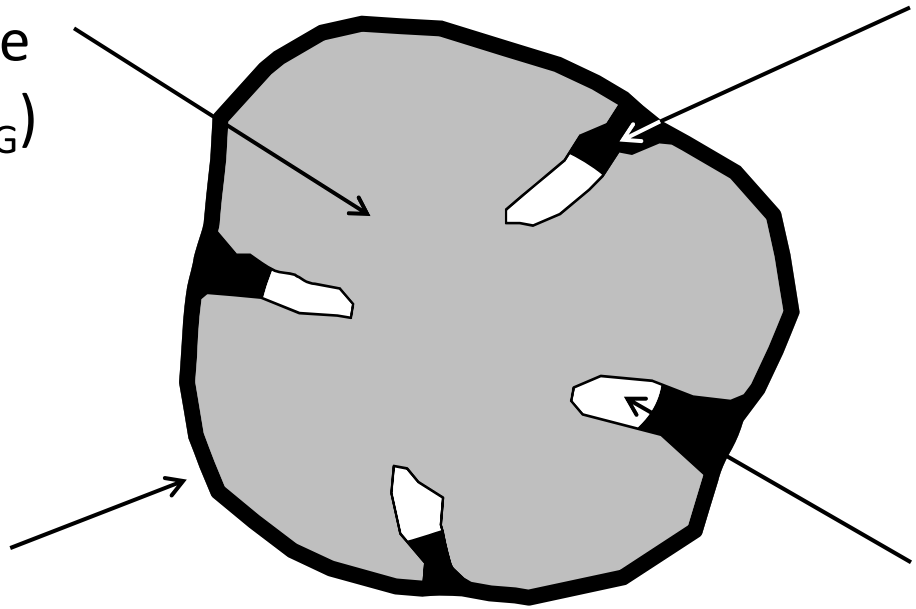
Another Question to Ponder

- Why does the trial asphalt content increase with increasing aggregate absorption?

NMAS (mm)	Aggregate Relative Density and Absorption			
	2.65 / 0.8%	2.65 / 1.6%	2.70 / 0.8%	2.70 / 1.6%
9.5	8.3	8.9	8.1	8.7
12.5	5.0	5.6	4.9	5.5
19	4.4	5.0	4.3	5.0
25	4.1	4.7	4.0	4.6

Mix Volumetrics

absorbed asphalt volume $\propto$ aggregate absorption



Aggregate
Particle
(M_G ,V_G)

Absorbed
Asphalt
(M_{BA} ,V_{BA})

Effective
Asphalt
(M_{BE} ,V_{BE})

Water
Permeable
Voids

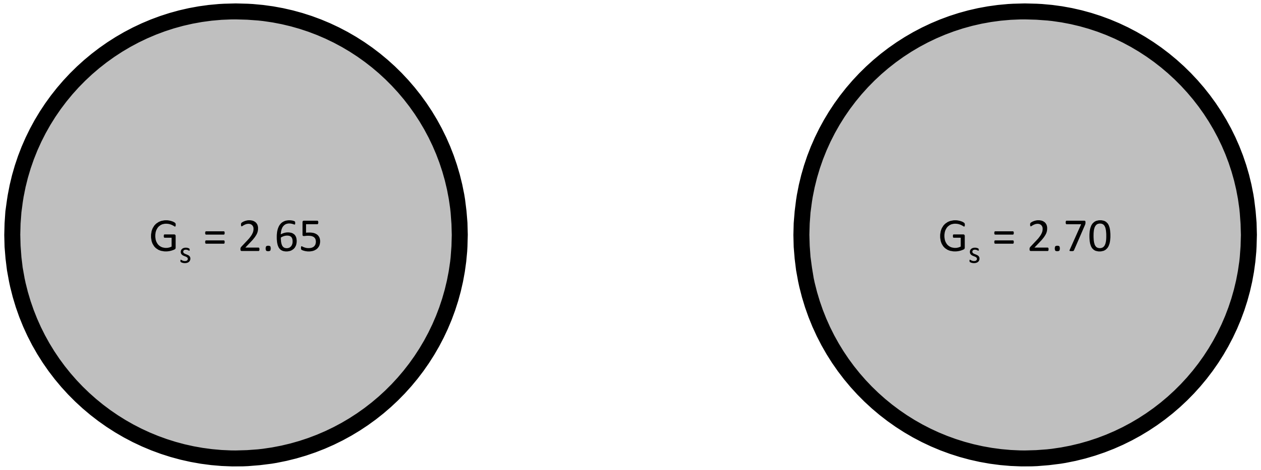
A Final Question to Ponder

- Why does the trial asphalt content decrease with increasing aggregate relative density?

NMAS (mm)	Aggregate Relative Density and Absorption			
	2.65 / 0.8%	2.65 / 1.6%	2.70 / 0.8%	2.70 / 1.6%
9.5	8.3	8.9	8.1	8.7
12.5	5.0	5.6	4.9	5.5
19	4.4	5.0	4.3	5.0
25	4.1	4.7	4.0	4.6

Binder Content

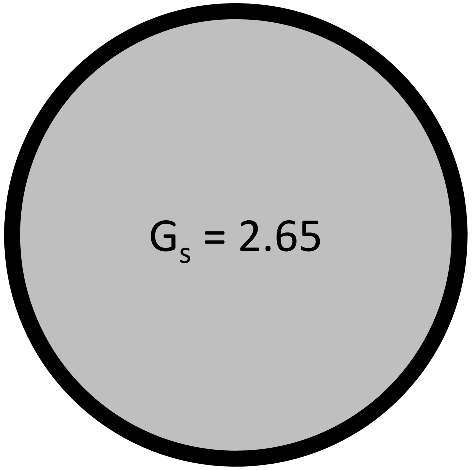
Assume two 2-cm-diameter aggregate spheres
each with a 0.05-cm-thick asphalt cement coating



$$m_{\text{asphalt}} = 1.03\left(0.9970\ \frac{\text{g}}{\text{cm}^3}\right)\frac{4}{3}\pi[(1.05\ \text{cm})^3 - (1.00\ \text{cm})^3] = 0.658\ \text{g}$$

Binder Content

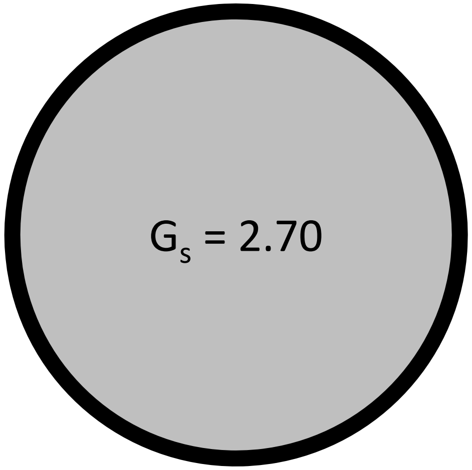
$$\mathrm{m_{aggregate}} \approx 2.65\left(0.9970\ \frac{\mathrm{g}}{\mathrm{cm^3}}\right)\frac{4}{3}\pi(1\ \mathrm{cm})^3 = 11.07\ \mathrm{g}$$



$$\mathrm{P_b} = \frac{\mathrm{m_{asphalt}}}{\mathrm{m_{asphalt}} + \mathrm{m_{agg}}} = \frac{0.658}{0.658 + 11.07} = 0.056 = 5.6\%$$

Binder Content

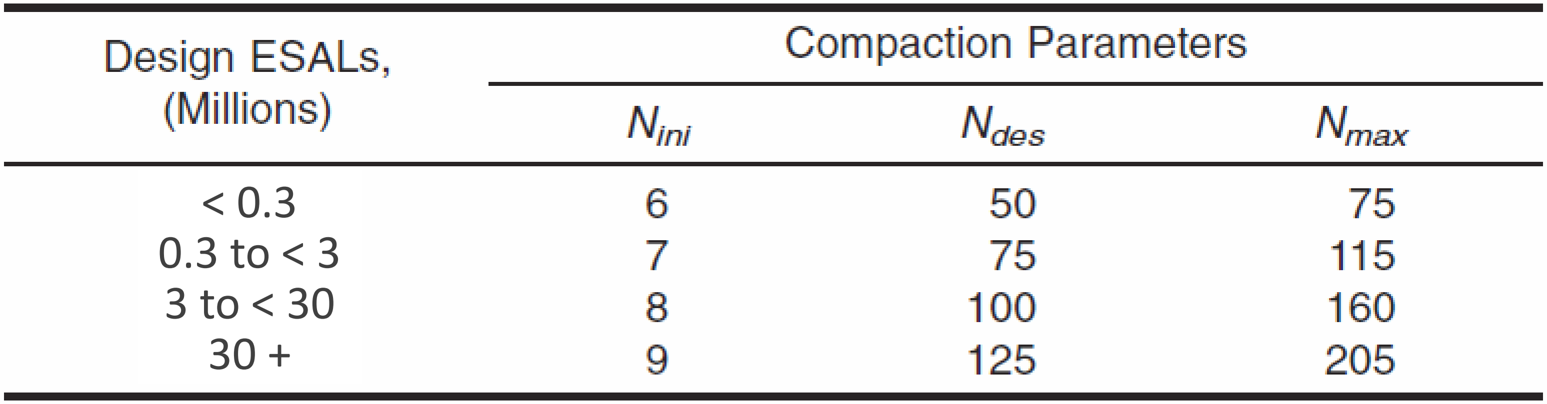
$$m_{aggregate} \approx 2.70\left(0.9970\ \frac{g}{cm^3}\right)\frac{4}{3}\pi(1\ cm)^3 = 11.28\ g$$



$$P_b = \frac{m_{asphalt}}{m_{asphalt} + m_{agg}} = \frac{0.658}{0.658 + 11.28} = 0.055 = 5.5\%$$

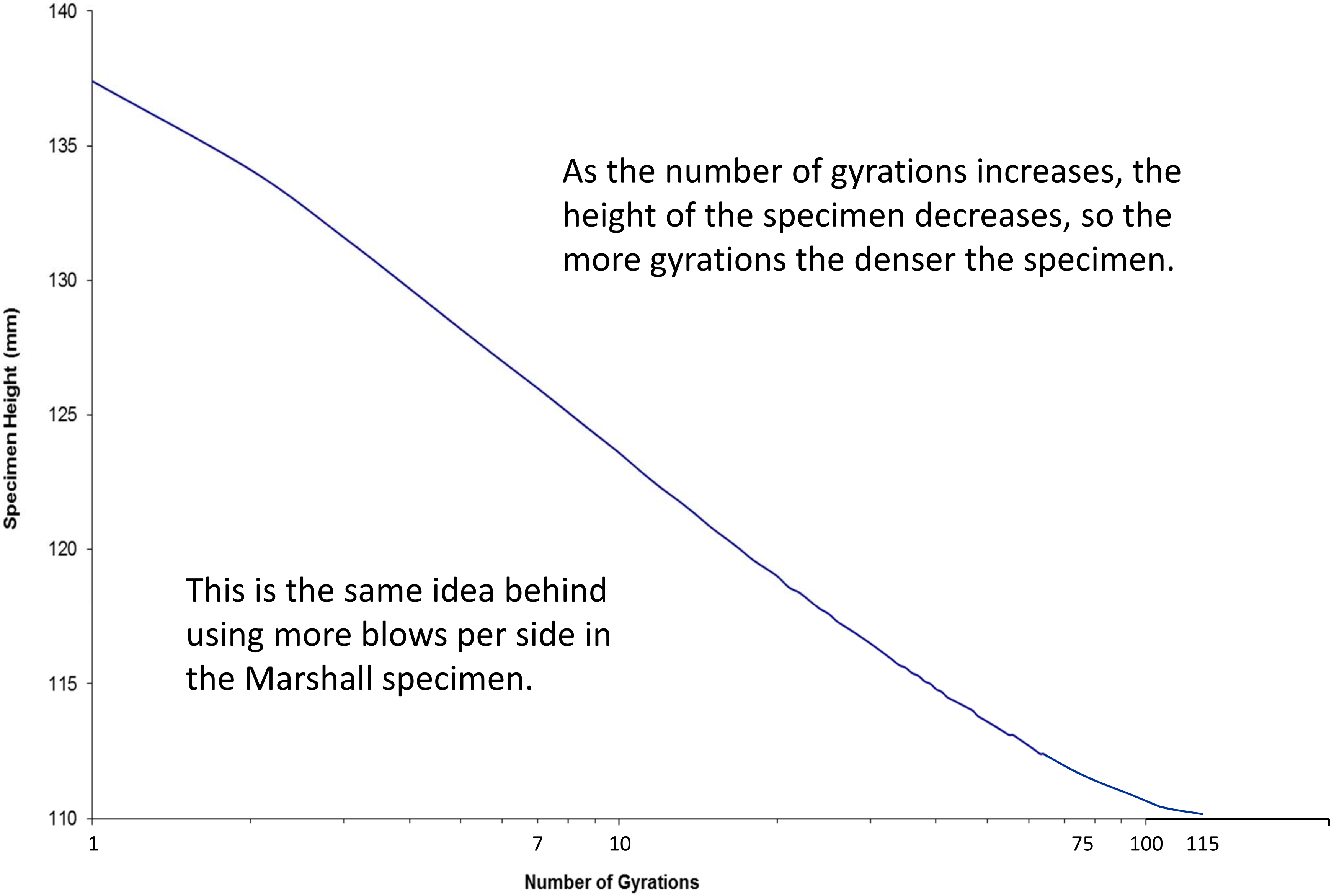
6. Select the compaction effort

N = number of revolutions in the gyratory compactor



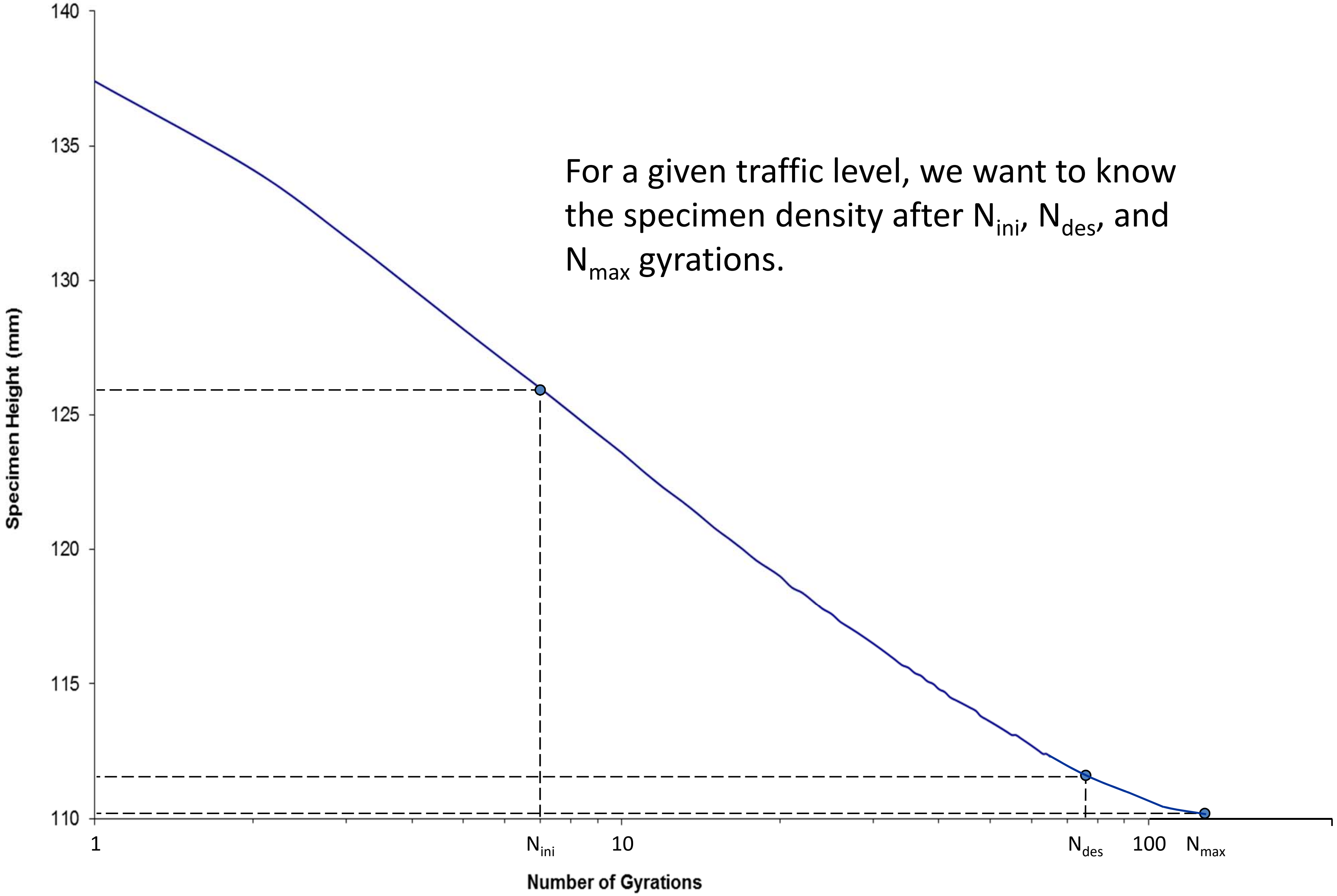
Design ESALs, (Millions)	Compaction Parameters		
	N_{ini}	N_{des}	N_{max}
< 0.3	6	50	75
0.3 to < 3	7	75	115
3 to < 30	8	100	160
30 +	9	125	205

Source: ASTM D6925 - 06



As the number of gyrations increases, the height of the specimen decreases, so the more gyrations the denser the specimen.

This is the same idea behind using more blows per side in the Marshall specimen.



For a given traffic level, we want to know the specimen density after N_{ini}, N_{des}, and N_{max} gyrations.

Superpave Compaction Levels

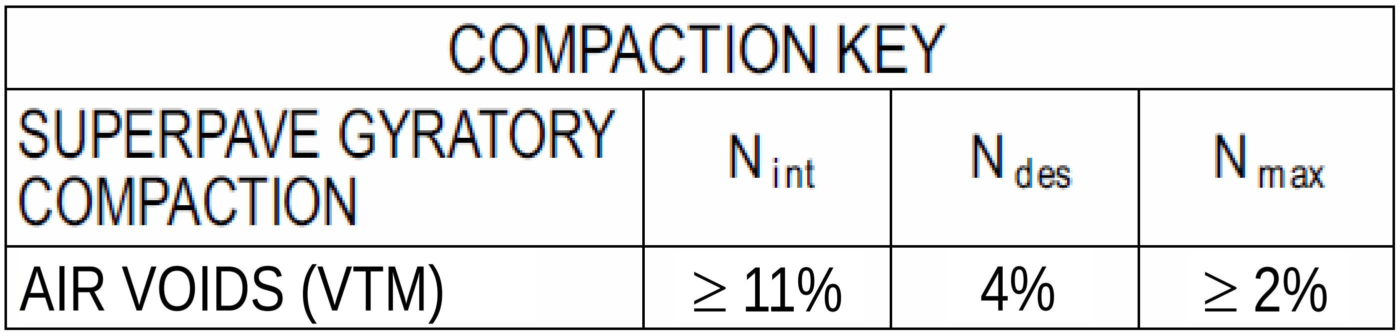
- $\mathbf{N}_{\mathbf{initial}}$ is used to gage how well the asphalt mix will compact during construction. If it compacts too quickly (the air voids are too low) the mix may be tender during construction and unstable when subjected to traffic.

- $\mathbf{N}_{\mathbf{design}}$ is the number of gyrations required to produce a sample with the same density as that expected in the field after being subjected to further compaction due to traffic. The asphalt mix should have 4% air voids at this density.

- $\mathbf{N}_{\mathbf{max}}$ is the number of gyrations required to produce a sample with greater density than is expected in the field after many years of traffic. If the mix compacts too much (the air voids are too low), it could bleed.

Compaction Requirements

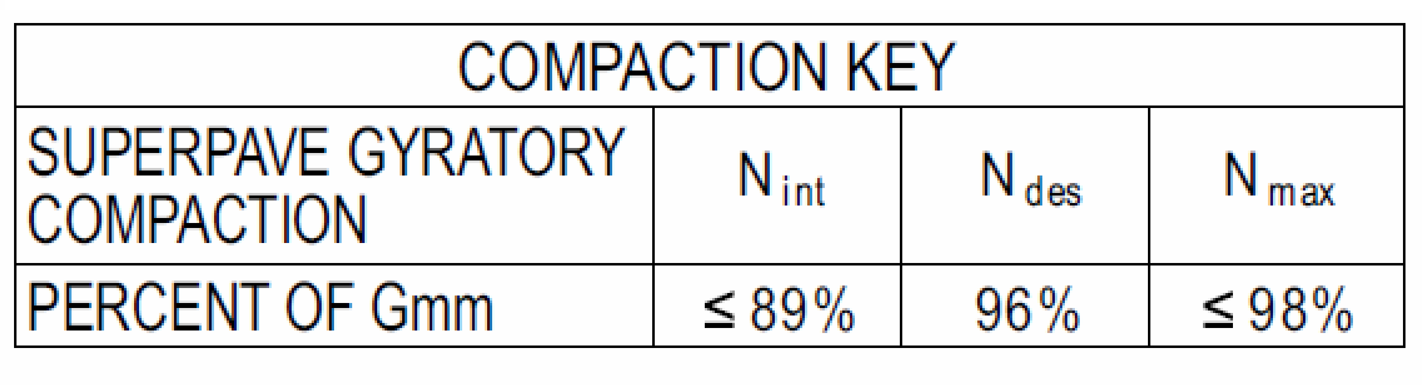
N = number of revolutions in the gyratory compactor



COMPACTION KEY			
SUPERPAVE GYRATORY COMPACTION	N_{int}	N_{des}	N_{max}
AIR VOIDS (VTM)	$\geq$ 11%	4%	$\geq$ 2%

Compaction Requirements

N = number of revolutions in the gyratory compactor

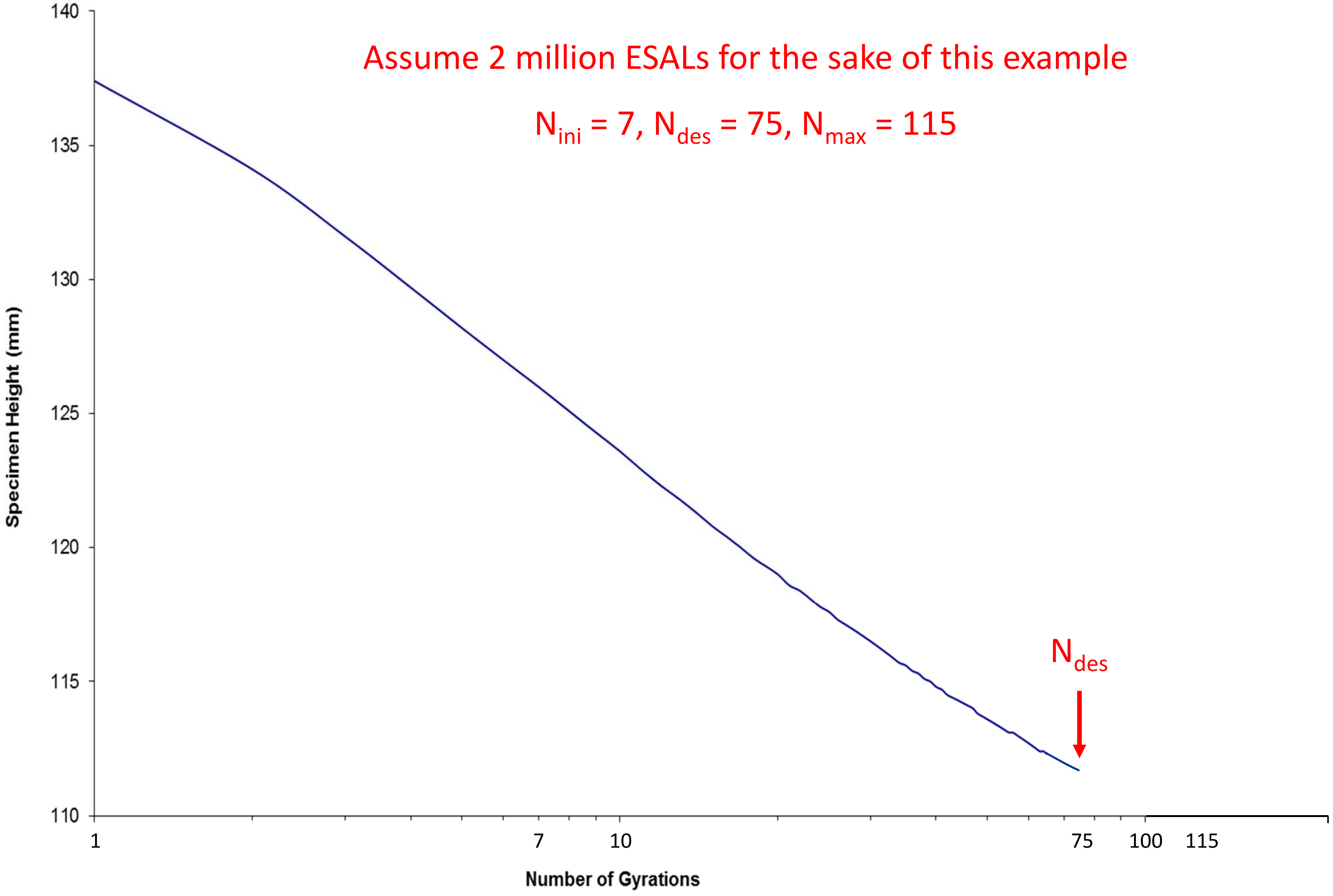


COMPACTION KEY			
SUPERPAVE GYRATORY COMPACTION	N_{int}	N_{des}	N_{max}
PERCENT OF Gmm	$\leq 89\%$	96%	$\leq 98\%$

Source: NCEES *FE Supplied Reference Handbook*

Initial Trial

- Compact two specimens (4700 g of aggregate each) to N_{des} gyrations.
- Determine the mix volumetrics (VTM, VMA, VFA).
- Estimate the asphalt content that will produce a mix with exactly 4% air voids at N_{des} gyrations.
- Estimate VMA, VFA and $\%G_{mm}@N_{ini}$ for a specimen with exactly 4% air voids.
- If the VMA, VFA and $\%G_{mm}@N_{ini}$ requirements are met, this is a suitable aggregate blend.



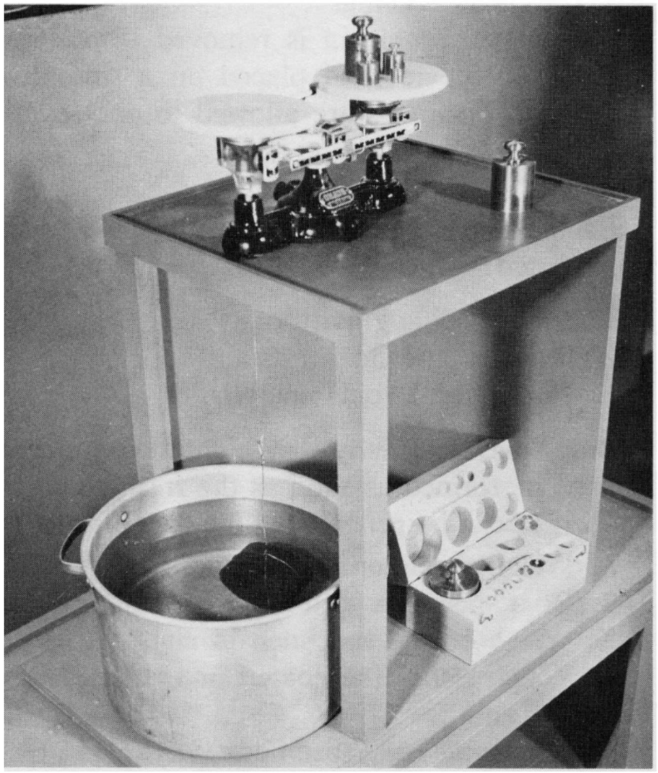
Assume 2 million ESALs for the sake of this example

$N_{ini} = 7$, $N_{des} = 75$, $N_{max} = 115$

Mix Volumetrics

(Taken from The Asphalt Institute Manual ES-1, Second Edition)

Weigh in Air



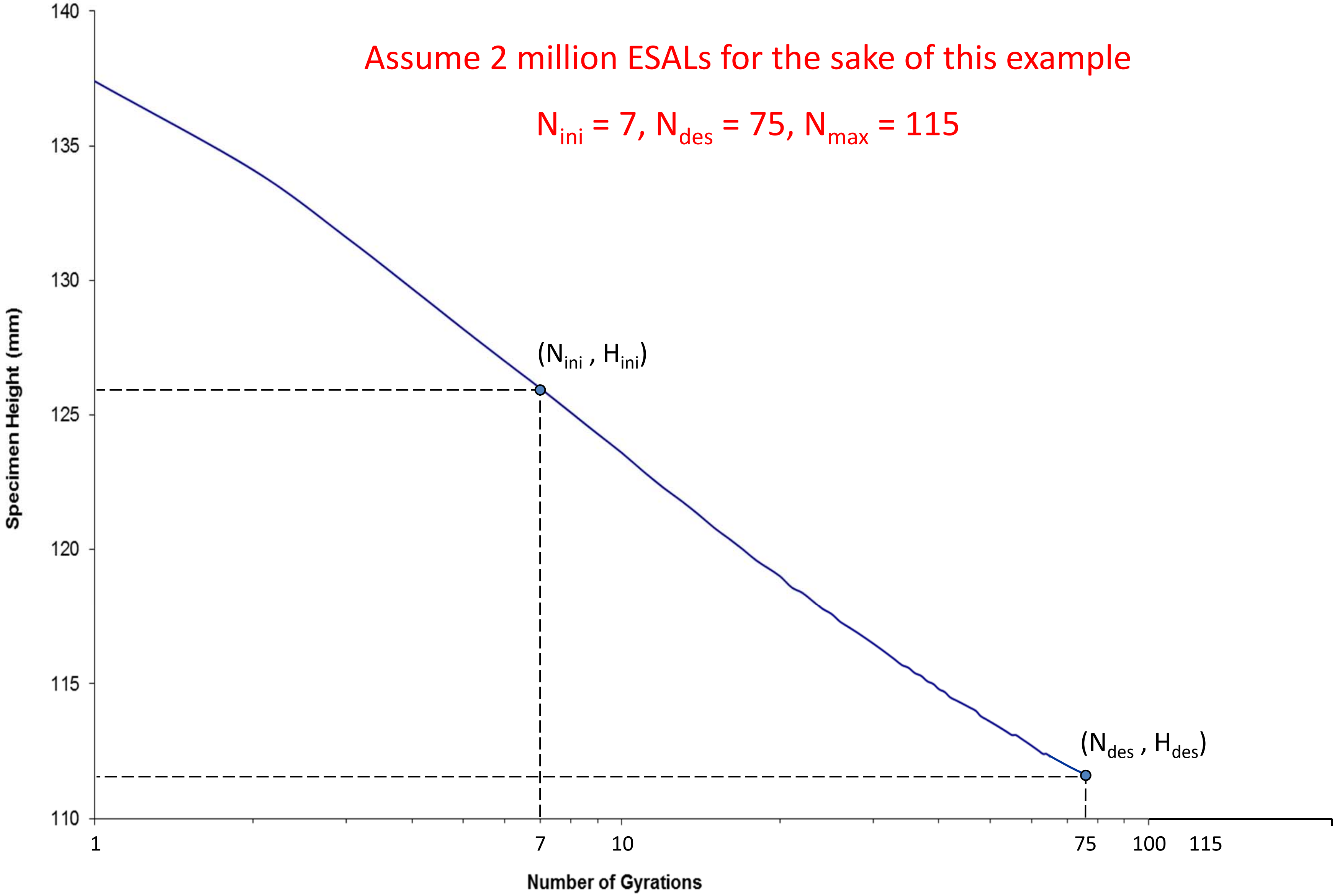
Weigh in Water

Calculate G_{mb} @ N_{des}

$$G_{mb} @ N_{des} = \frac{W_{\text{in air}}}{W_{SSD} - W_{\text{in water}}}$$

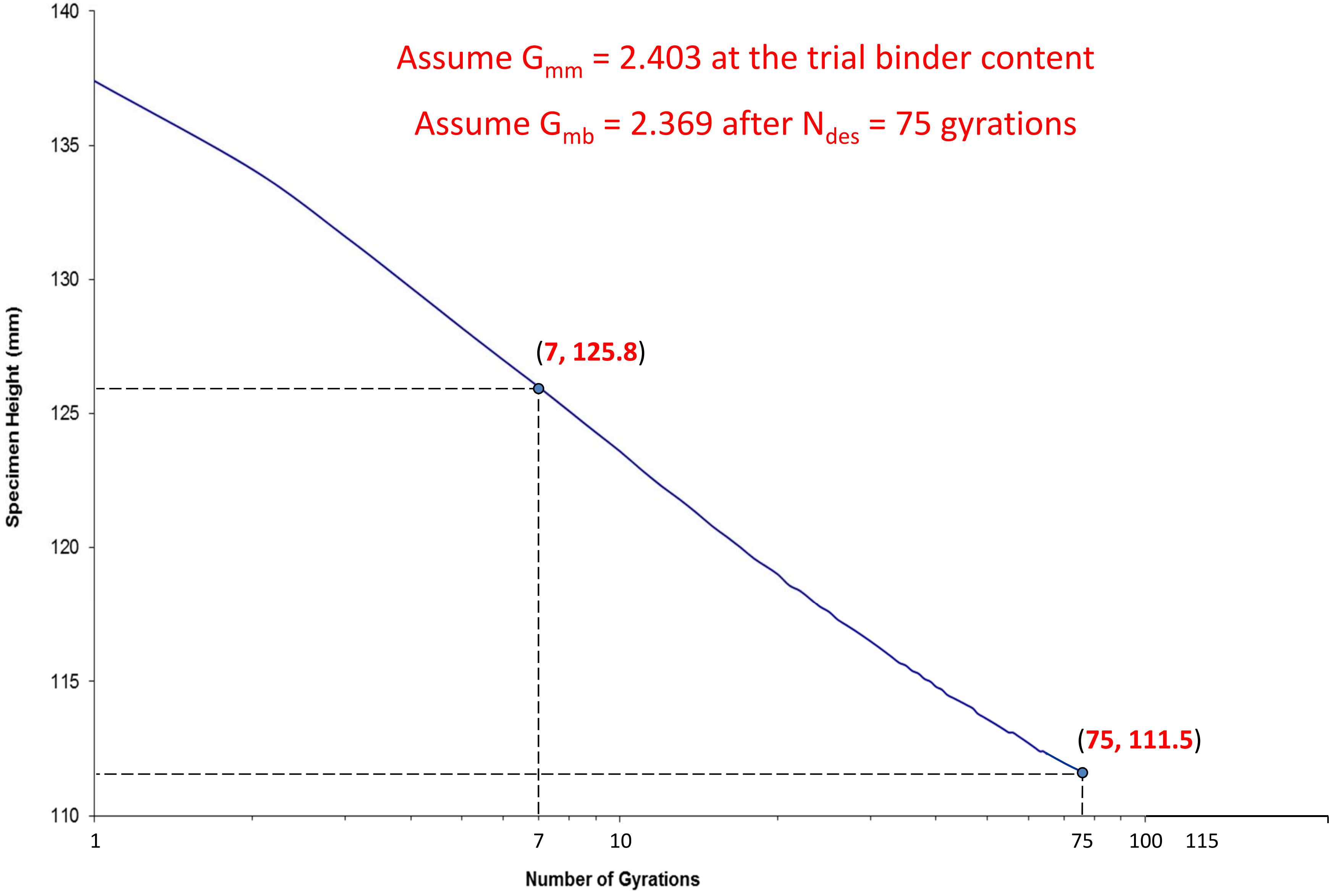
Calculate %G_{mm} at N_{ini}

$$\%G_{mm} @ N_{ini} = \left(\frac{G_{mb} @ N_{des}}{G_{mm}}\right)\left(\frac{H_{des}}{H_{ini}}\right) \times 100\%$$



Assume 2 million ESALs for the sake of this example

$N_{ini} = 7$, $N_{des} = 75$, $N_{max} = 115$



Assume G_{mm} = 2.403 at the trial binder content

Assume G_{mb} = 2.369 after N_{des} = 75 gyrations

Calculate %G_{mm} at N_{ini}

$$\%G_{mm}@N_{ini}=\left(\frac{G_{mb}@N_{des}}{G_{mm}}\right)\left(\frac{H_{des}}{H_{ini}}\right)\times 100\%$$

$$\%G_{mm}@N_{ini}=\left(\frac{2.369}{2.403}\right)\left(\frac{111.5}{125.8}\right)\times 100\%=87.3\%$$

Voids in Total Mix (Air Voids)

$$\mathrm{VTM} = \left(1 - \frac{G_{mb} @ N_{des}}{G_{mm}}\right) \times 100\%$$

G_{mb} = bulk specific gravity of compacted mixture

D 2726 - Bulk Specific Gravity and Density
of Compacted Bituminous Mixtures

G_{mm} = maximum specific gravity of the mixture

D 2041 - Theoretical Maximum Specific Gravity
and Density of Bituminous Paving Mixtures

Voids in Mineral Aggregate

$$\mathrm{VMA} = \left(1 - \frac{G_{mb} @ N_{des} \left(1 - P_b\right)}{G_{sb}}\right) \times 100\%$$

G_{mb} = bulk specific gravity of compacted mixture
G_{sb} = bulk specific gravity of the aggregate blend
P_b = asphalt binder content of mixture

Voids Filled with Asphalt

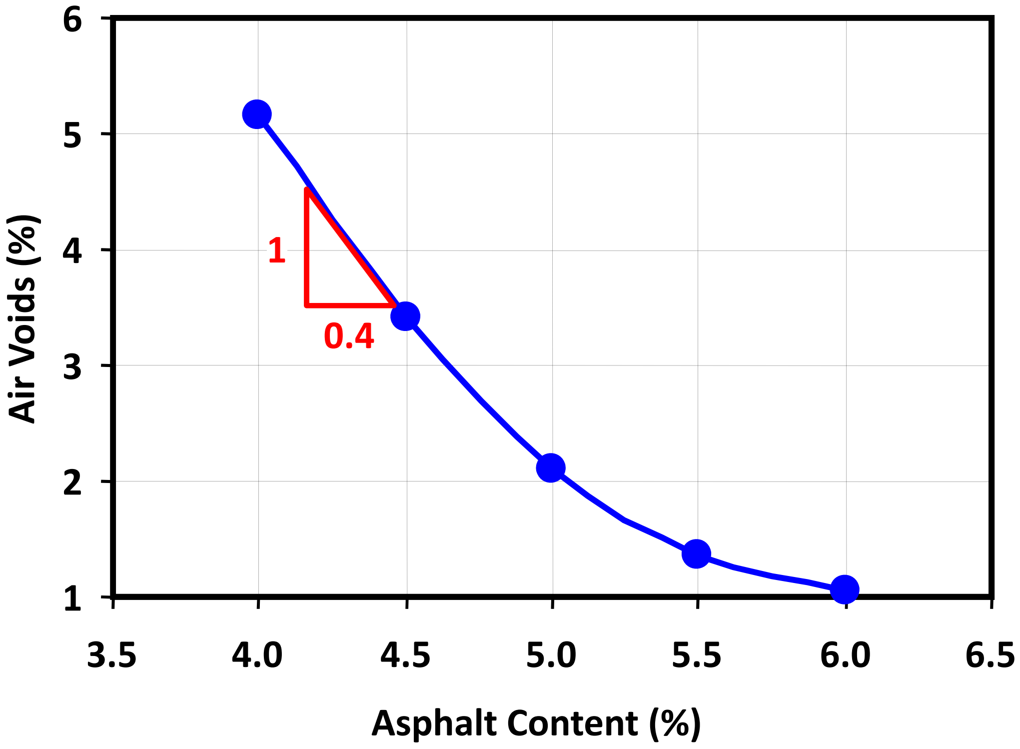
$$\mathrm{VFA} = \left(1 - \frac{\mathrm{VTM}}{\mathrm{VMA}}\right) \times 100\%$$

VFA is the percentage of the available space between the aggregate particles (the VMA) that is occupied by asphalt binder rather than by air voids.

Estimate P_b @ 4% Air Voids

$$P_b\,@\,4\% = P_b - 0.4\left(4\% - \text{VTM}\right)$$

Marshall Mix Design



Estimate P_b @ 4% Air Voids

Assume VTM = 2.6%

$$\begin{aligned} P_b @ 4\% &= P_b - 0.4(4\% - 2.6\%) \\ &= P_b - 0.4(1.4\%) \\ &= P_b - 0.56\% \end{aligned}$$

To increase air voids, you'll have to reduce binder content

Estimate P_b @ 4% Air Voids

Assume VTM = 5.4%

$$\begin{aligned} P_b @ 4\% &= P_b - 0.4(4\% - 5.4\%) \\ &= P_b - 0.4(-1.4\%) \\ &= P_b + 0.56\% \end{aligned}$$

To decrease air voids, you'll have to increase binder content

Estimate VMA @ 4% Air Voids

$$\underline{\text{if VTM} < 4\%}$$

$$\text{VMA}@4\% = \text{VMA} + 0.1\left(4\% - \text{VTM}\right)$$

$$\underline{\text{if VTM} > 4\%}$$

$$\text{VMA}@4\% = \text{VMA} + 0.2\left(4\% - \text{VTM}\right)$$

Estimate VMA @ 4% Air Voids

Assume VTM = 2.6%

$$\begin{aligned}\text{VMA}@4\% &= \text{VMA}+0.1\left(4\%-2.6\right)\\ &= \text{VMA}+0.1\left(1.4\%\right)\\ &= \text{VMA}+0.14\%\end{aligned}$$

If you increase the air voids the VMA will increase

Estimate VMA @ 4% Air Voids

Assume VTM = 5.4%

$$
\begin{aligned}
\text{VMA}@4\% &= \text{VMA} + 0.2(4\% - 5.4) \\
&= \text{VMA} + 0.2(-1.4\%) \\
&= \text{VMA} - 0.28\%
\end{aligned}
$$

If you decrease the air voids the VMA will decrease

VMA Criteria

Nominal Maximum Aggregate Size	*Minimum VMA (percent)*
9.5 mm	15.0
12.5 mm	14.0
19.0 mm	13.0
25.0 mm	12.0
37.5 mm	11.0

This is the same as the Marshall criteria

Estimate VFA @ 4% Air Voids

$$\mathrm{VFA} = \left(1 - \frac{4\%}{\mathrm{VMA}}\right) \times 100\%$$

VFA Criteria

Traffic (million ESALs)	***Design VFA (percent)***
< 0.3	65 – 80
0.3 to 3.0	65 – 78
> 3.0	65 - 75

This is similar to the Marshall criteria

Estimate $\%G_{mm}$ @ N_{ini}

$$\%G_{mm} @ N_{ini} = \%G_{mm} @ N_{ini} - \left(4\% - VTM\right)$$

Estimate %G_{mm} @ 4% Air Voids

Assume VTM = 2.6%

$$
\begin{aligned}
\%G_{mm} @ N_{ini} &= 86.3\% - \left(4\% - 2.6\%\right) \\
&= 86.3\% - (1.4\%) \\
&= 84.9\%
\end{aligned}
$$

If you increase the air voids the density will decrease

Estimate %G_{mm} @ 4% Air Voids

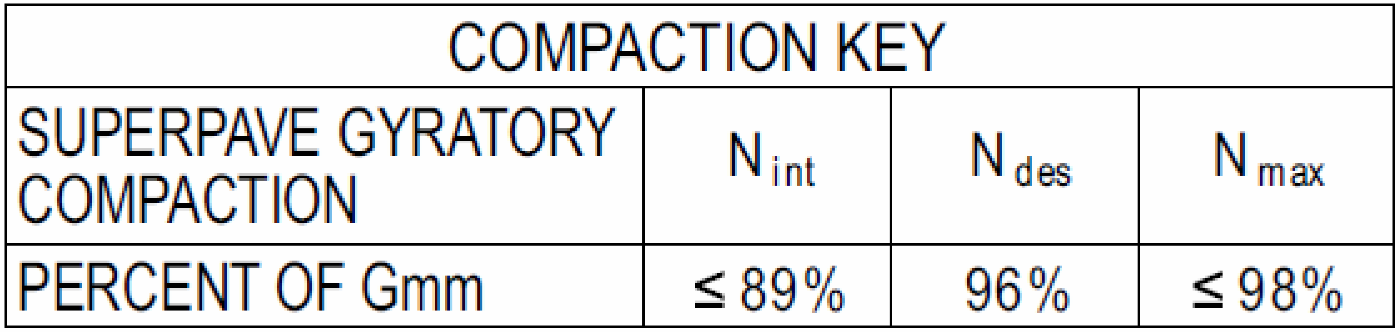
Assume VTM = 5.4%

$$\begin{aligned}\%G_{mm}\,@\,N_{ini} &= 86.3\% - \left(4\% - 2.6\%\right)\\ &= 86.3\% - (-1.4\%)\\ &= 87.7\%\end{aligned}$$

If you decrease the air voids the density will increase

Compaction Requirements

N = number of revolutions in the gyratory compactor



COMPACTION KEY			
SUPERPAVE GYRATORY COMPACTION	N_{int}	N_{des}	N_{max}
PERCENT OF Gmm	≤ 89%	96%	≤ 98%

Source: NCEES *FE Supplied Reference Handbook*

Optimum Asphalt Content

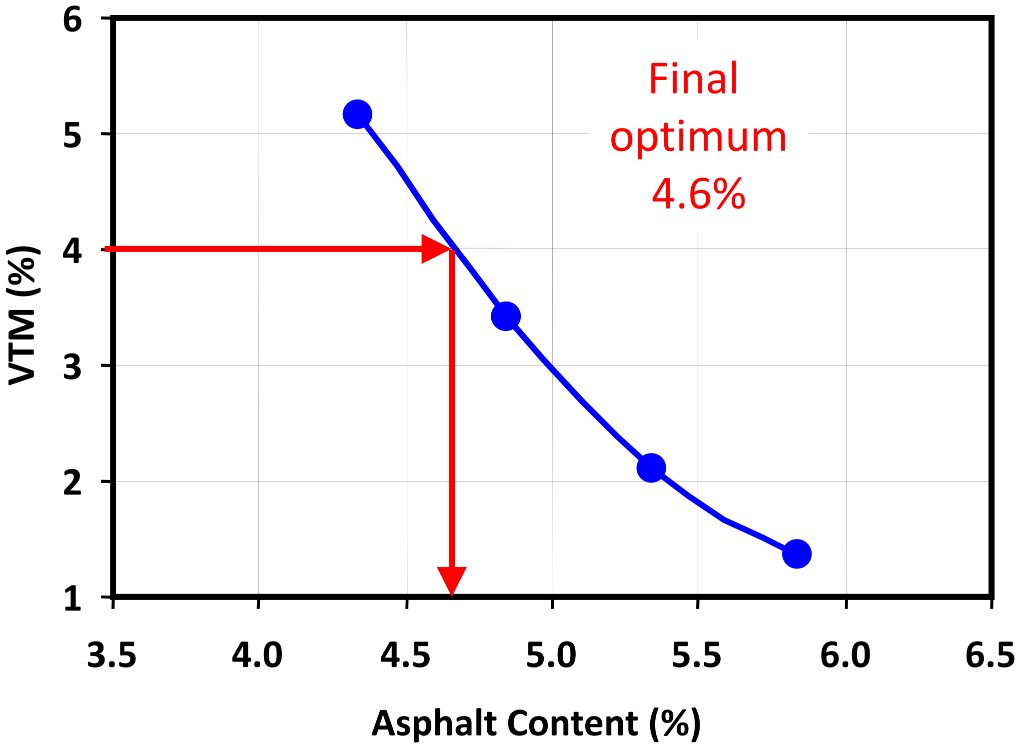
- If our estimated VMA, VFA and G_{mm}@N_{ini} at 4% air voids meet the requirements, we have assembled a suitable aggregate structure.
- To determine the final binder content, we'll compact four new specimens to N_{des} gyrations using the adjusted binder content and binder contents that are 0.5% less, 0.5% more and 1.0% more than the adjusted binder content.

Optimum Asphalt Content

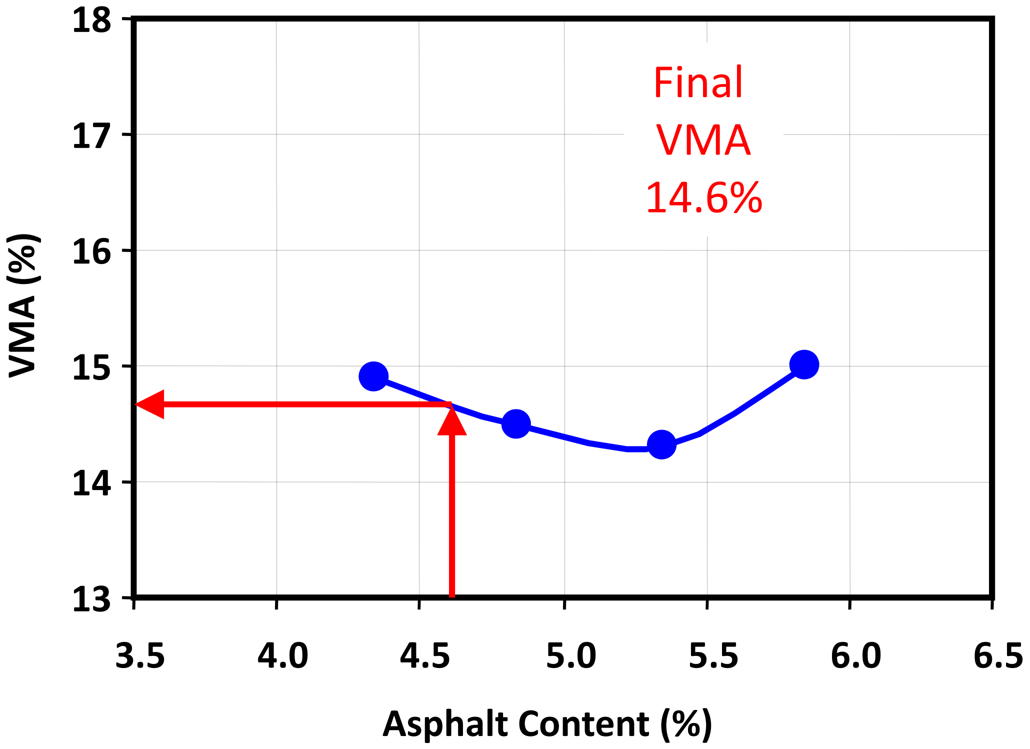
- We will then calculate and plot VTM, VMA, VFA and $\%G_{mm}@N_{ini}$ as a function of binder content.
- We will interpolate the final binder content as that one that gives exactly 96% G_{mm} (4% VTM) at N_{des} gyrations and check to make sure that binder content also produces suitable VTM, VMA, VFA and $\%G_{mm}@N_{ini}$.

VTM Results

Assume estimated AC @ 4% air voids = 4.8%



VMA Results

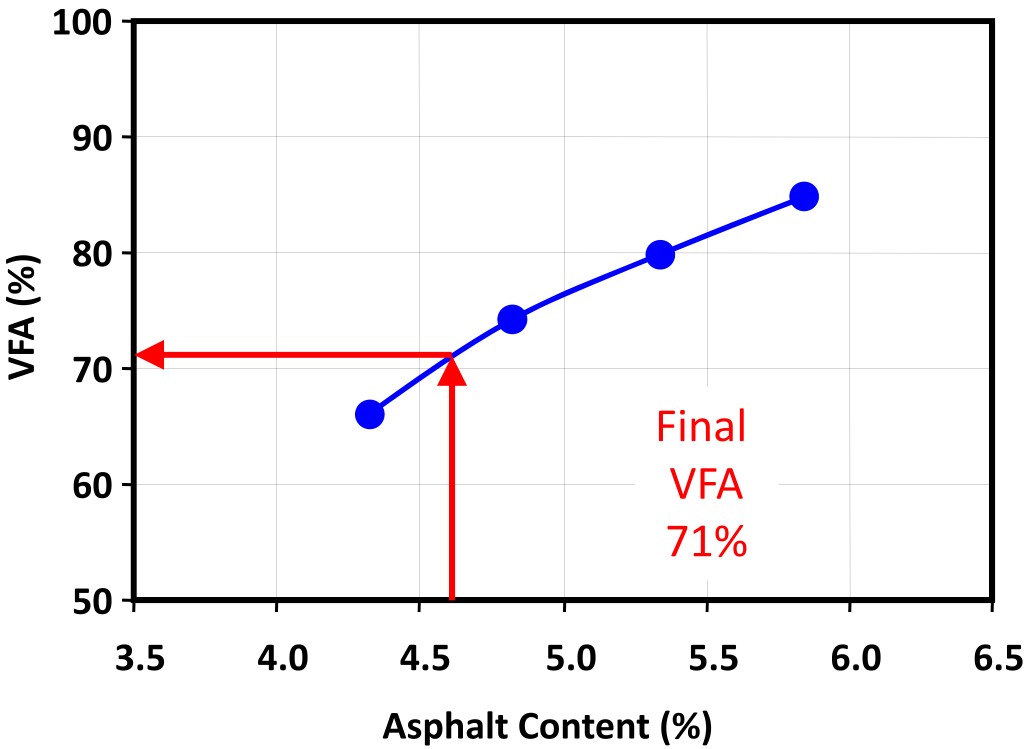

Final
VMA
14.6%
18
17
16
15
14
13
VMA (%)
3.5
4.0
4.5
5.0
5.5
6.0
6.5
Asphalt Content (%)

VMA Criteria

Nominal Maximum Aggregate Size	*Minimum VMA (percent)*
9.5 mm	15.0
12.5 mm	14.0
19.0 mm	13.0
25.0 mm	12.0
37.5 mm	11.0

This is the same as the Marshall criteria

VFA Results



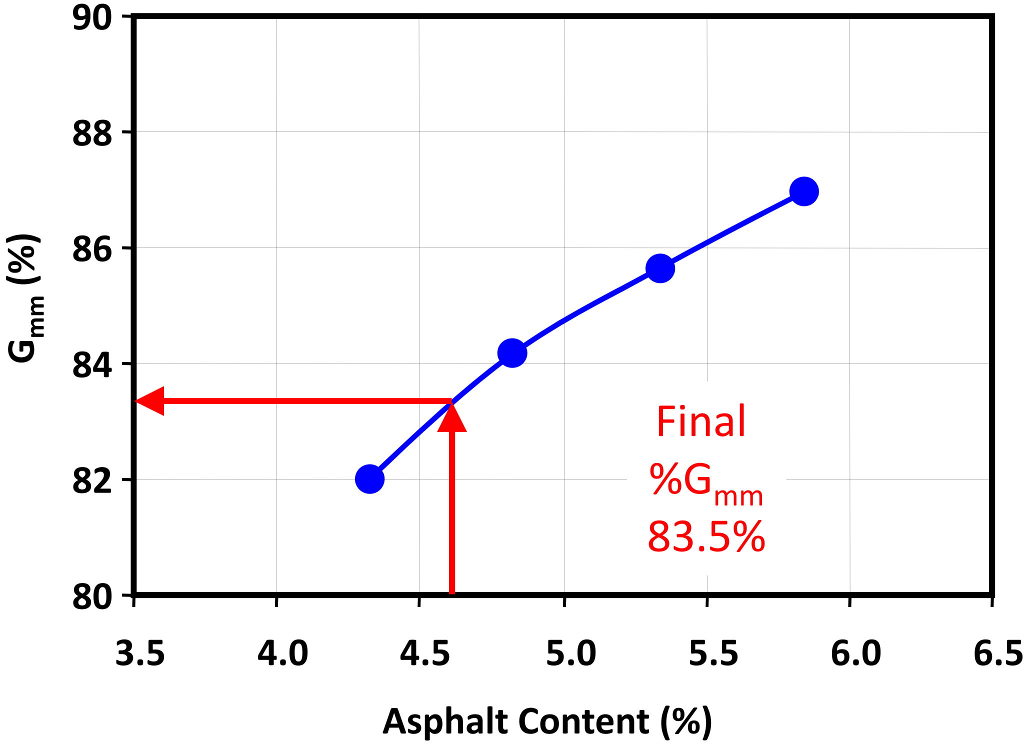
Final
VFA
71%

VFA Criteria

Traffic (million ESALs)	***Design VFA (percent)***
< 0.3	65 – 80
0.3 to 3.0	65 – 78
> 3.0	65 - 75

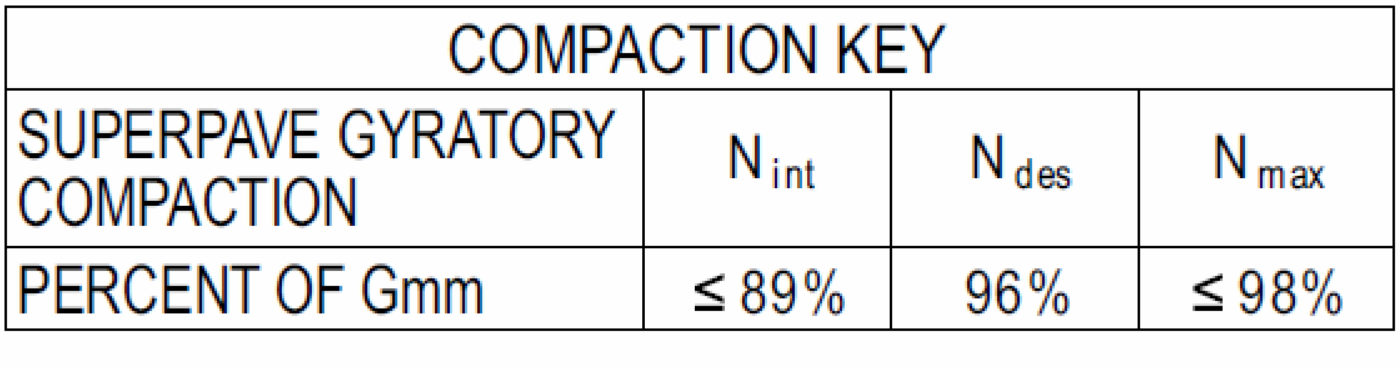
This is similar to the Marshall criteria

%G_{mm} @ N_{ini} Results



Compaction Requirements

N = number of revolutions in the gyratory compactor



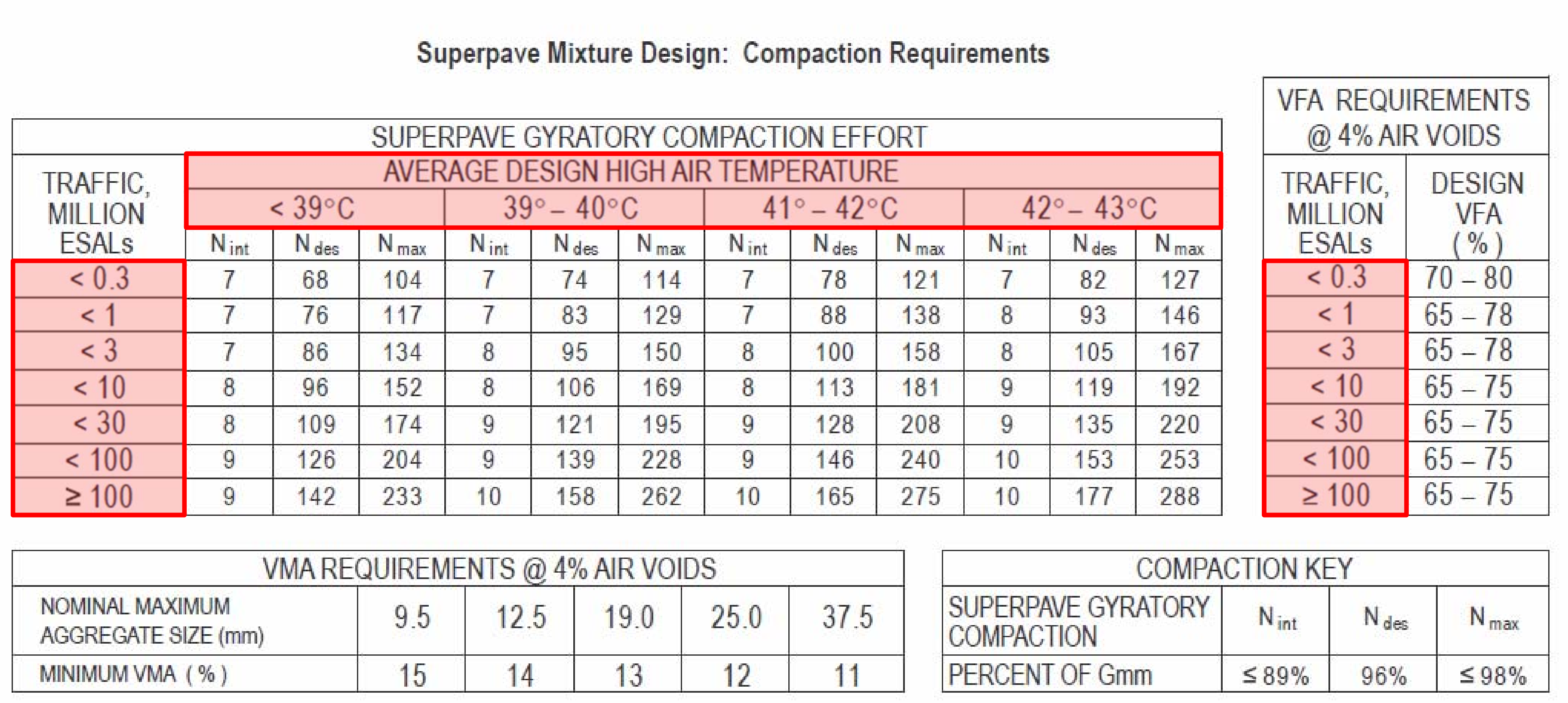
COMPACTION KEY			
SUPERPAVE GYRATORY COMPACTION	N_{int}	N_{des}	N_{max}
PERCENT OF Gmm	$\leq 89\%$	96%	$\leq 98\%$

Source: NCEES *FE Supplied Reference Handbook*

Optimum Asphalt Content

- Finally, we will compact two more specimens made at the optimum asphalt content to N_{max} gyrations and check to make sure the $\%G_{mm}$ is less than 98%.

CAUTION: FE Reference Handbook



Superpave Mixture Design: Compaction Requirements

SUPERPAVE GYRATORY COMPACTION EFFORT												
TRAFFIC, MILLION ESALs	AVERAGE DESIGN HIGH AIR TEMPERATURE											
	< 39°C			39° – 40°C			41° – 42°C			42° – 43°C		
	N_{int}	N_{des}	N_{max}	N_{int}	N_{des}	N_{max}	N_{int}	N_{des}	N_{max}	N_{int}	N_{des}	N_{max}
< 0.3	7	68	104	7	74	114	7	78	121	7	82	127
< 1	7	76	117	7	83	129	7	88	138	8	93	146
< 3	7	86	134	8	95	150	8	100	158	8	105	167
< 10	8	96	152	8	106	169	8	113	181	9	119	192
< 30	8	109	174	9	121	195	9	128	208	9	135	220
< 100	9	126	204	9	139	228	9	146	240	10	153	253
≥ 100	9	142	233	10	158	262	10	165	275	10	177	288

VFA REQUIREMENTS @ 4% AIR VOIDS	
TRAFFIC, MILLION ESALs	DESIGN VFA (%)
< 0.3	70 – 80
< 1	65 – 78
< 3	65 – 78
< 10	65 – 75
< 30	65 – 75
< 100	65 – 75
≥ 100	65 – 75

VMA REQUIREMENTS @ 4% AIR VOIDS					
NOMINAL MAXIMUM AGGREGATE SIZE (mm)	9.5	12.5	19.0	25.0	37.5
MINIMUM VMA (%)	15	14	13	12	11

COMPACTION KEY			
SUPERPAVE GYRATORY COMPACTION	N_{int}	N_{des}	N_{max}
PERCENT OF Gmm	≤ 89%	96%	≤ 98%

Source: NCEES *FE Supplied Reference Handbook*