# Reducing Mix Designs: Using a Single $N_{design}$

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# Original SGC Compaction Effort

| Design ESALs (millions) | Average Design High Air Temperature | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | <39 °C | | | 39 - 40 °C | | | 41 - 42 °C | | | 43 - 44 °C | | |
| | $N_{ini}$ | $N_{des}$ | $N_{max}$ | $N_{ini}$ | $N_{des}$ | $N_{max}$ | $N_{ini}$ | $N_{des}$ | $N_{max}$ | $N_{ini}$ | $N_{des}$ | $N_{max}$ |
| < 0.3 | 7 | 68 | 104 | 7 | 74 | 114 | 7 | 78 | 121 | 7 | 82 | 127 |
| 0.3 - 1 | 7 | 76 | 117 | 7 | 83 | 129 | 7 | 88 | 138 | 8 | 93 | 146 |
| 1 - 3 | 7 | 86 | 134 | 8 | 95 | 150 | 8 | 100 | 158 | 8 | 105 | 167 |
| 3 - 10 | 8 | 96 | 152 | 8 | 106 | 169 | 8 | 113 | 181 | 9 | 119 | 192 |
| 10 - 30 | 8 | 109 | 174 | 9 | 121 | 195 | 9 | 128 | 208 | 9 | 135 | 220 |
| 30 - 100 | 9 | 126 | 204 | 9 | 139 | 228 | 9 | 146 | 240 | 10 | 153 | 253 |
| > 100 | 9 | 143 | 233 | 10 | 158 | 262 | 10 | 165 | 275 | 10 | 172 | 288 |

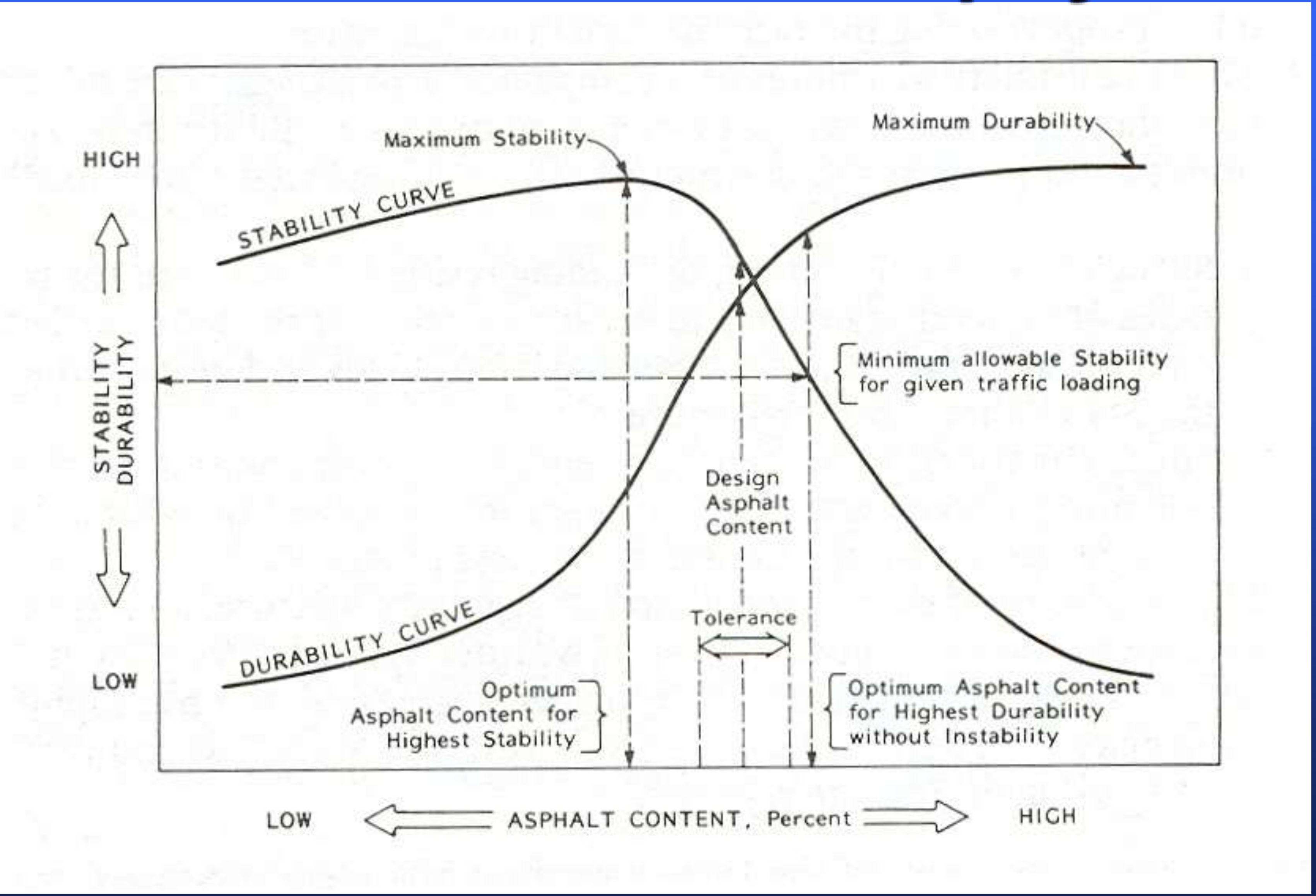
# Illinois DOT $N_{design}$ Table

| 20-Year Design ESALs | Nini | Ndes |
|---|---|---|
| <0.3 | 6 | 30 |
| 0.3 to 3 | 6 | 50 |
| 3 to 10 | 7 | 70 |
| 10 to 30 | 8 | 90 |
| > 30 | 8 | 105 |

2 diff. mix

Four NMAS

# Hveem's Philosophy

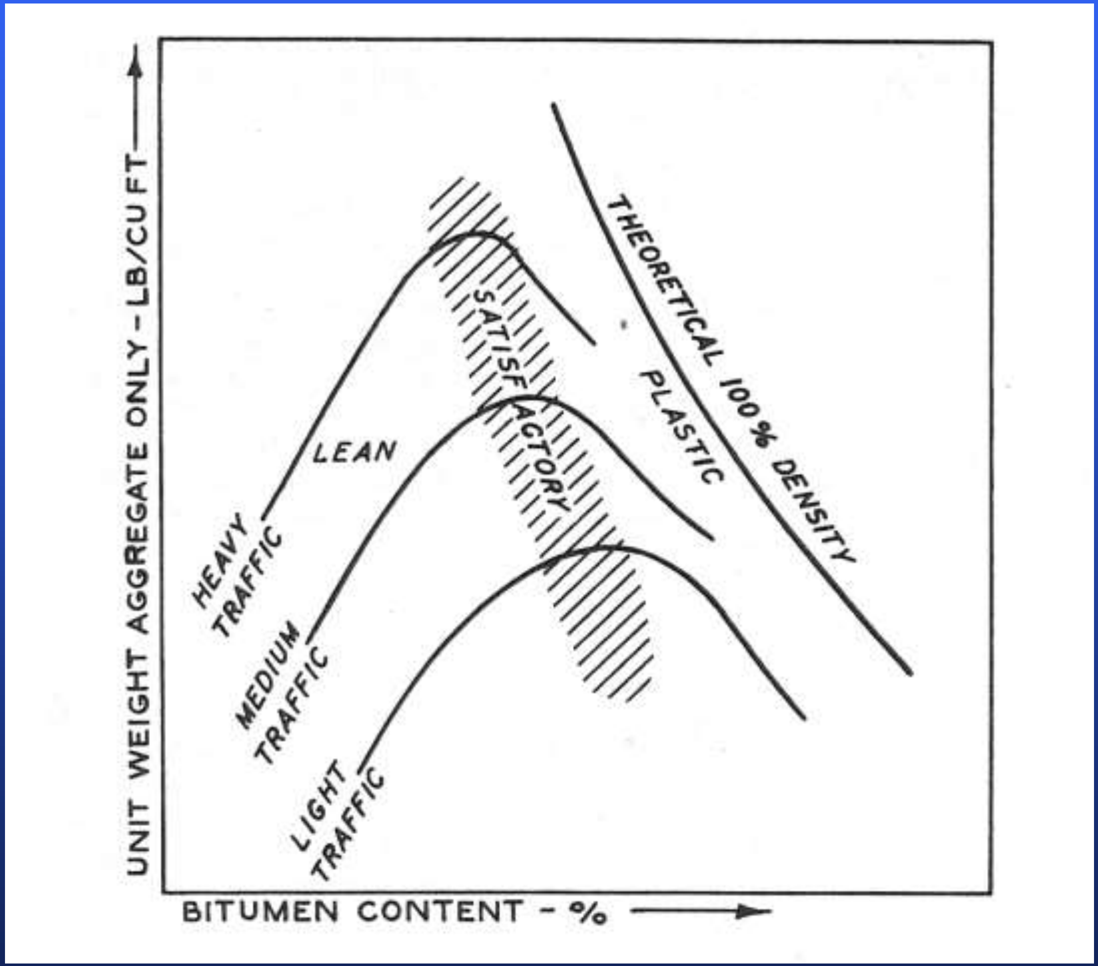



Vallegra and Lovering, AAPT, 1985

**The compaction effort used in a volumetric mix design should produce laboratory samples which approximate the ultimate density of the pavement**

Ortolani and Sandberg, Jr. AAPT, 1951

# McRae's Tiered Approach




AAPT, 1958

# Conclusions on In-Place Density from Literature

- In-place density may be the single factor that most affects the performance of a properly designed mixture
- A mediocre mix, well constructed with good in-place air voids, will often perform better than a good mix that has been poorly constructed
- In-place density, between 92 and 97 % Gmm for dense and fine graded mixes will generally provide good performance
- In-place density > than 93 to 95 % of Gmm may be required for coarse-graded or larger NMAS mixtures to limit permeability

# National Efforts to Address $N_{design}$

- Asphalt Institute - $N_{design}$II Experiment
  - Examined field densification of SPS-9 pavements
  - Looked at mixture stiffness (G*) with SST
- NCAT - NCHRP 9-9 Evaluation of the SGC Procedure
  - Looked at sensitivity of mix volumetrics to changes in $N_{design}$ **25 gyration = approx. 1% VMA**
- A new $N_{design}$ Table was developed from each effort

# SGC Compaction Effort 1999

| 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.

# NCHRP 9-9(1) Objectives

- Evaluate field densification of Superpave designed mixes
- Verify or determine Ndesign levels to maximize field performance
- Evaluate locking point concept, Ninitial and Nmaximum

# NCHRP 9-9 (1): Field Project Locations

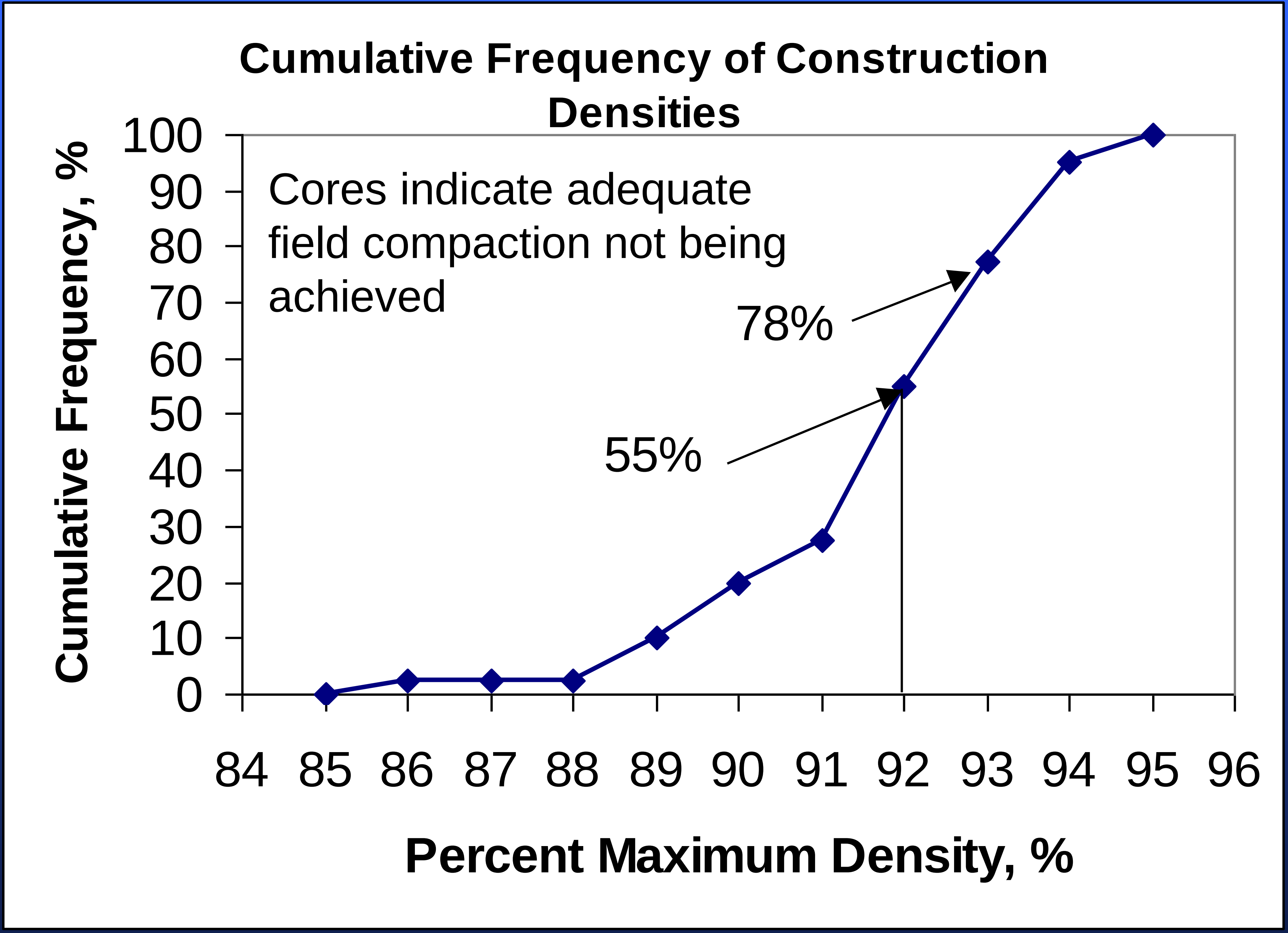
## Legend

● : Project Site

# Experimental Plan

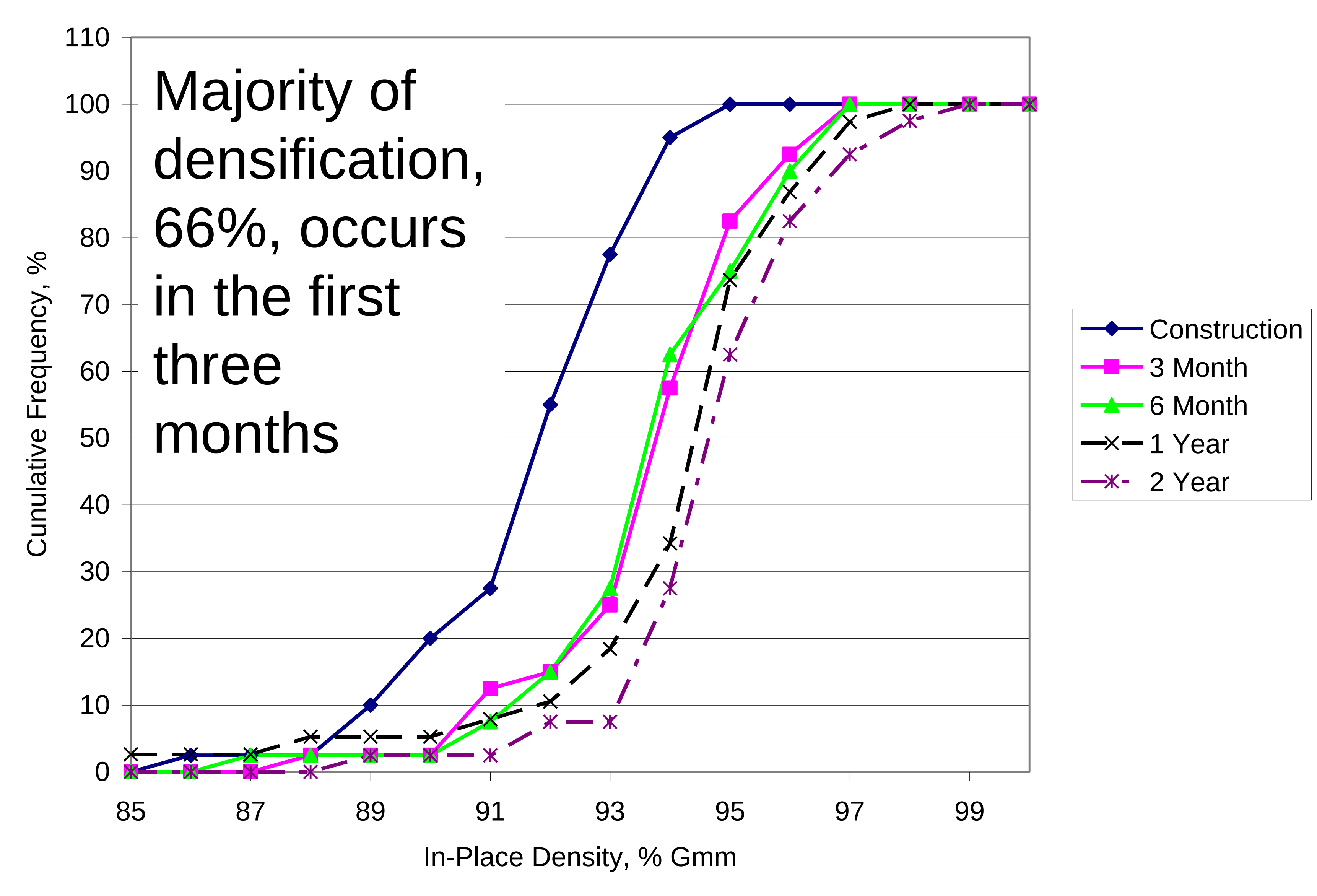
- Loose mix compacted on-site (no reheating) in Pine AFG1a and Troxler 4141
- Targeted three samples at each project with three replicates for each sample
- Roadway cores taken at construction, 3 months, 6 months, 1 year, and 2 years after construction from right wheel path
- Project extended to monitor projects 4 years after construction

# NCHRP 9-9 (1) Findings

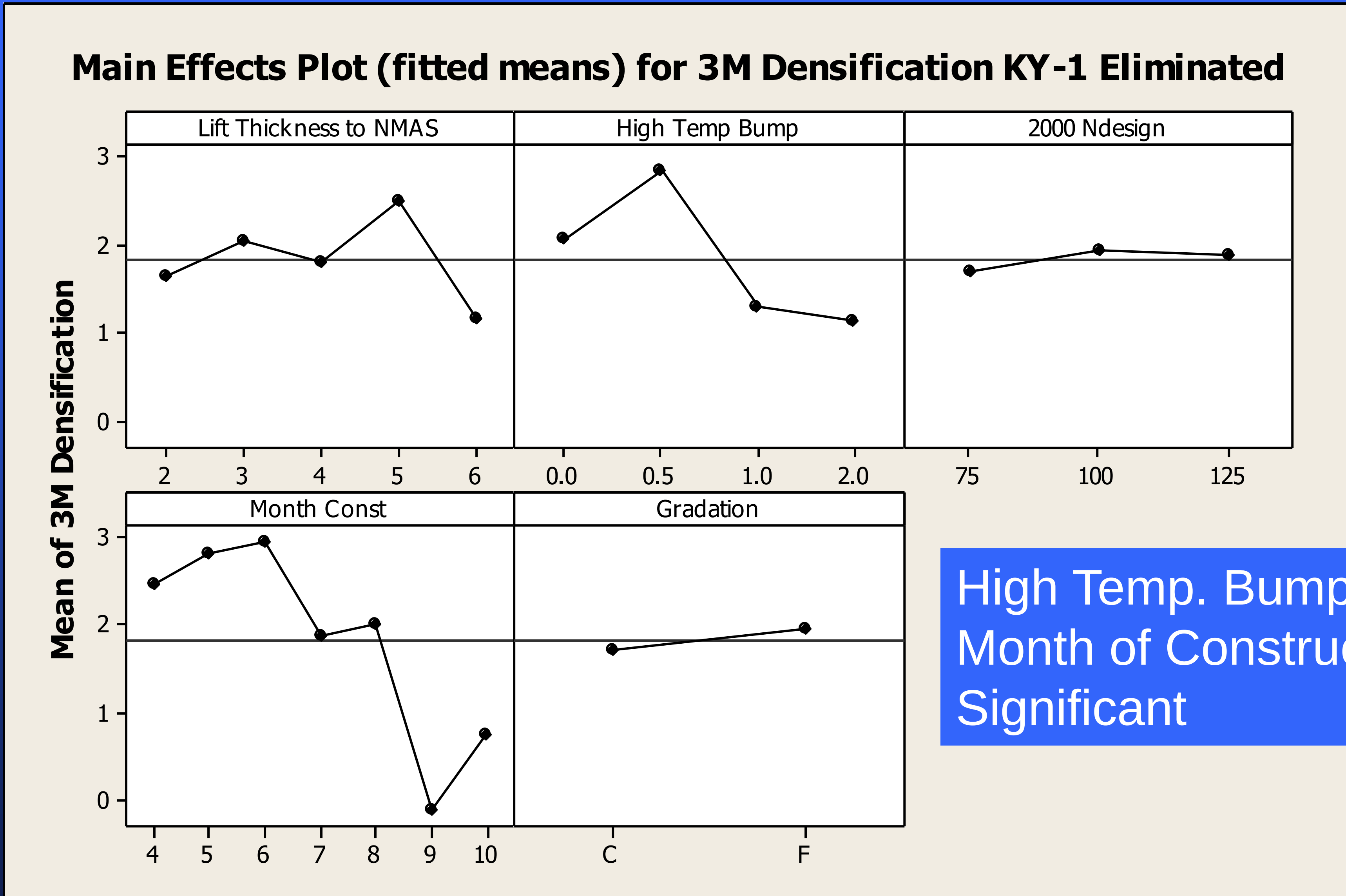


Cumulative Frequency of Construction Densities
Cumulative Frequency, %
100
90
80
70
60
50
40
30
20
10
0
Cores indicate adequate field compaction not being achieved
78%
55%
84
85
86
87
88
89
90
91
92
93
94
95
96
Percent Maximum Density, %

# Pavement Densification



# Factors Affecting 3-Month Densification




High Temp. Bump and Month of Construction Significant

# Ultimate Density

- Overall average 2- and 4-year in-place density both = 94.6%
- 4-year density less than 2-year density in 15 of 35 cases
- Paired t-test significantly different in 8 cases, 4-year density higher in 6 of 8 cases
- Population t-test significantly different in one case, density lower
- Ultimate density reached after 2-years

# Summary of Field Performance of NCHRP 9-9(1) Projects

- Average rut depth 1.7 mm, one project with 6.4 mm (high traffic, unmodified)
- Raveling common
- Overlays over PCC evidence reflective cracking, even when total (new) overlay 3.5 inches or more, most after 2-years
- Joints vary from fair to very good
- Some permeability evidenced by wet spots

# Model Developed Based on % of Lab Density

- Model developed to predict % of lab density, based on as-constructed density, HGP and traffic ($R^2$=0.53)
- Number of gyrations to match % of lab density similar for all mixes (STD approximately 8)

$$Ndesign = 16.8 - 1.27 \times HPG + 20.1 \times Log\left(20\ Year\ ESALs\right)$$

HPG = High temperature binder grade

$R^2$=0.97, SE = 3.54

# NCHRP 9-9(1)Recommended Ndesign Table

**Proposed Ndesign Levels for an SGC DIA of 1.16 ± 0.02 Degrees**

| 20-Year Design Traffic, ESALs | 2-Year Design Traffic, ESALs | Ndesign Unmodified | Ndesign PG 76-22 |
|---|---|---|---|
| < 300,000 | < 30,000 | 50 | NA |
| 300,000 to 3,000,000 | 30,000 to 230,000 | 65 | 50 |
| 3,000,000 to 10,000,000 | 230,000 to 925,000 | 80 | 65 |
| 10,000,000 to 30,000,000 | 925,000 to 2,500,000 | 80 | 65 |
| > 30,000,000 | > 2,500,000 | 100 | 80 |

Based on equation to predict Ndesign at 92% ACD

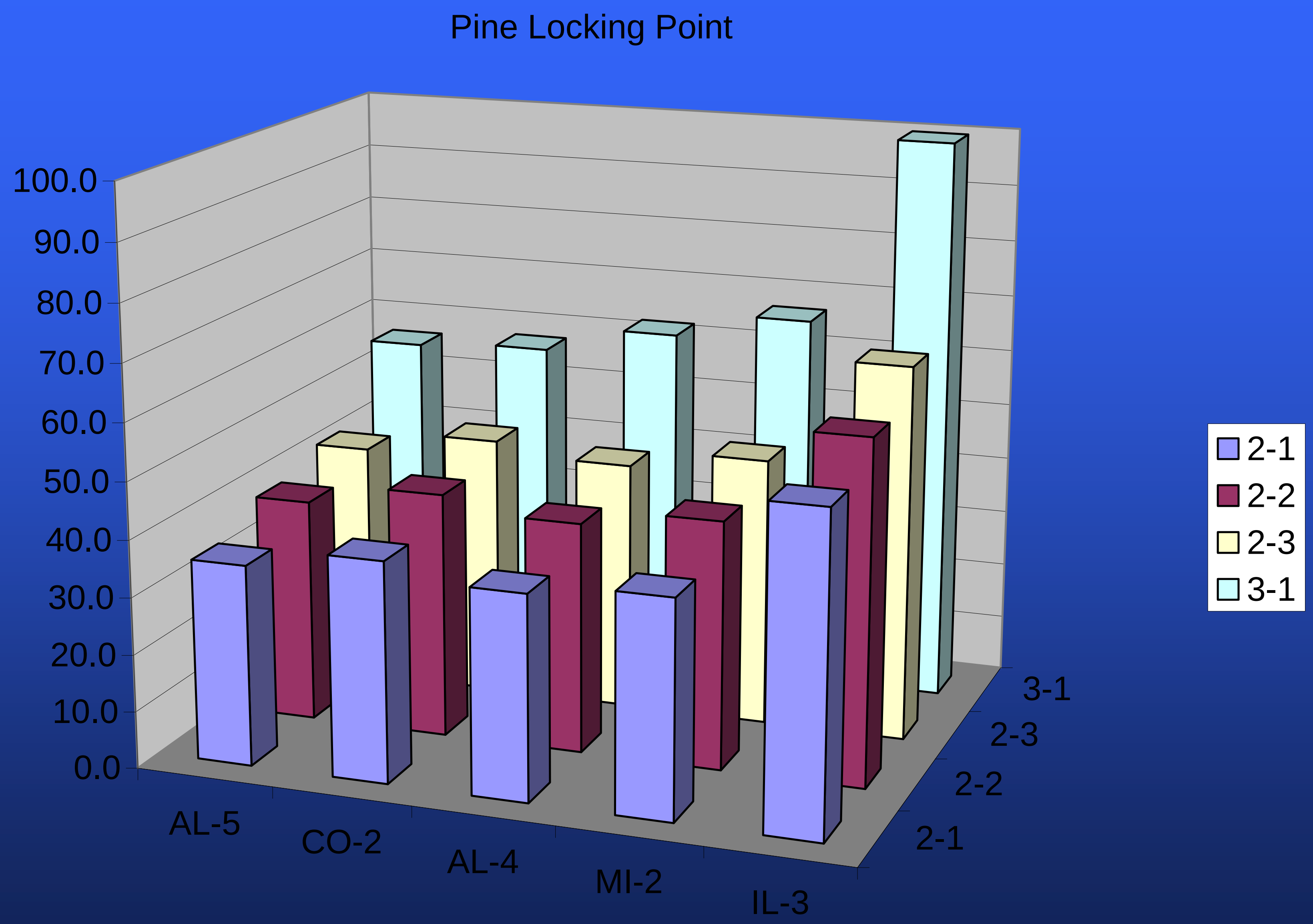
# Locking Point

- Concept developed by Illinois DOT (Bill Pine)
- Plot of Log gyrations vs. density non-linear beyond locking point
- Point where aggregate locks together – additional gyrations degrade aggregate
- Point after which change rule 25 gyrations = 1% VMA = 0.4 AC% generally true

# Definition of Locking Point

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| 60 | 111.9 | 111.9 | 111.8 | 111.8 | 111.7 | 111.7 | 111.6 | 111.6 | 111.5 | 111.5 |
| 70 | 111.4 | 111.4 | 111.3 | 111.3 | 111.2 | 111.2 | 111.2 | 111.1 | 111.1 | 111.0 |
| 80 | 111.0 | 110.9 | 110.9 | 110.8 | 110.8 | 110.8 | 110.7 | 110.7 | 110.7 | 110.6 |

Locking Point


Pine Locking Point
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
AL-5
CO-2
AL-4
MI-2
IL-3
3-1
2-3
2-2
2-1
2-1
2-2
2-3
3-1

# Effect of Design Compaction

| Property | Increased Ndesign | Decreased Ndesign |
| --- | --- | --- |
| Coarse Aggregate Angularity | Increased demand for crushed aggregate | Reduced demand for crushed aggregate or no change |
| Fine aggregate angularity | Reduce natural sand | Reduced need for manufactured sand or no change |
| Gradation | Change to increase VMA | Change to reduce VMA or no change |
| Air Voids | No effect | No effect |
| Voids in Mineral Aggregate | No effect after mix adjustment | No effect after mix adjustment |
| Voids filled with asphalt | Little or no change | Little or no change |
| Compaction on road | More difficult | Less difficult |
| Mixture stiffness | Increased stiffness | Decreased stiffness |

Minimums set by aggregate properties

Huber and Anderson AAPT

# How Does This Mesh with NCHRP 9-25/31?

- In-place air voids
  - Each 1% decrease in air voids decreases the rutting rate by 18%
  - Increasing air voids decreases fatigue life
- Increase aggregate fineness by 10 ($FM_{300}$) decreases rutting rate by a factor of 2
  - $FM_{300} = \sum$ (percent passing 0.300, 0.150, and 0.075 mm sieves)
- Increase high temperature PG by one grade decreases rutting rate by a factor of 2.5
- Increase $N_{design}$ by 25 gyrations decrease rutting rate by 15 to 25%

Increasing required compaction energy produces a better mix,
If you can get the mix compacted

## What are other States doing?

23 states have altered $N_{design}$ levels (Gibson)

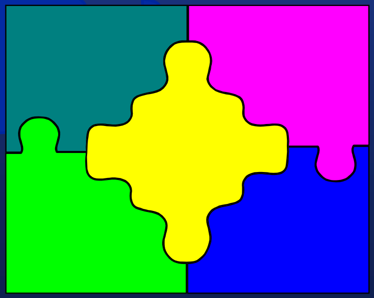
# Florida

| Traffic Level | Design Traffic, million ESALs | FDOT $N_{design}$ | Current AASHTO $N_{design}$ |
|---|---|---|---|
| A | < 0.3 | 50 | 50 |
| B | 0.3 to <3 | 75 | 75 |
| C | 3 to <10 | 75 | 100 |
| D | 10 to <30 | 100 | 100 |
| E | ≥30 | 100 | 125 |

# Changes in VDOT's Specifications adopted in 2000

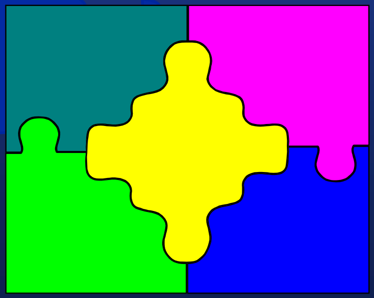
# Pieces of the Puzzle

- VDOT's experience with 75-blow Marshall mixes indicated the mixes were rut resistant, but durability suffered
- Early Superpave test sections produced at low voids (accidentally) have not rutted



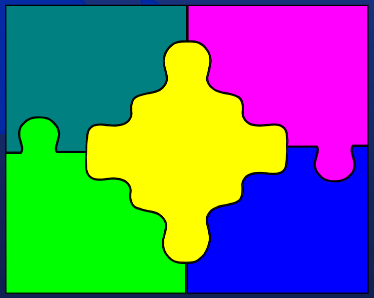
# More Pieces of the Puzzle

- Asphalt Pavement Analyzer
  - Indicates binder stiffness can provide rut resistance without sacrificing durability
  - Correlated with field performance (WesTrack)
  - Criteria developed to monitor field mixes
- Four year history of binder “bumping” with 50-blow Marshall mixes



# Last Pieces of the Puzzle

- Asphalt Institute Ndesign II experiment
  - Suggested lower gyrations based on mixture stiffness and field performance
  - Suggested 1 binder grade = approximately 20-30 gyrations in mixture stiffness
- NCAT survey of early sections suggested no rutting, mixes dry



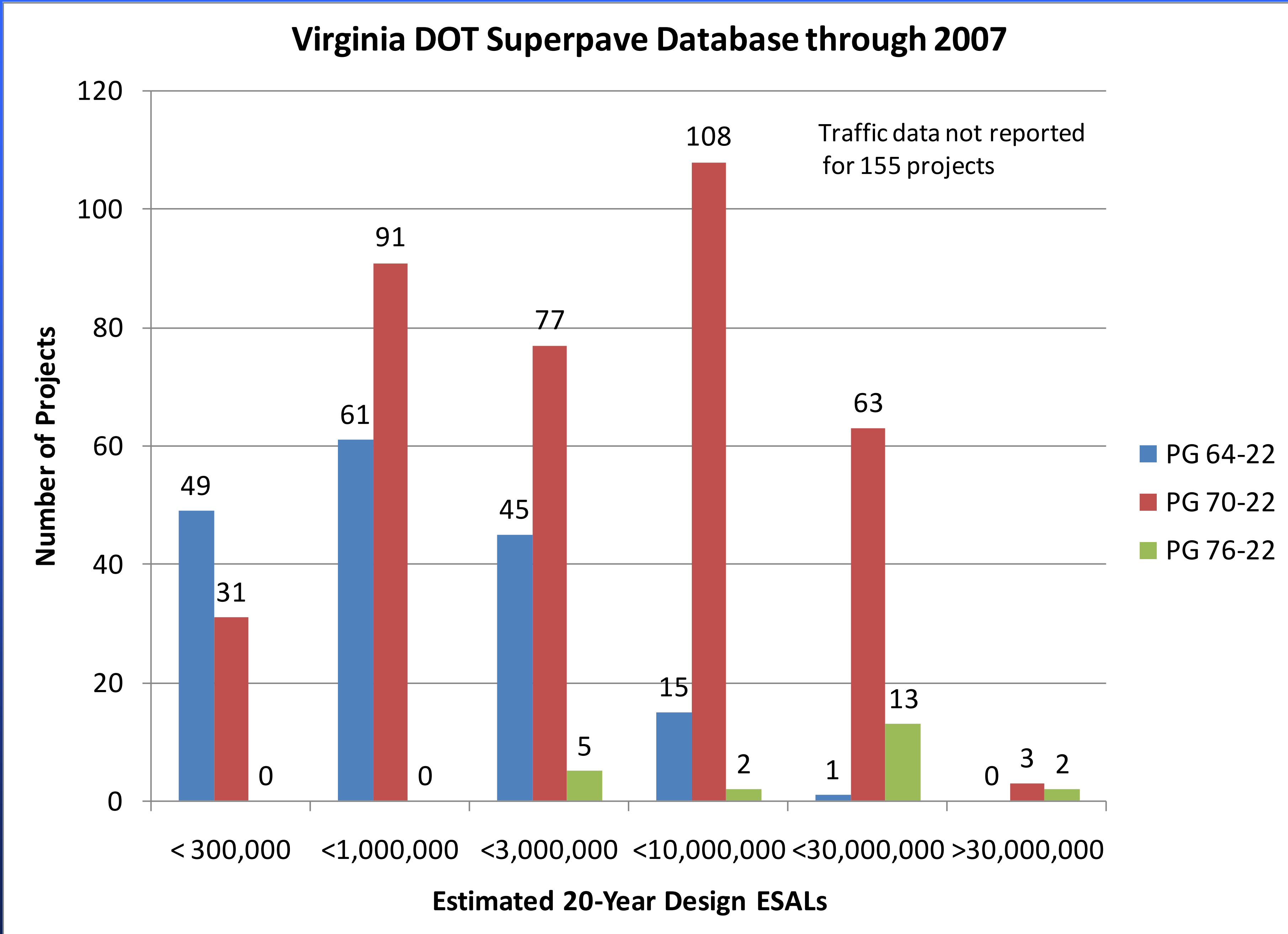
# VDOT's Y2K $N_{design}$ Table

| Traffic Million ESALs | PG Binder | $N_{design}$ |
|---|---|---|
| <3 | 64-22 | 65 |
| 3-10 | 70-22 | 75 |
| >10 | 76-22 | 75 |

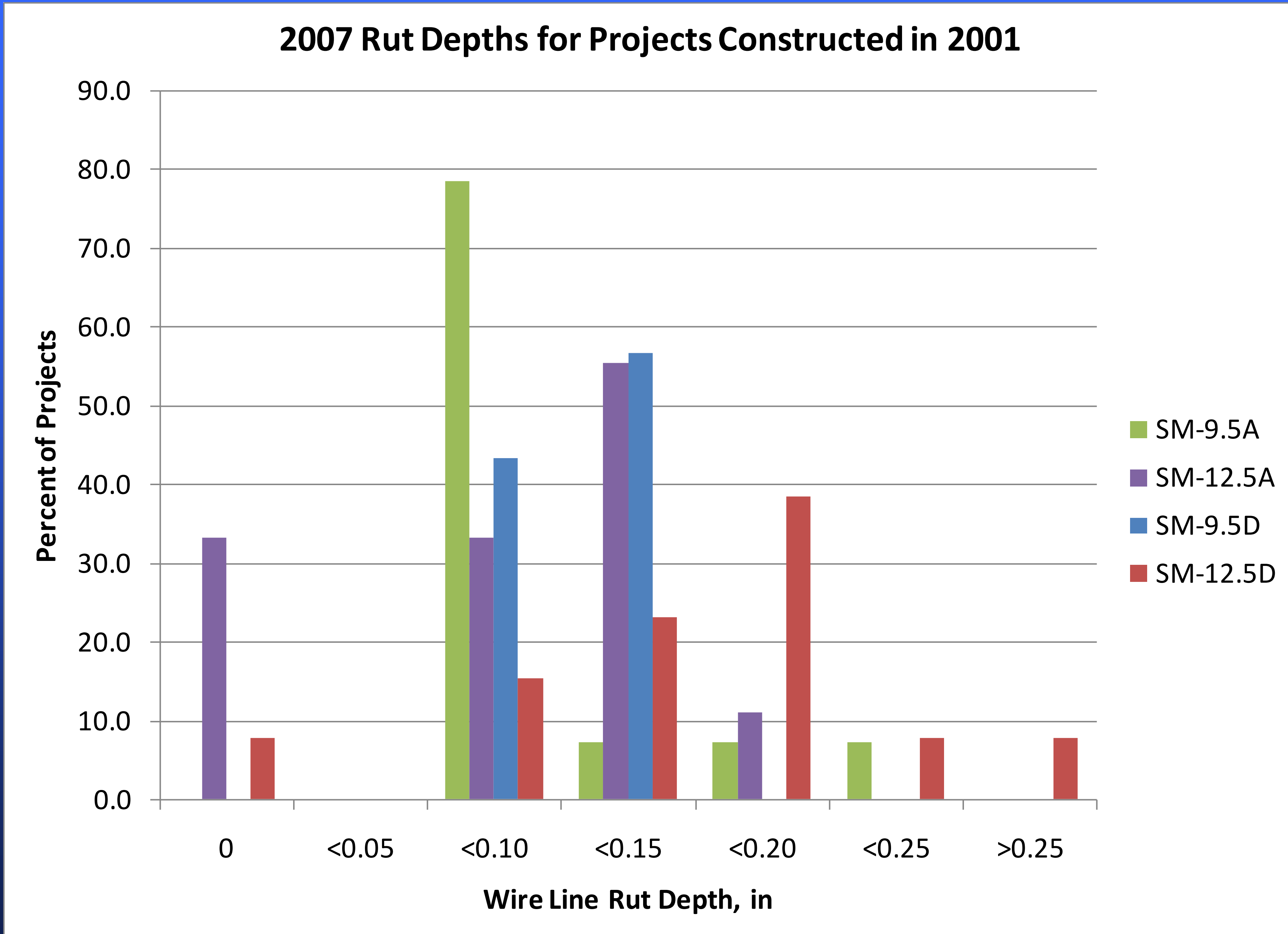
**Typically do not use 20 year design life**

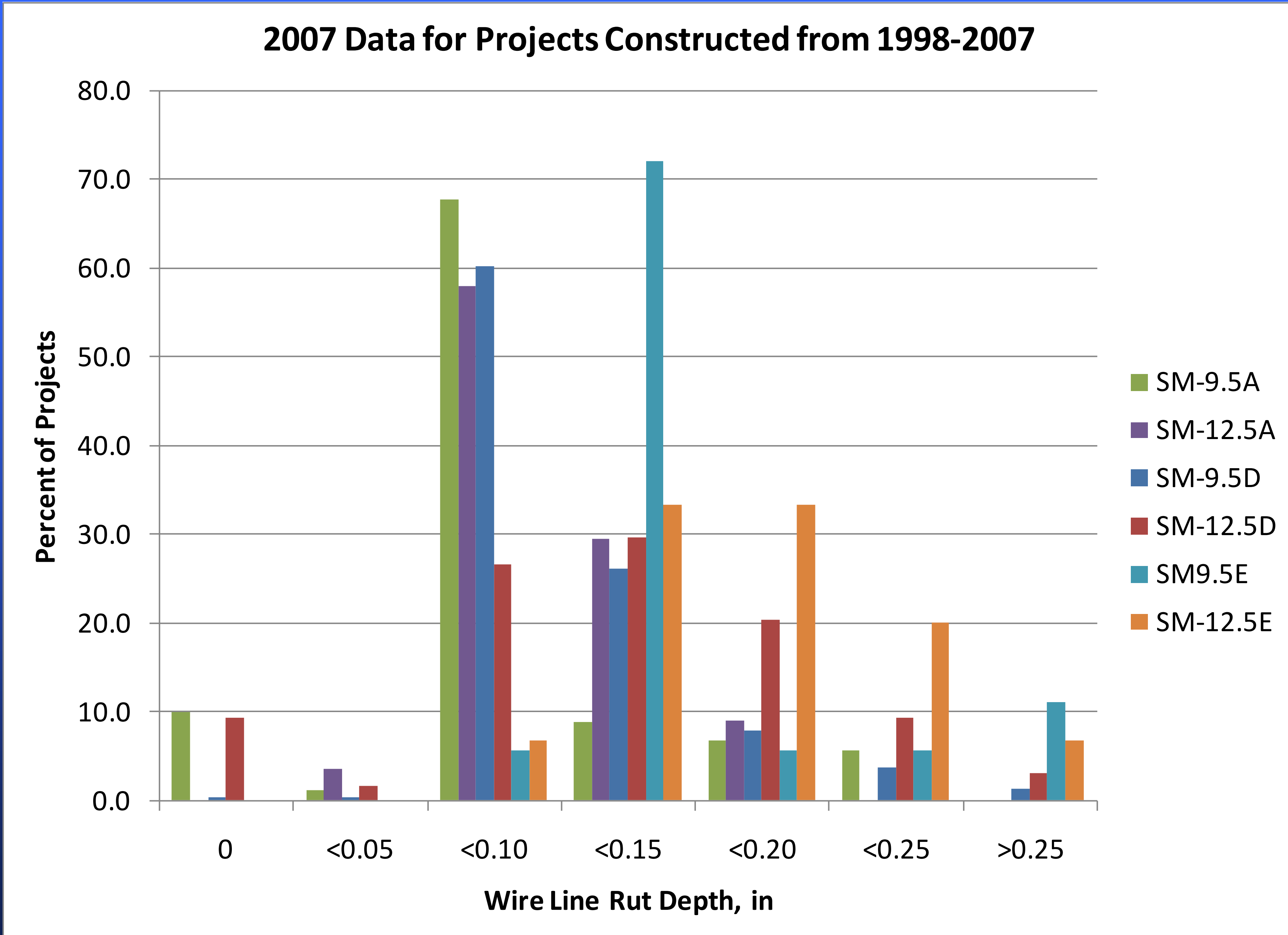
# Virginia

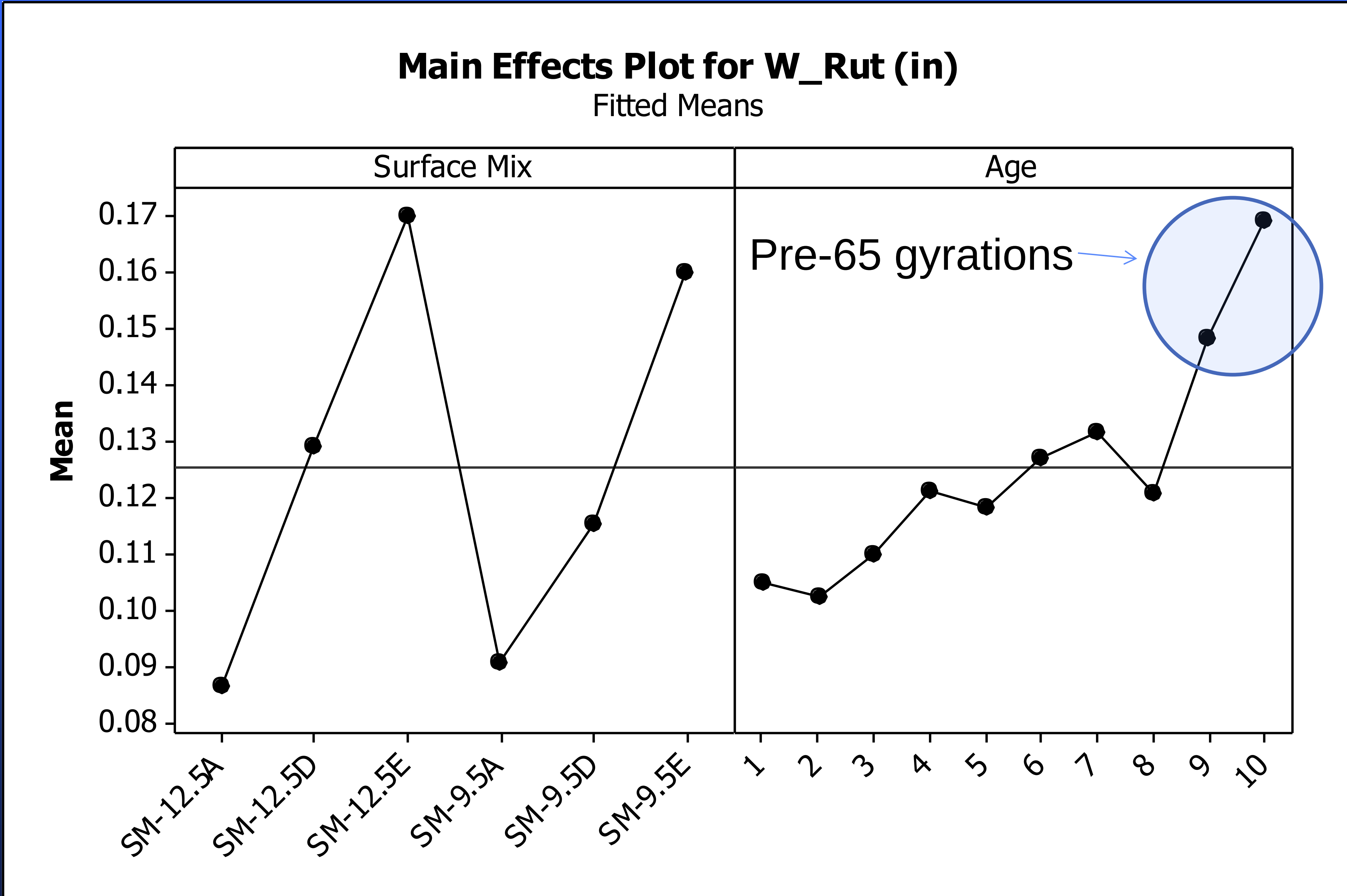
- Adopted 65 and 75 gyrations in 2000
- Adopted 65 gyrations for all mixes in 2001
- Use PG 64-22 (A) , PG 70-22 (D), and PG 76-22 (E), depending on traffic speed/level
- Have continued to look at ways to increase AC%



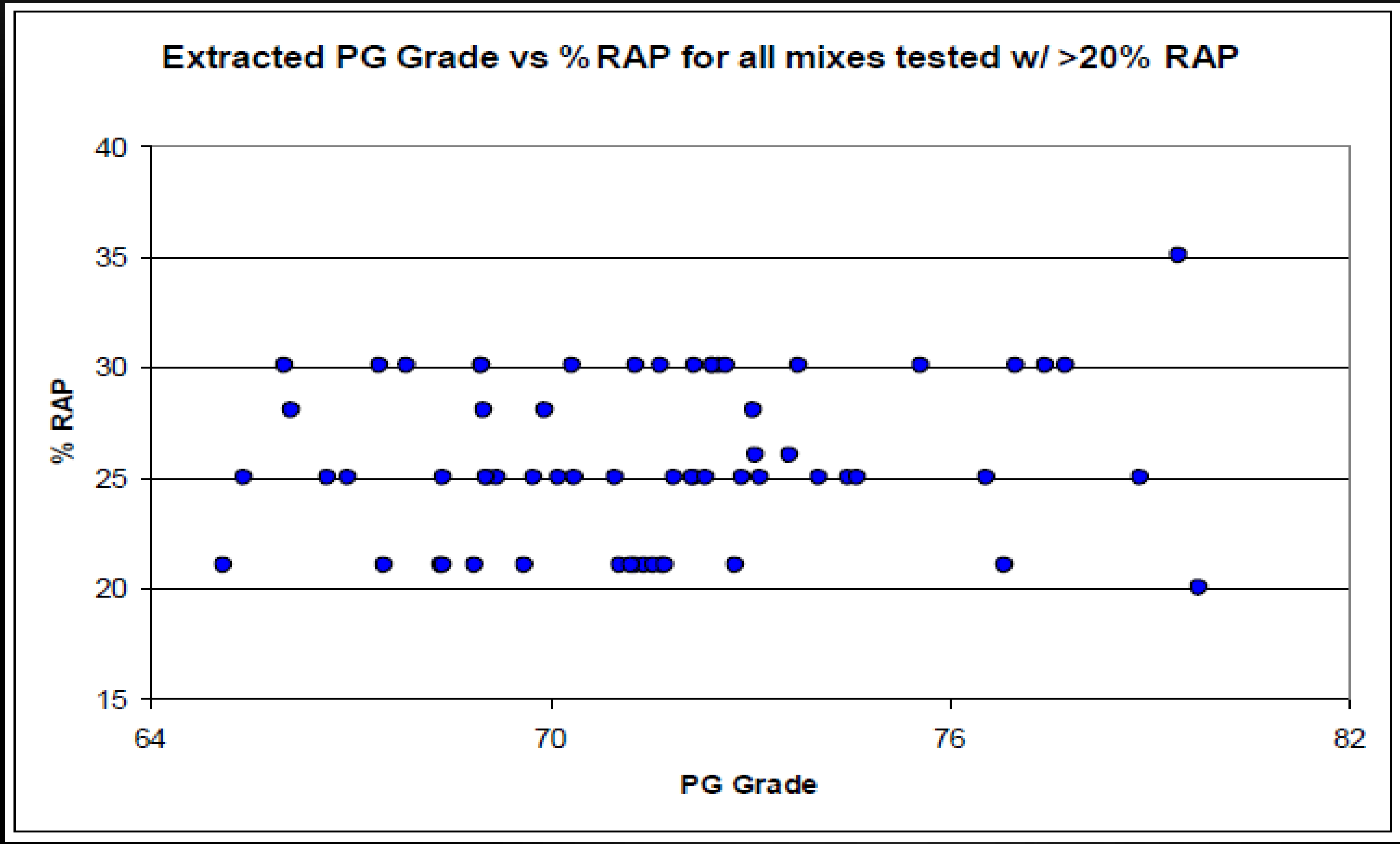
Virginia DOT Superpave Database through 2007
Number of Projects
120
100
80
60
40
20
0
Traffic data not reported for 155 projects
49
31
0
61
91
0
45
77
5
15
108
2
1
63
13
0
3
2
< 300,000
<1,000,000
<3,000,000
<10,000,000
<30,000,000
>30,000,000
Estimated 20-Year Design ESALs
PG 64-22
PG 70-22
PG 76-22


2007 Rut Depths for Projects Constructed in 2001
Percent of Projects
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
<0.05
<0.10
<0.15
<0.20
<0.25
>0.25
Wire Line Rut Depth, in
SM-9.5A
SM-12.5A
SM-9.5D
SM-12.5D


2007 Data for Projects Constructed from 1998-2007
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
Percent of Projects
0
<0.05
<0.10
<0.15
<0.20
<0.25
>0.25
Wire Line Rut Depth, in
SM-9.5A
SM-12.5A
SM-9.5D
SM-12.5D
SM9.5E
SM-12.5E


Main Effects Plot for W_Rut (in)
Fitted Means
Surface Mix
Age
Pre-65 gyrations
Mean
0.17
0.16
0.15
0.14
0.13
0.12
0.11
0.10
0.09
0.08
SM-12.5A
SM-12.5D
SM-12.5E
SM-9.5A
SM-9.5D
SM-9.5E
1
2
3
4
5
6
7
8
9
10

# TRUE GRADE OF RECOVERED RAP MIX BINDER




33/56 (59%) Mixes Graded Failed to Meet PG 70!

# VDOT's Binder Specifications

**TABLE II-14A**
**Recommended Performance Grade of Asphalt Cement**

| Mix Type | Percentage of Reclaimed Asphalt Pavement (RAP) in Mix | | |
|---|---|---|---|
| | %RAP ≤ 25.0% | 25.0% < %RAP ≤ 30% | 25.0% < %RAP ≤ 35% |
| SM-4.75A, SM-9.0A, SM-9.5A, SM-12.5A | PG 64-22 | PG 64-22 | |
| SM-4.75D, SM-9.0D, SM-9.5D, SM-12.5D | PG 70-22 | PG 64-22 | |
| IM-19.0A | PG 64-22 | PG 64-22 | |
| IM-19.0D | PG 70-22 | PG 64-22 | |
| BM-25.0A | PG 64-22 | | PG 64-22 |
| BM-25.0D | PG 70-22 | | PG 64-22 |

Based on rut testing performed by the Department and/or field performance of the job mix, the Engineer reserves the right to require adjustments to the job-mix formula.

December 18, 2012 Special Provision

# ALDOT Specifications 2007

| ESALs | Base and Lower Binder | Surface and Upper Binder |
| --- | --- | --- |
| < 1 million | 50 | 65 |
| 1 to 10 million | 65 | 80 |
| 10 to 30 million | 80 | 80 |

Use lesser of locking point (> 60) or specified

# Alabama

- Experimented with NCHRP 9-9(1) gyration levels and locking point.
- Currently specify $N_{design}$ = 60 gyrations for all traffic levels.
- Increased VMA
  - 0.5% for mixes with gradations below restricted zone
  - 1.5% for mixes with gradations above the restricted zone

# GA DOT

2005

- Special Provision for Locking Point
- Level I – two-way AADT < 10,000
  - Lesser of first locking point or 65 gyrations
- Level II - > 10,000 AADT
  - Lesser of second locking point or 80 gyrations

2014

- Mixes designed at 65 gyrations

# Conclusions

- Ultimate pavement density reached after 2 years
- $N_{design}$ appears to be slightly high, no need for AASHTO 125 gyrations or Illinois 105 gyrations
- Virginia has successfully used a single gyration level since 2001, other states have followed.

# Questions?

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