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Superpave5

How Increasing Air Voids Can Improve Asphalt Pavement Durability

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Superpave5

How Increasing Air Voids Can Improve Asphalt Pavement Durability

Synopsis of Workshop Session 1029
101st Annual Meeting of the Transportation Research Board

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Preface

This e-circular captures information exchanged during the 101st Annual Meeting of the Transportation Research Board in Workshop 1029, Superpave5: Can Increasing Air Voids Improve Asphalt Pavement Durability? Jim Scherocman presided over the session, which was held on Sunday, January 9th, 2022, and was sponsored by the Standing Committee on Production and Use of Asphalt (AKM10). The primary objective of Workshop 1029 was to present the Superpave5 concept and highlight its rationale, research and development efforts, and corresponding field data with contractor and agency perspectives. Thanks are due to all who presented in the workshop as well as those who worked to prepare the information contained in this publication.

Asphalt mix design has always been considered a balance of rutting resistance and durability. The conventional Superpave mix design system targets 4% air voids during design and is referred to in this circular as Superpave4. Despite designing to 4% air voids, Superpave4 generally targets 7 to 8% air voids during construction (i.e., 92 to 93% of theoretical maximum specific gravity, G_{mm}). This e-circular introduces the Superpave5 concept as a modification to the conventional Superpave4 approach. By targeting 5% air voids during design, Superpave5 yields a more compactible mixture, meaning higher in-place densities targeting 95% G_{mm} can be achieved without increasing compactive effort relative to that typically used for Superpave4. All other factors being equal, higher in-place densities correspond to less permeable, more durable pavements with data in Indiana showing that pavements constructed using Superpave5 mixtures maintained similar ride and rutting performance as Superpave4 mixtures but with reduced levels of aging and cracking. In addition to providing supporting information for the development of Superpave5, this e-circular provides practical guidance and items for consideration that would be of benefit to other agencies wishing to implement Superpave5 concepts.

Contents

PUBLISHER'S NOTE

The views expressed in this publication are those of the committee and do not necessarily reflect the views of the Transportation Research Board or the National Academies of Sciences, Engineering, and Medicine. This publication has not been subjected to the formal TRB review process.

Mix Design Background and Development of Superpave

GEOFF ROWE

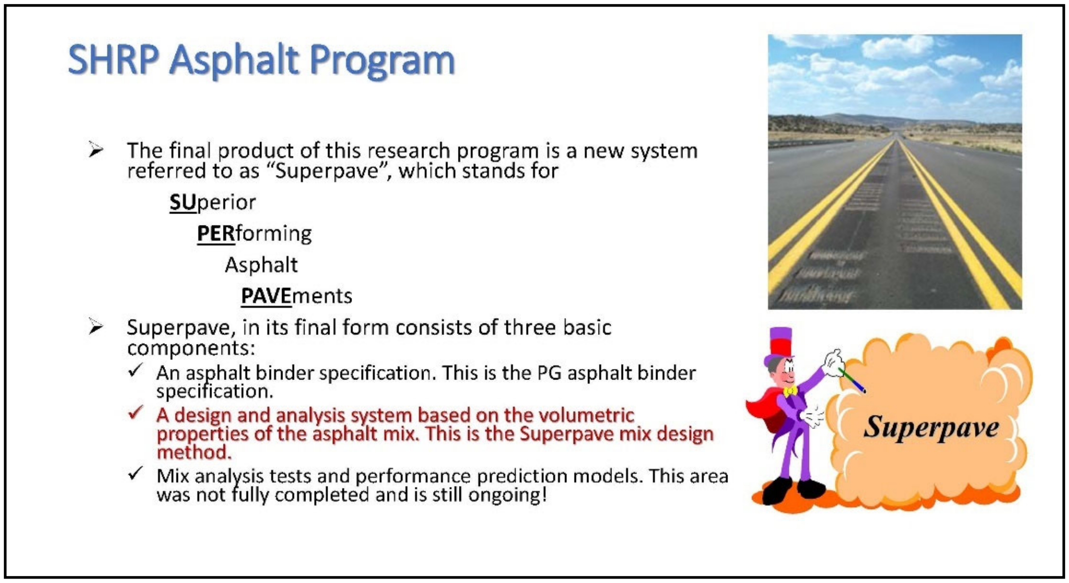
Abatech, Inc.

Superpave was developed in the early 1990s as a new mix design method that was developed as an output from the Strategic Highway Research Program (SHRP). This presentation provides some background information on that development program and also discusses the importance of several aspects of mix design.

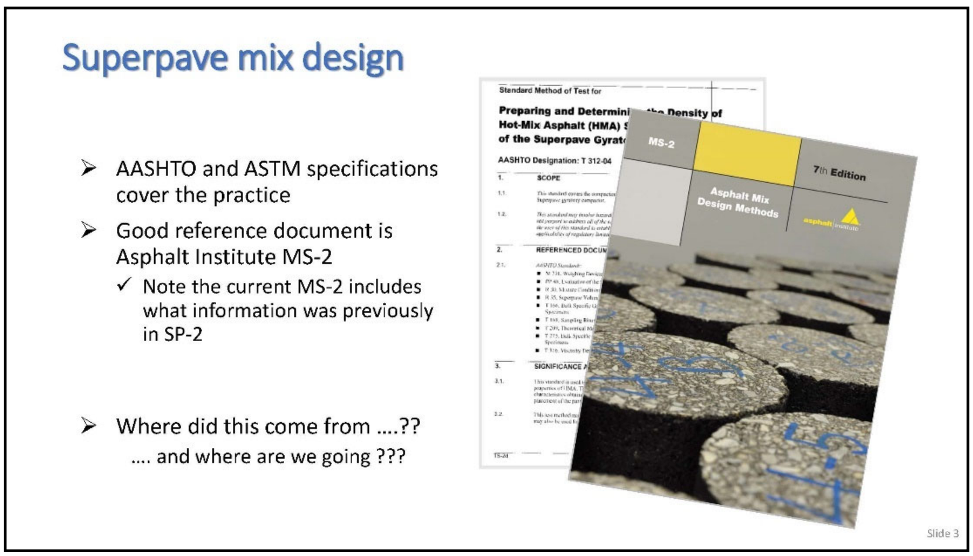
The acronym Superpave results from the concept of Superior Performing Asphalt Pavements which was one of the desired results of the SHRP contracts. In the implementation, three concepts were introduced: 1) a binder specification which is implemented in AASHTO (American Association of State Highway Transportation Officials) and ASTM (American Society for Testing and Materials) specifications, 2) a design and analysis system based on volumetric properties of the asphalt mix—termed the Superpave mix design method, and 3) mix analysis tests and performance prediction models. This last item was not successful in the initial implementation in the early to mid-1990s and additional work is ongoing to explore different performance test methods that can be implemented in the United States. This presentation focuses on item 2 from those concepts introduced.

With high performance materials, the risk for pavement design is considered lower—for example the roadway shown in this slide (Slide 1, top right) is Highway 550 approximately 30 miles north of Albuquerque, New Mexico, (approximately 35°23'47.02"N, 106°38'21.86"W) which was built as a design build contract around 20 years ago.

The Asphalt Institute has supported the implementation effort with the publication of various training documentation since the mid-1990s (Slide 2). The most current MS-2 combines the earlier information published in the SP-2 manuals with that from the older MS-2 documents into a single document that details the various mix design methods, including Superpave. Other reference documents include various ASTM and AASHTO documents.



SLIDE 1

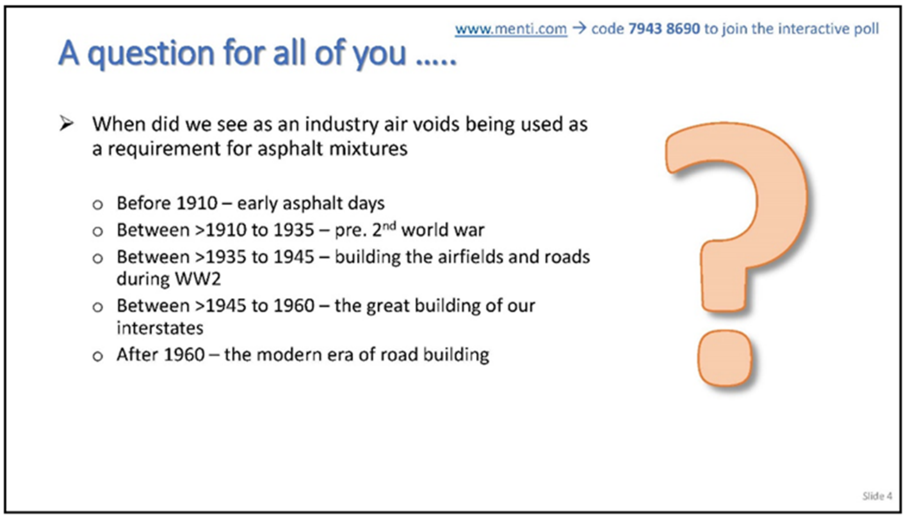


SLIDE 2

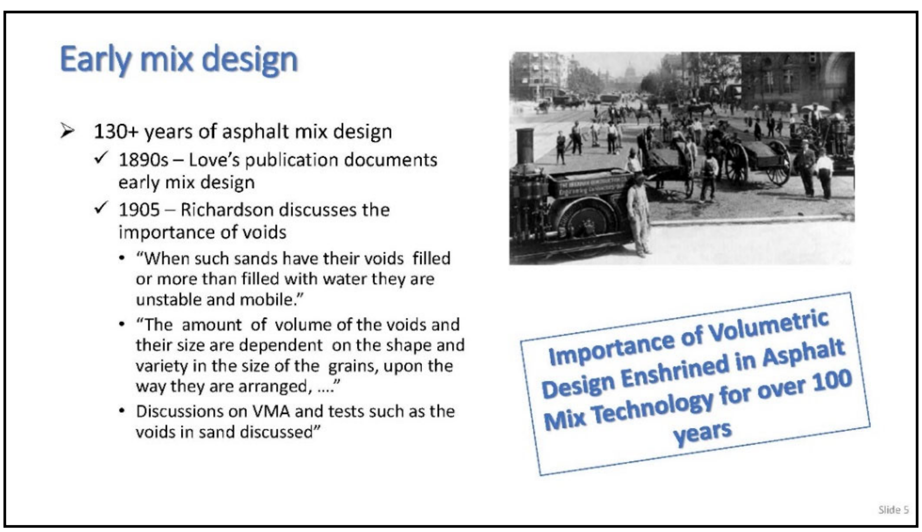
These documents will be updated by the various organizations as these methods further develop. Additional background documents describing the foundation of the Superpave mix design method can be found in various SHRP documents published in the early 1990s along with technical papers such as the journals from the Association of Asphalt Paving Technologists (AAPT) and the *Transportation Research Record* from the Transportation Research Board.

In the workshop, we posed the question in Slide 3 regarding the foundations of mix design. The authors' earliest books on this subject area date from the late 1800s and early 1900s (Love, 1890; Richardson, 1905). As shown in Slide 4, both these books talk about the need for careful selection of materials with information that can be effectively considered as mix design methods that pay attention to the level of voids in the asphalt materials. These methods evolved over time, with more precise and better measurement methods, to those we are using today.

Copies of these early books can be downloaded from the following links: Love (1890) and Richardson (1905). From this information we conclude that the importance of volumetric design has been enshrined in asphalt mix technology for well over 100 years.



SLIDE 3



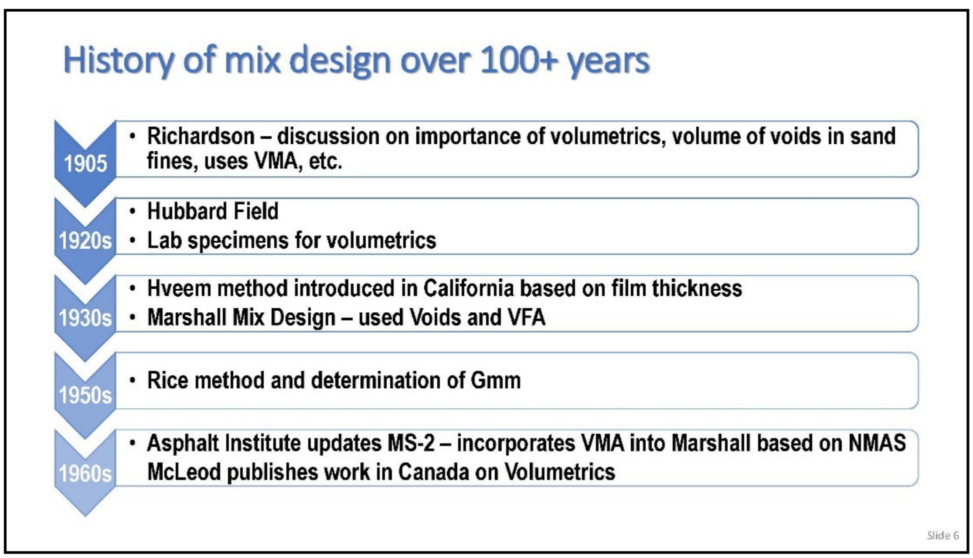
SLIDE 4

Slide 5 gives the historical sequence of the implementation of formal use of volumetrics in the United States. From the implementation of MS-2 in the 1960s to the development of the Superpave system of mixture design, little change was made regarding the concepts adopted, with the two major methods being Hveem and Marshall. The development of the test for the maximum specific gravity of a paving mixture (Rice, 1953) has been key to the understanding of mixture volumetrics and the effect of absorbed asphalt.

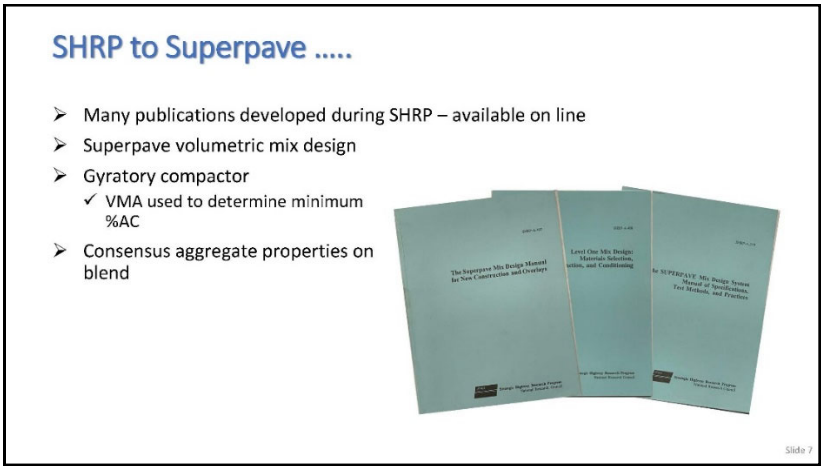
During the period from 1989 to 1994, the Superpave mix design method (Slide 6) was developed as part of SHRP. The critical difference between this method and previous ones is the use of the gyratory compactor developed during the SHRP program and additional consensus aggregate properties and volumetric controls.

While earlier gyratory compactors existed in the industry, the SHRP researchers considered that it was important to have a machine that would produce a larger specimen size of 150 mm diameter and to have a device that gyrated with an angle close to 1 degree with a defined pressure and recordation of the height of the specimen during the compaction process (Slide 7). The larger specimen size helps when compacting large nominal size aggregates in the production of a specimen that is closer in volumetrics to that obtained by rolling compaction in the field.

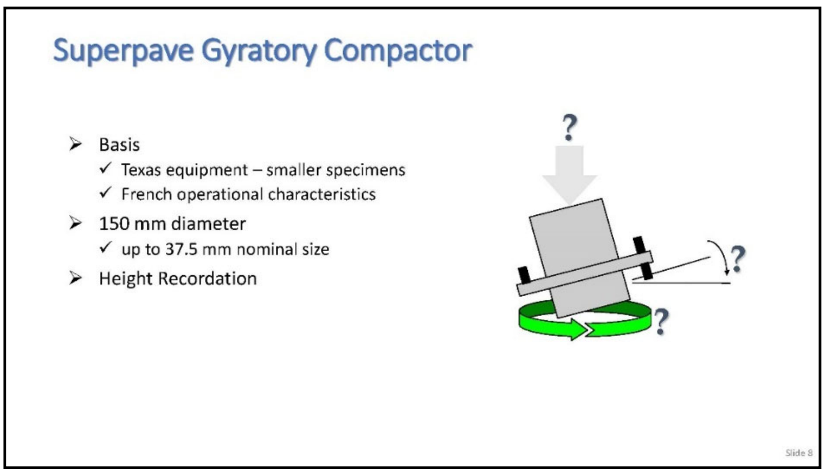
The Superpave mix design "Level One" method is based upon volumetrics with specimens manufactured in the gyratory compactor.



SLIDE 5

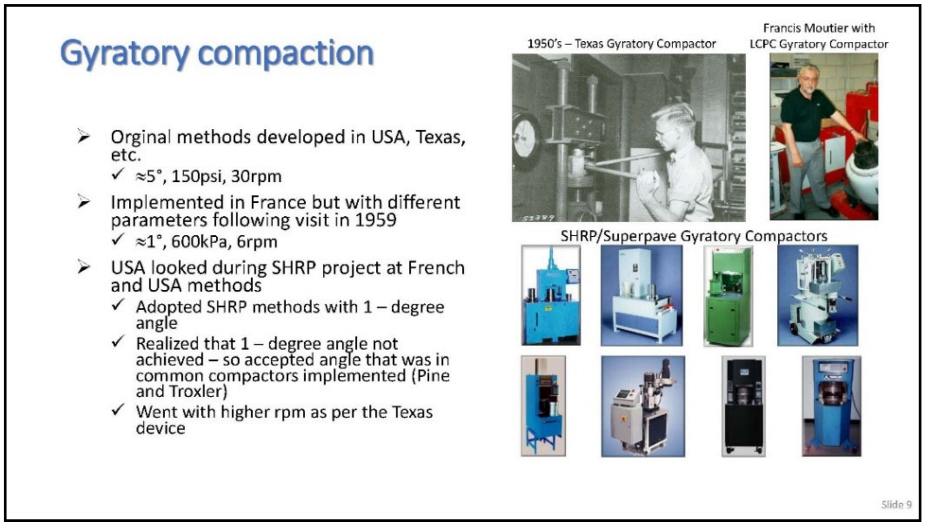


SLIDE 6



SLIDE 7

Slide 8 contrasts the original method developed in Texas to that developed and implemented in in France. The method developed in Texas had a larger gyration angle (5 degrees), lower pressure and faster rotation speed. The French further developed the method into mix designs in France. SHRP researchers visited France many times during the program and determined that this system was better than the Marshall and achieved specimens that could be assessed for volumetrics. Of note, the speed of the gyration as used in Texas was adopted. More details of this back-and-forth across the Atlantic with exchange of ideas can be found in *NCHRP Web-Only Document 186: The Superpave Mix Design System: Anatomy of a Research Program* (McDaniel et al., 2012) (https://www.nap.edu/catalog/22812/the-superpave-mix-design-system-anatomy-of-a-research-program). SHRP researchers considered the 1-degree angle adopted by the French to be better, but the SHRP compactor made use of the higher rotations per minute as per the Texas device.



SLIDE 8

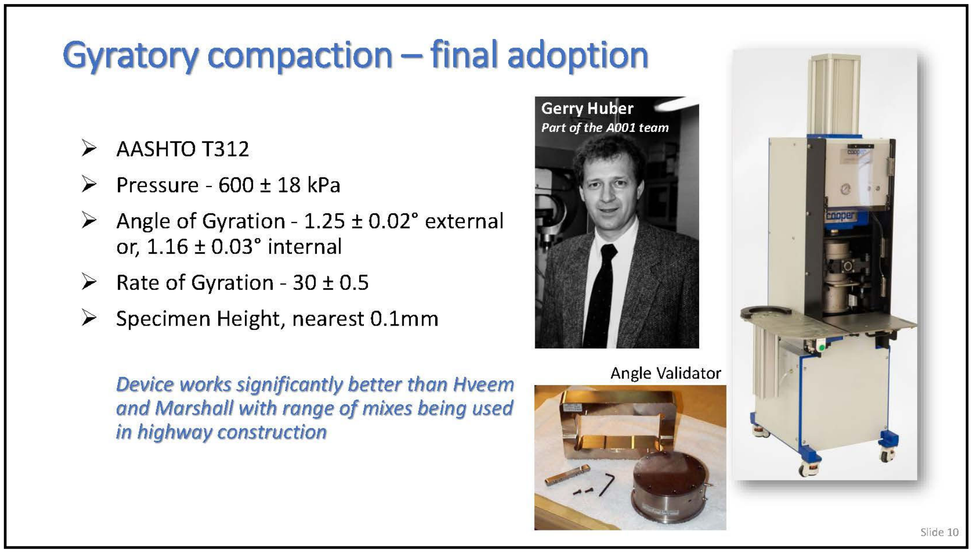
However, during the implementation, researchers realized that the angle in the commercial devices varied. Depending on whether the angle was measured as either external or external, different results were obtained. Slide 9, shows the final conditions adopted—a 1.25 external angle and 1.16 internal angle (tolerances +/- 0.02 and +/- 0.03 respectively). Also, shown in the figure along with some of the equipment is the developer of the methods associated with the Superpave Gyratory Compactor, Gerry Huber.

As noted earlier, the development of materials for paving have traditionally relied upon a careful consideration of asphalt volumetrics. The current designs are typically based on 4% air voids, although historically the void content used has typically ranged between 3 and 5%. The critical component of mix design in addition to air voids is the voids in the mineral aggregate (VMA) since this effectively controls the volume of binder. Volume of effective binder is equal to the VMA minus the amount of air voids.

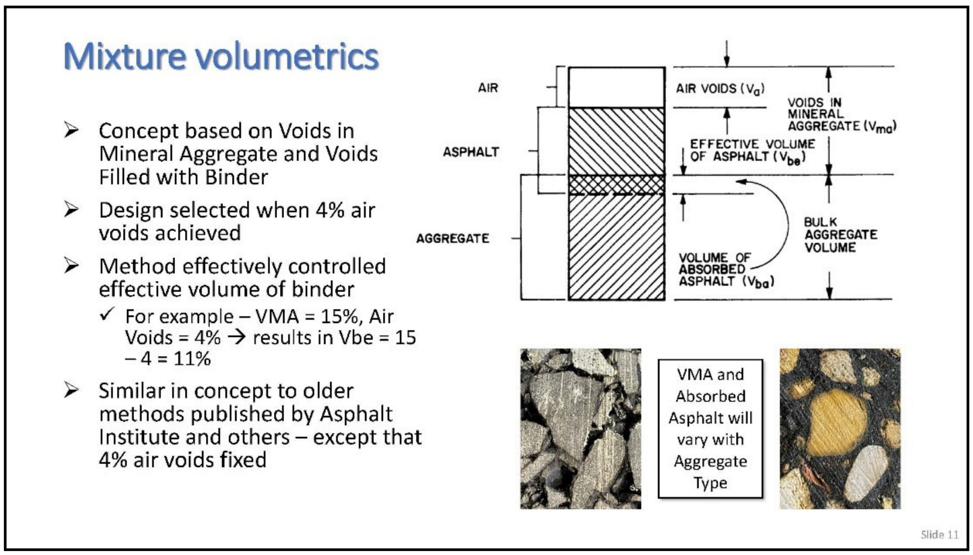
The critical aspect introduced here is the need to consider the "effective" volume of binder (V_{be}) which is dependent upon the binder absorption into the aggregate being used in the mix. Two mixes are shown in Slide 10 which shows that the binder has absorbed into the aggregate particles in a very different manner. The left-hand side shows considerably less absorption than the sample to the right.

For years, the Asphalt Institute has published in its MS-2 document (and SP-2 for the Superpave implementation period) a scientifically robust method for assessing the binder absorption and the calculation of asphalt mixture volumetrics that correctly accounts for the binder absorption.

The volumetric diagram in Slide 10 identifies the volumetric components of an asphalt mixture and identifies the amount of absorbed asphalt.



SLIDE 9



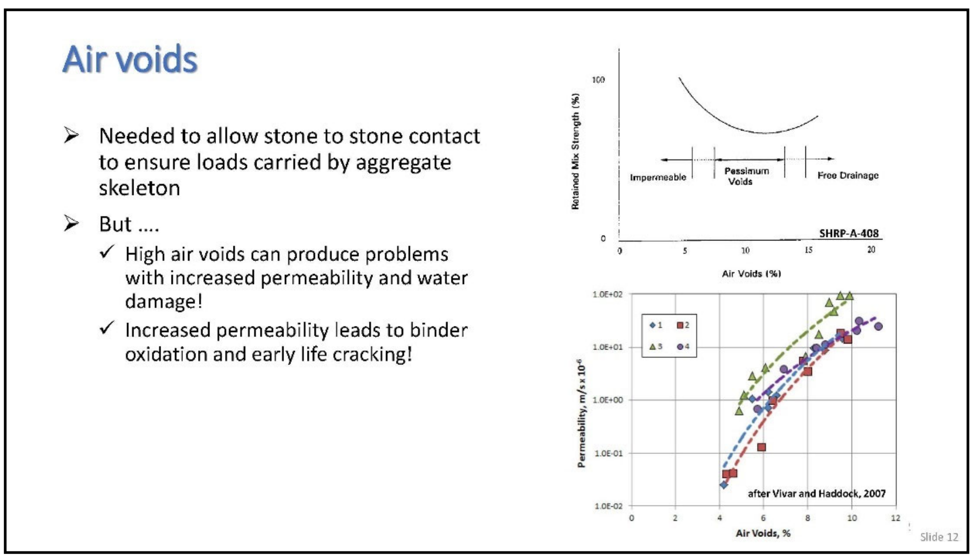
SLIDE 10

In an asphalt mixture it is preferable to have loads carried by a good aggregate stone-to-stone contact skeleton. A structure of this kind is less dependent on the binder to carry load at high temperature when the binder is less stiff. Voids approaching zero (say less than 2%) present a risk that a continuous binder phase will be responsible for some of the load carrying, and with conventional asphalt binders, this can lead to a rut susceptible mixture.

Mixtures with a void content below 4 to 5% will be impermeable, whereas mixtures with voids greater than approximately 15% will generally have free draining characteristics. Terrel and Al-Swailmi (1994) developed the concept of a “Pessimum Voids” content (Slide 11, top right), which describes a region in void contents where an asphalt mixture is most sensitive to damage due to water entrapment, suggesting a critical range from about 7 to 13%. For optimal performance, Terrel and Al-Swailmi (1994) considered it necessary to compact mixtures to an extent that they are not in this range. Porous mix designs should have a void content greater than 15%, whereas dense mixes should be compacted to a void content less than 7%.

In mixes produced and compacted (Haddock and Vivar, 2007), the permeability of a mixture varies depending on the size of the aggregate and the gradation (Slide 11, bottom right). The mixes represented in Slide 11 are described in Table 1.

Goode and Lufsey (1965) reported similar data in the 1960s but with air permeability, so the linkage of permeability with voids and different aggregate gradations has been well known for a considerable time. Thus, as air voids increase with our dense asphalt mixes, two problems exist: 1) we have mixes that can have problems in relation to water damage, and 2) the increased permeability allows more rapid oxidation to occur which can lead to early-life cracking. Consequently, we need to strive for careful control of mixture volumetrics to ensure optimal performance of mixtures in our pavement projects.



SLIDE 11

TABLE 1 Descriptions from Haddock and Vivar (2007) Table 3 of Reference

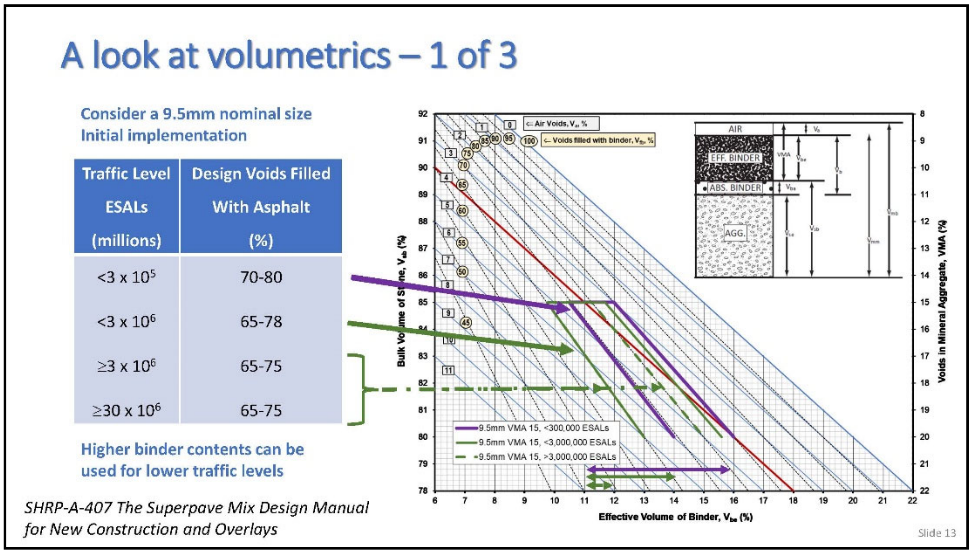
Mix Reference	Nominal Maximum Size of Aggregate	Gradation
1	9.5	Coarse
2		Fine
3	19.0	Course
4		Fine

A chart (Slide 12) developed by John Edwards in the 1980s (Edwards, 1989) shows all volumetric parameters and provides information similar to that originally suggested by McLeod (1959). When a mix design is plotted on a chart of this type, the representation is similar to a Proctor curve which is used extensively in soil mechanics. This chart shows volume of binder on the horizontal axis and VMA (or volume of stone, 100-VMA) on the vertical axis. Two sets of sloping lines represent air voids and voids filled with binder.

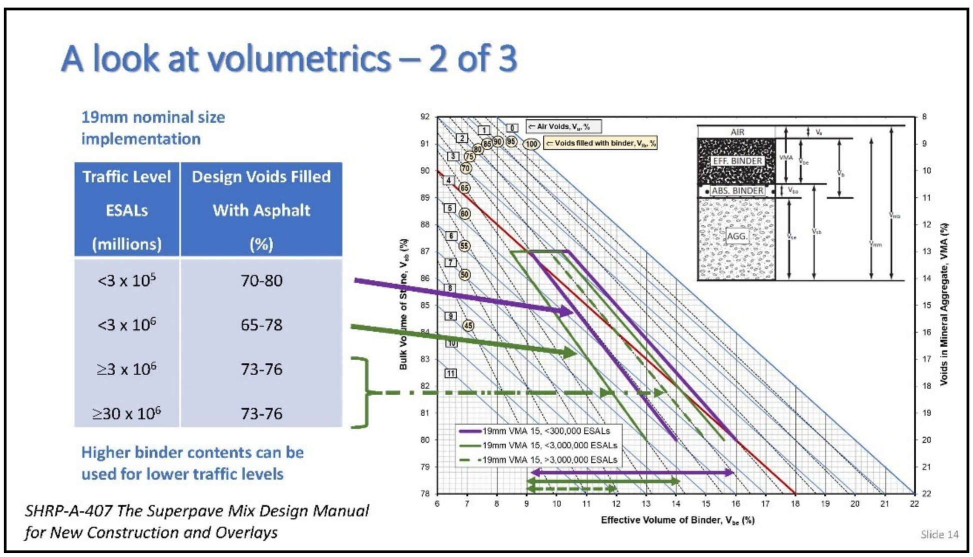
Plotting the specification limits on this chart shows how a design must be developed and the associated effective volume of binder specified by the VMA and VFA (voids filled with asphalt) limits applied in the Superpave specifications.

In Slide 12, we added the limits introduced in 1994 for a 9.5 mm Superpave mix with a 15% VMA specified (Cominsky et al., 1994). The horizontal axis is effective binder content by volume. If an absorptive aggregate is used, more binder will be used by percent weight than compared to a non-absorptive aggregate since the bulk gravity of stone used in this calculation considers the binder absorbed. For the higher traffic levels, a designer may choose to add more asphalt binder. However, economics will often dictate that the minimum binder volume of around 11% will be used. Thus, the same mix design can be used for all traffic levels since this will be the most economical solution that can be developed by a contractor.

A similar plot for the 19-mm mix (Slide 13) shows that for the lower traffic level a marginally higher minimum binder must be used for the lowest traffic level. However, a designer can make use of higher binder contents, although contract economics will generally result in effective binder volume just above 9% for a 19-mm mix design compared to just above 11% for a 9.5-mm mix design.



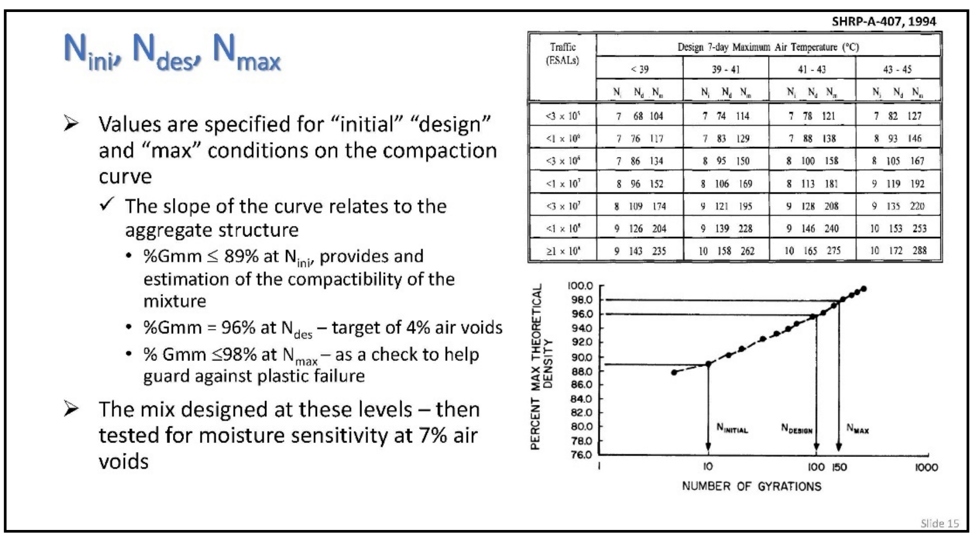
SLIDE 12



SLIDE 13

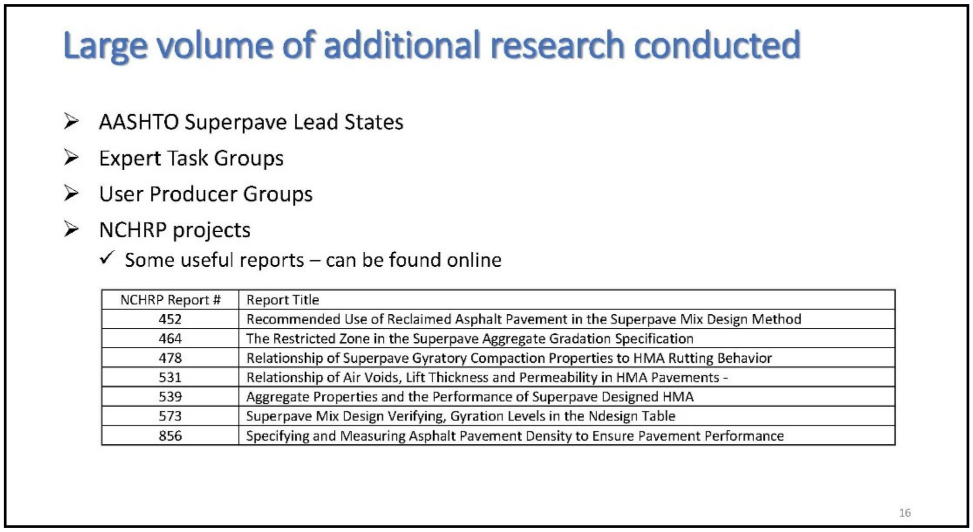
With the Superpave method, we see compaction measured at three points (Slide 14): number of gyrations to initial, design, and maximum (N_{ini}, N_{des} and N_{max}) conditions. The N_{des} is associated with the 4% air voids value, N_{max} ensures that we do not go to effectively zero air voids and end up with a mix that will flow in a plastic manner. The Nini provides some guidance on the compactibility of the mix. Effectively, we are controlling the slope of the curve (log-linear) since this informs us of information relating to the aggregate structure. The table shown in Slide 14 is from the 1994 SHRP report (Cominsky et al., 1994) and was implemented in the first Superpave specifications. The need for assessment of the mix at 7% air voids for water damage exists, which is essentially the lower limit of the range suggested for the Pessimum air voids.

Various groups over the last nearly 30 years have contributed to and further developed the ideas in the initial implementation. A list of National Cooperative Highway Research Program (NCHRP) reports is presented in Slide 15 which provide support for some of the changes that have been implemented in the Superpave specifications over the recent years. The N_{des} table shown in Slide 14 is discussed in detail in *NCHRP Web-Only Document 96*: *Appendixes to NCHRP Report 573: Superpave Mix Design: Verifying Gyration Levels in the N_{design} Table*, (Prowell and Brown, 2006). The appendices contain interesting backup information but need to be downloaded from the NCHRP website as a separate document.



Traffic (ESALs)	Design 7-day Maximum Air Temperature (°C)											
	< 39			39 - 41			41 - 43			43 - 45		
	N_i	N_d	N_m	N_i	N_d	N_m	N_i	N_d	N_m	N_i	N_d	N_m
$<3 \times 10^5$	7	68	104	7	74	114	7	78	121	7	82	127
$<1 \times 10^6$	7	76	117	7	83	129	7	88	138	8	93	146
$<3 \times 10^6$	7	86	134	8	95	150	8	100	158	8	105	167
$<1 \times 10^7$	8	96	152	8	106	169	8	113	181	9	119	192
$<3 \times 10^7$	8	109	174	9	121	195	9	128	208	9	135	220
$<1 \times 10^8$	9	126	204	9	139	228	9	146	240	10	153	253
$\geq 1 \times 10^8$	9	143	235	10	158	262	10	165	275	10	172	288

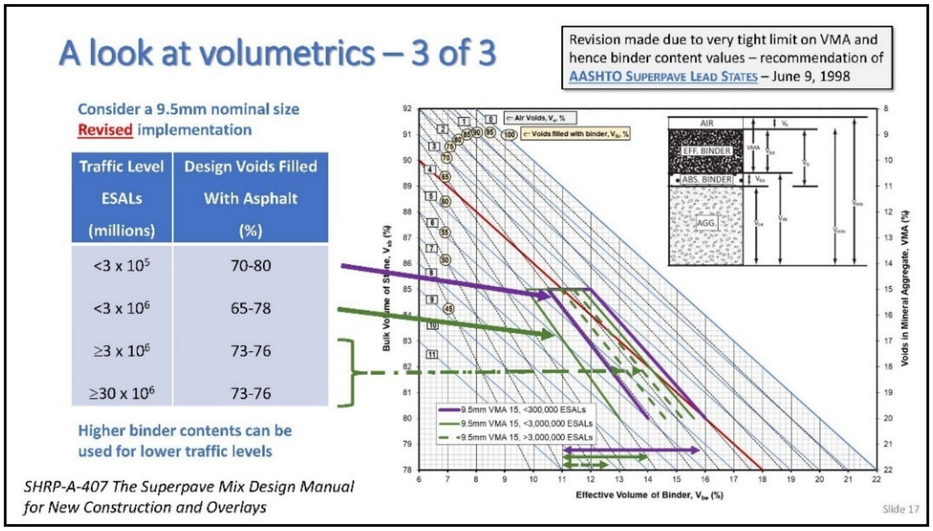
SLIDE 14



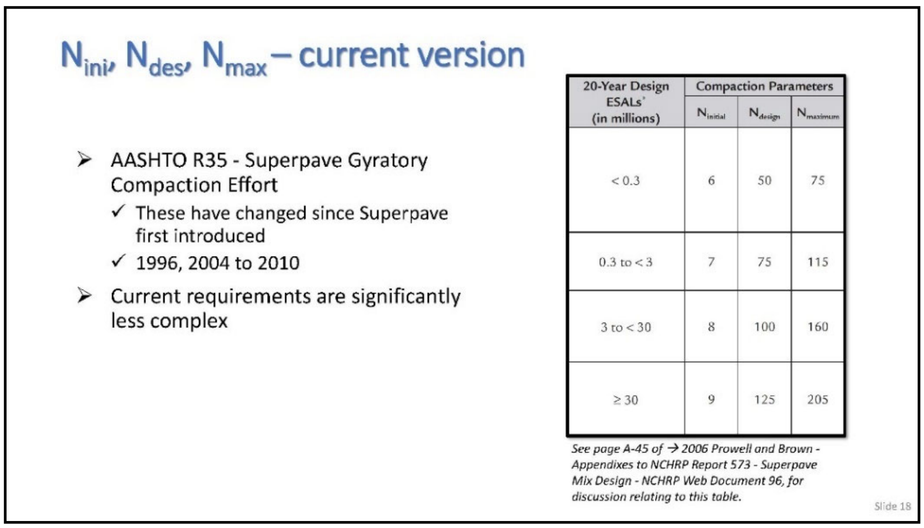
SLIDE 15

The revisions published in the early 2000s also allow additional binder to be used for the higher traffic levels. This revision was made to give designs more flexibility with the design of 9.5-mm mixes for higher traffic levels, with more VMA range and effectively more V_{be} range (Slide 16). However, since the target VMA and V_a effectively control the volume of binder, this change does not result in any significant changes. The result is that a contractor designing a mixture for the most economical design will effectively be designing for a binder volume of 11.0% for all traffic levels. Similar notes can be found for some other nominal aggregate sizes (4.75 and 37.5 mm) to adjust the VMA and V_{be} allowed range.

Over time we have seen significant simplifications to the gyration table; the 28 initial options in Slide 15 have now been reduced to four with the climate requirement removed and traffic levels simplified as shown in Slide 17. The discussion supporting this is given on page A-45 of the *NCHRP Web-Only Document 186: Appendixes to NCHRP Report 573: Superpave Mix Design: Verifying Gyration Levels in the N_{design} Table* (Prowell and Brown, 2006).

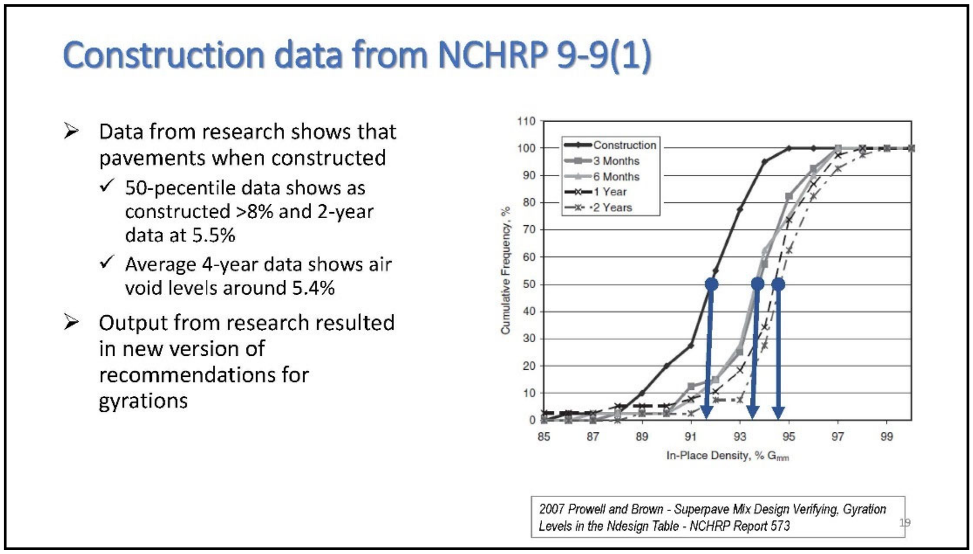


SLIDE 16

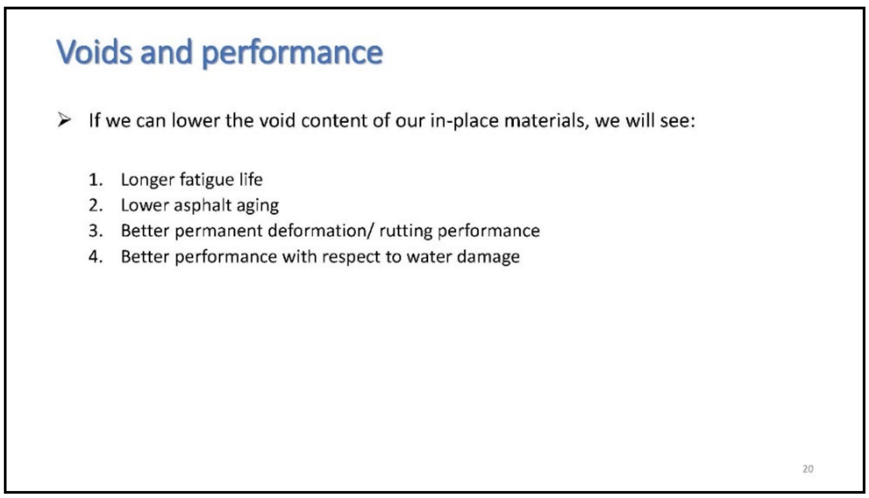


SLIDE 17

To achieve a 90% PWL (percent within limits) with normal variability and a lower specification limit of 91.5%, the mean value required is about 93%. The data shown in Prowell and Brown's *NCHRP Web-Only Document 186: Appendixes to NCHRP Report 573* (page 25) appears to be consistent with this with 50-percentile density being at or even a bit better than this at the time of construction (Slide 18). Over time the mix densifies and approaches a 50-percentile value that represents 5% air voids. The effect of an initial higher air void content is poorly understood, but it could be reasonably assessed that this will result in increased aging and other factors that will lead to reduced life. Many aspects of performance are affected by air voids (Slide 19), including fatigue life, binder aging, water damage, rutting, etc., and extensive information exists in asphalt technology literature that has been published over the years.



SLIDE 18

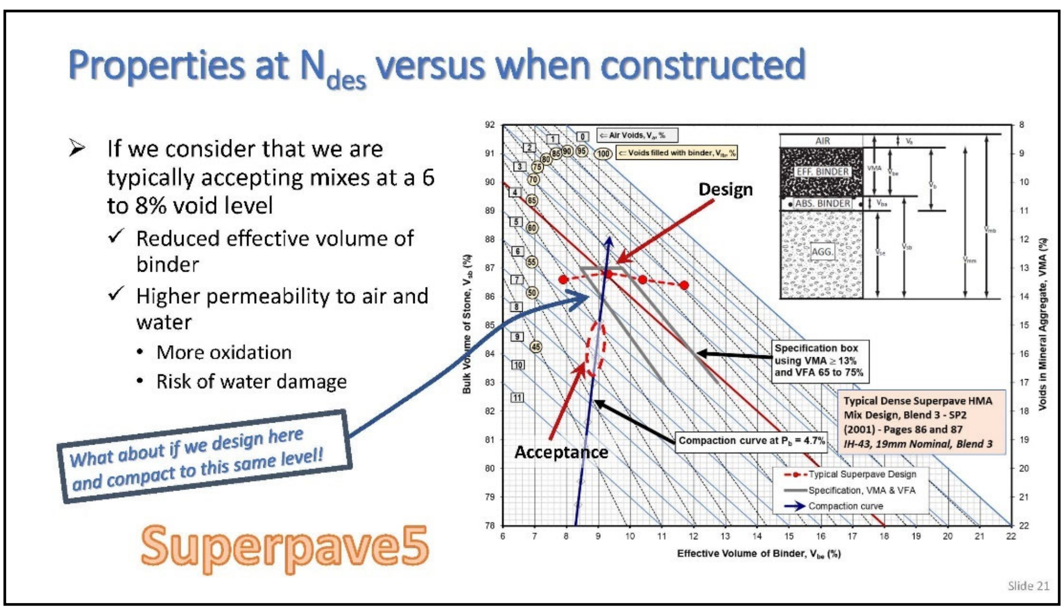


SLIDE 19

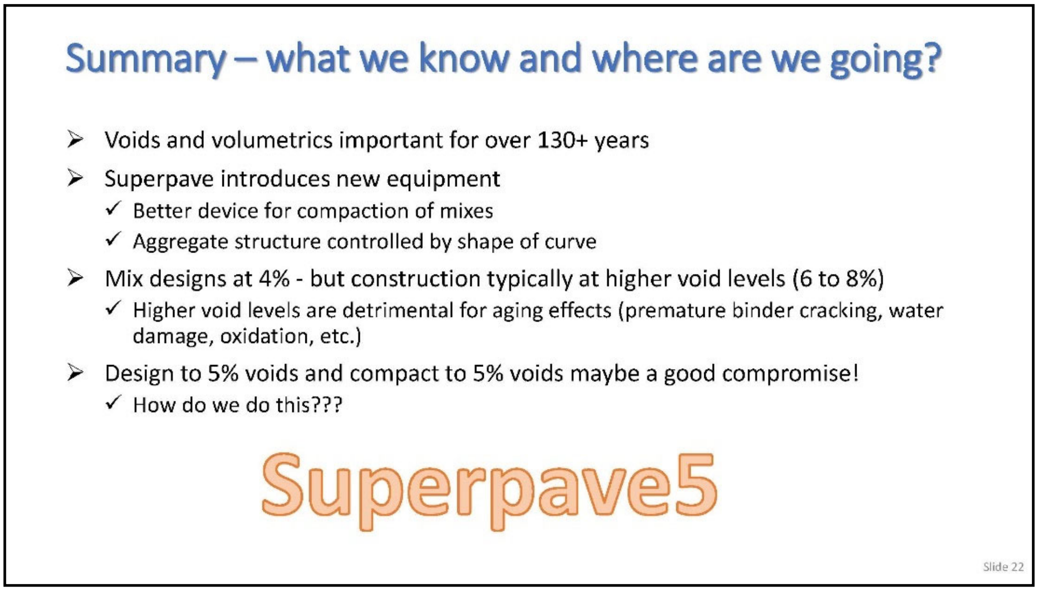
If we consider the properties of the design versus the field (Slide 20), we are typically accepting mixes at a 6 to 8% void level, whereas the design was at a 4% void content. This in effect reduces the effective binder volume, increases the permeability, allows more oxidation, and increases the risk of water damage. For performance, lower void levels will result in longer life and thus we must endeavor to achieve this to increase performance. An incremental improvement is to routinely aim for 5% compacted air voids on site. By adjusting the mix design marginally and designing at 5% air voids, this has been recognized as being achievable. This has led to the concept of Superpave5. If we consider the design shown in Slide 21, 5% is just about consistent with that upper volume of asphalt filled limit and about halfway between the typical acceptance levels and the design at 4% air voids. Building our pavements with an initial density for acceptance at this level of compaction will result in a more durable pavement, and this is effectively what the Superpave5 concept is archiving.

SUMMARY

In summary (Slide 21), we need to understand the past on mix design ideas and then apply the knowledge learned to develop the path for where we are going. For many years we have known that volumetrics is of key importance. Superpave introduction with gyratory compaction gave us a better tool for design of mixes, and it can compact those used in construction in a consistent and acceptable manner. The slope and shape of the compaction curve informs us about the aggregate structure. However, while we design our mixes at 4% air voids, we typically accept compaction at higher void levels (6 to 8%), which will have a detrimental effect on durability. As shown a 5% design level, if we compact to a 5% void level, results in design and field properties that will give volumetrics that lie between the existing criteria (4% design and traditional acceptance range). The question is: How do we achieve this and what changes are made?



SLIDE 20



SLIDE 21

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Setting Design Conditions for Superpave5

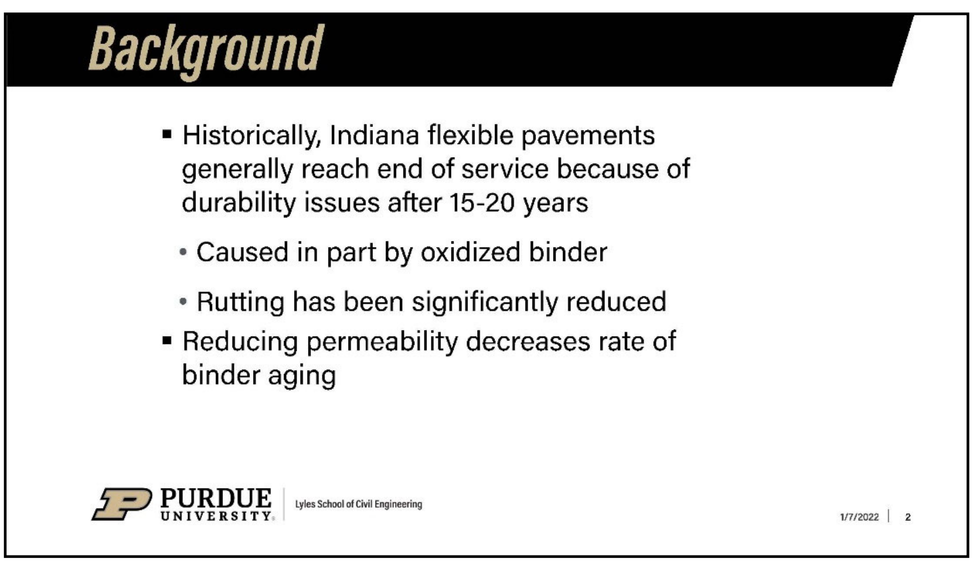
John E. Haddock

Purdue University

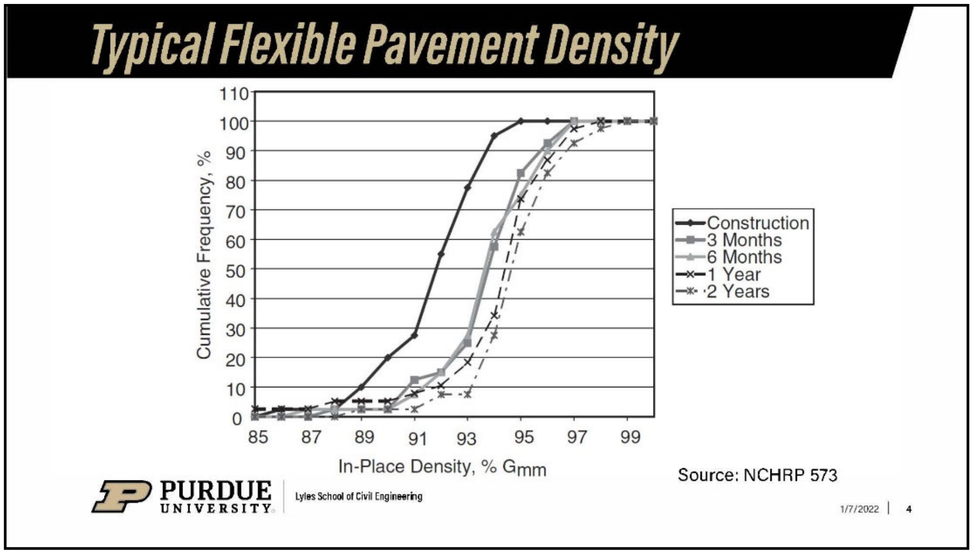
This presentation discusses a laboratory study undertaken to guide the Indiana Department of Transportation (INDOT) effort to implement an improved mixture design method that allows for increased asphalt pavement mat densities during construction (Slide 1).

INDOT has seen adequate performance from asphalt pavements designed using the standard Superpave mixture design method, often referred to as Superpave4. Given the INDOT Superpave4 mat density specifications, most pavements were constructed with initial densities in the 92–93% G_{mm} range (Slide 2). Since increasing mat density can decrease mat permeability and thereby reduce asphalt binder oxidation, INDOT sought mixture design changes that could increase initial mat densities.

The data in Slide 2 come from *NCHRP Web-Only Document 96: Appendices to NCHRP Report 573: Superpave Mix Design: Verifying Gyration Levels in the N_{design} Table* (Prowell and Brown, 2006) and show how mat density can change over time. The thinking at INDOT was to ask the question: “Can we increase initial mat density so that construction densities are in the 95% of G_{mm} realm, thus lowering initial pavement permeability and decreasing the density change over time?”



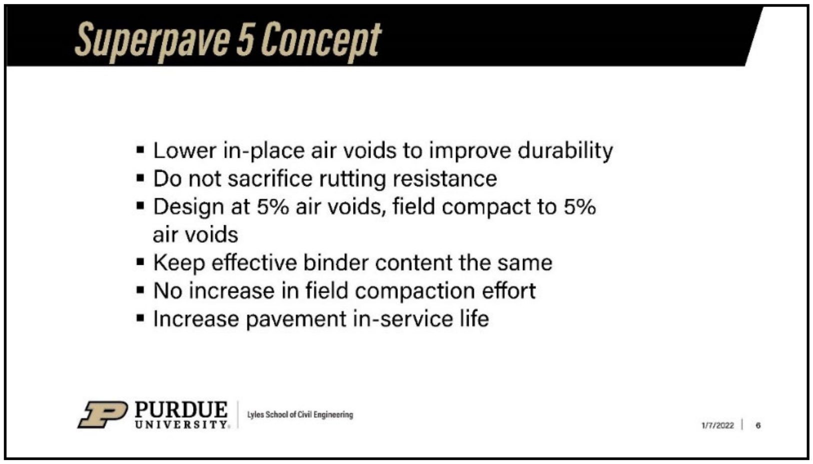
SLIDE 1



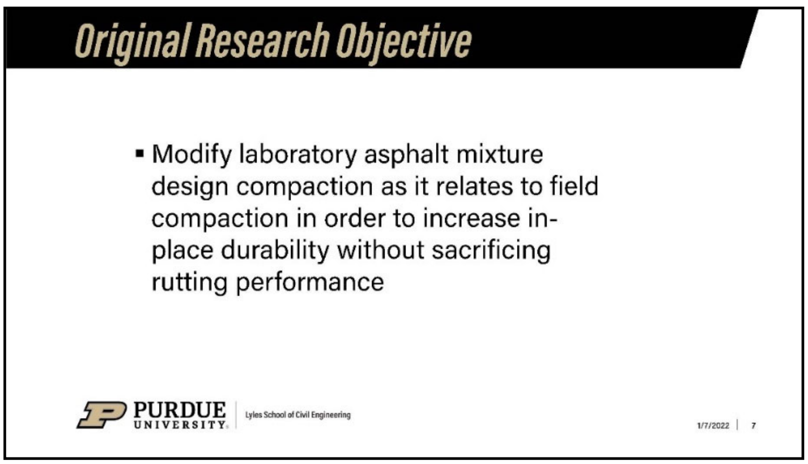
SLIDE 2

As shown in Slide 3, Superpave5, the concept of designing asphalt mixtures at 5% air voids, rather than 4% air voids, was conceived to increase initial asphalt mat densities. The belief was that mixtures designed at 5% air voids should then be compacted to 5% air voids (95% G_{mm}) during construction. Three criteria were included in development of the Superpave5 method: 1) effective binder content was not allowed to be lower than in comparable Superpave4 mixtures, and 2) no increase in field compaction effort would be needed to compact the Superpave5 mixtures to mat densities of 95% of G_{mm} (5% air voids), and mixture rutting resistance had to be at least as good as the standard Superpave 4 mixtures.

The objective of the laboratory research project (Slide 4) was to determine what changes could be made to laboratory compaction during the mixture design phase, to both reflect field compaction and allow for a higher compaction level during construction.

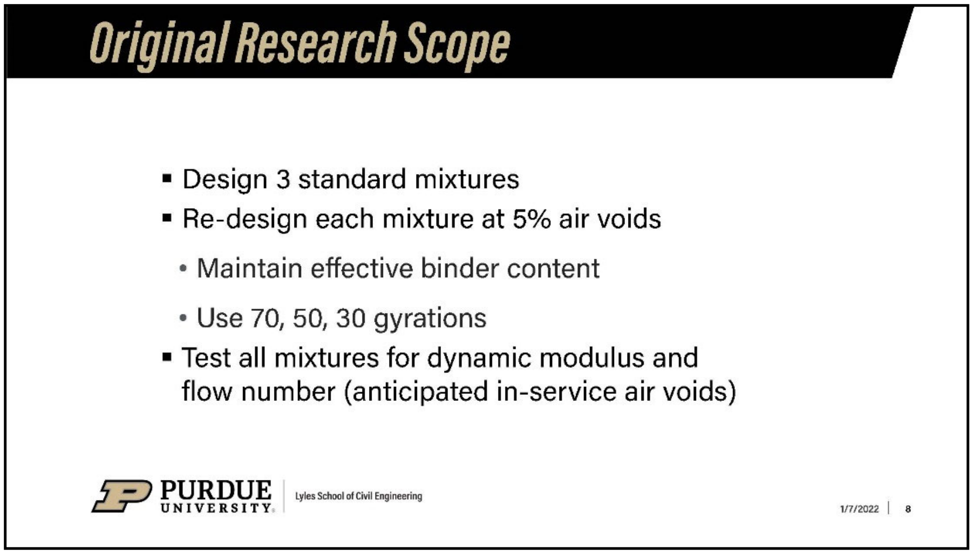


SLIDE 3



SLIDE 4

To accomplish the project objective, a research scope was developed (Slide 5) to use three Superpave4 mixtures that had been designed and placed in the field. Each mixture would be redesigned, choosing optimum binder content at 5% air voids, rather than 4%. Each Superpave mixture had the same effective binder content as its comparable Superpave4 mixture, and Superpave5 designs were completed using 30, 50, and 70 design gyrations. All 12 mixtures, three original Superpave4 mixtures (N_{des} of 100) and nine Superpave mixtures, were tested to determine mixture dynamic modulus and flow number. It is important to understand that each mixture was tested at its anticipated as-constructed density. Thus, the Superpave 4 mixtures were tested at 7% air voids (93% of G_{mm}), and the Superpave5 mixtures at 5% air voids (95% of G_{mm}).

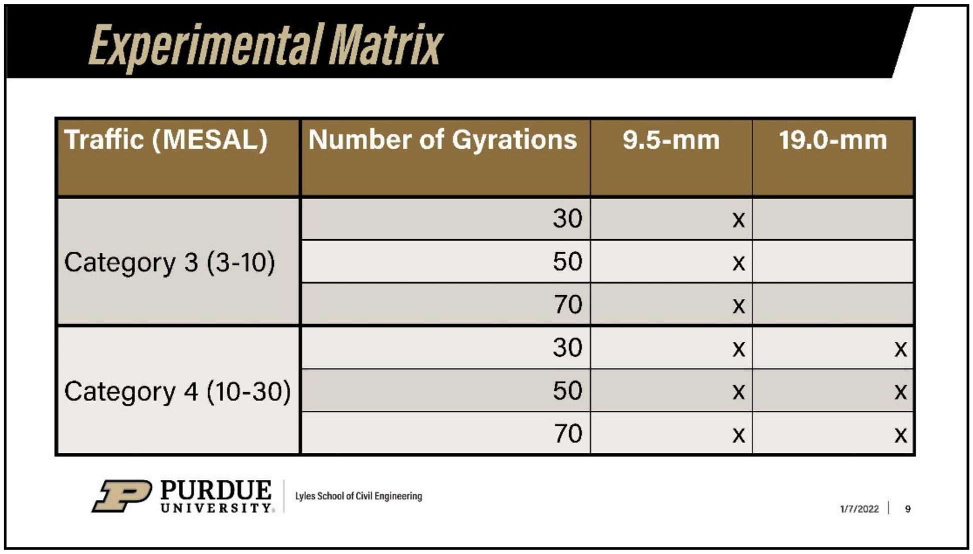


SLIDE 5

The experimental matrix (Slide 6) for the project shows the nine Superpave5 mixtures used. These mixtures covered two traffic categories, based on anticipated 20-year equivalent single axle load (ESAL) counts, two mixture sizes, and three laboratory compaction levels.

Materials used in the mixtures (Slide 7) included limestone, dolomite, blast furnace slag, and natural sand with a performance grade (PG) 64-22 binder. These are typical aggregates and binder grades used in Indiana. No recycled materials were used to avoid complicating the experiment.

The volumetric information from the four Category 4, 19.0-mm mixtures (Slide 8) shows the effective binder content of the four mixtures staying relatively constant, while the air voids, binder content, and VMA increase for the Superpave5 mixtures. This was accomplished by varying the mixture gradations as the compaction effort was changed.



Experimental Matrix

Traffic (MESAL)	Number of Gyrations	9.5-mm	19.0-mm
Category 3 (3-10)	30	x	
	50	x	
	70	x	
Category 4 (10-30)	30	x	x
	50	x	x
	70	x	x

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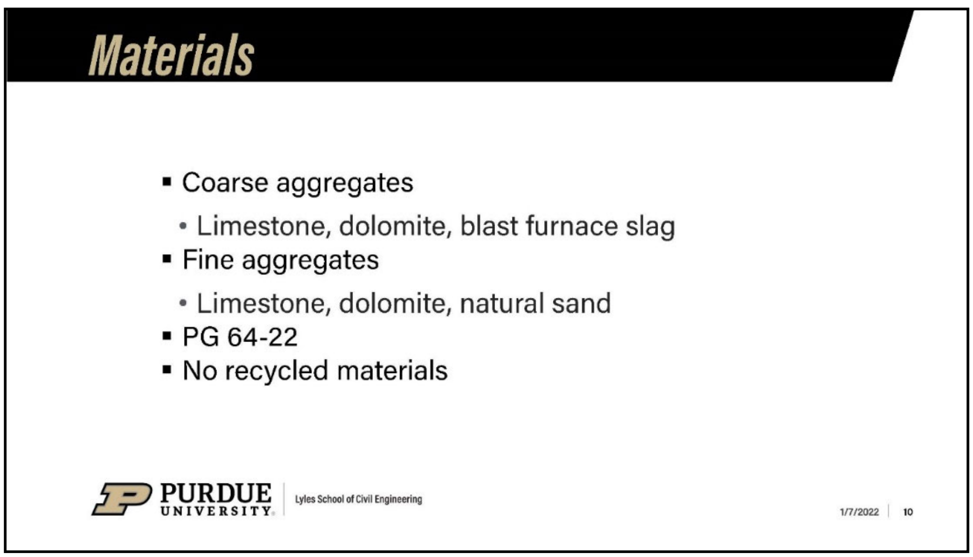
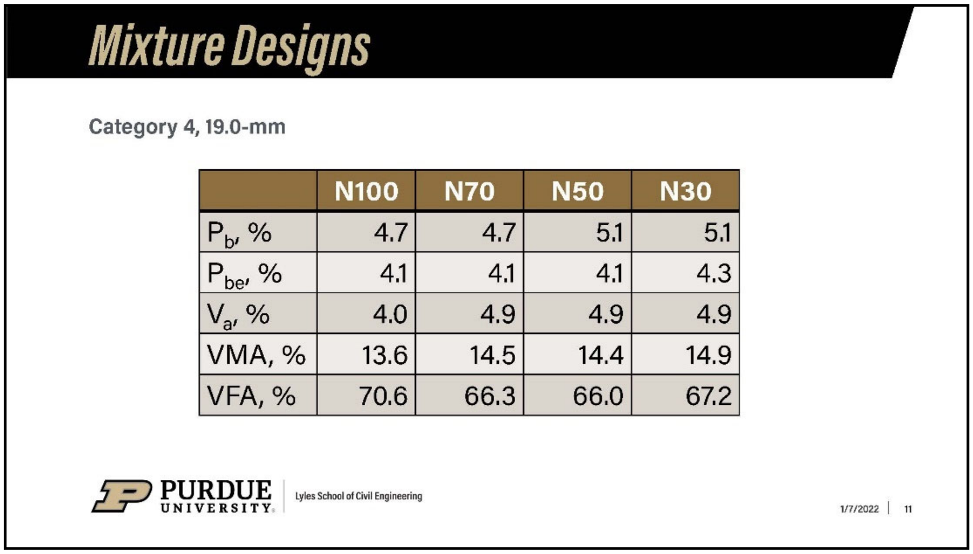
SLIDE 6



SLIDE 7



	N100	N70	N50	N30
P_b, %	4.7	4.7	5.1	5.1
P_{be}, %	4.1	4.1	4.1	4.3
V_a, %	4.0	4.9	4.9	4.9
VMA, %	13.6	14.5	14.4	14.9
VFA, %	70.6	66.3	66.0	67.2

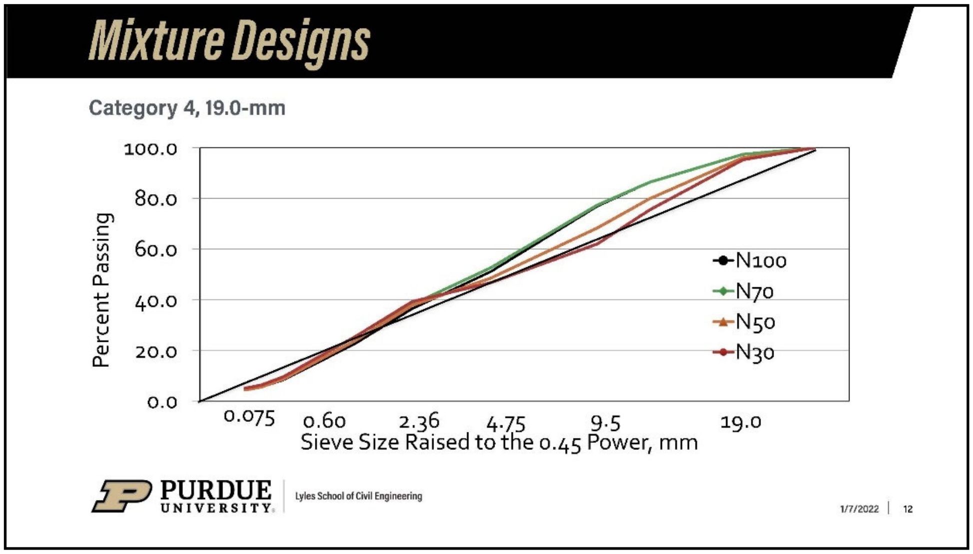
SLIDE 8

The changes in mixture gradation were slight, with the N100 (Superpave4) and N70 (Superpave5) mixture gradations being indistinguishable as shown in Slide 9.

The volumetric information from the four Category 3, 9.5-mm mixtures (Slide 10) shows the effective binder content of the four mixtures staying relatively constant, while the air voids and VMA of the Superpave5 mixtures increase. However, unlike the 19.0-mm mixture, the binder content of the four mixtures was relatively stable. Again, the changes were accomplished by varying the mixture gradations as the compaction effort changed.

The changes in mixture gradation were again slight, with the N100 (Superpave4) and N70 (Superpave5) mixture gradations being nearly indistinguishable as shown in Slide 11.

The data from the first two mixtures clearly indicated the N70 Superpave5 mixture was virtually identical to the N100 Superpave4 mixture, except for higher air voids and VMA. In effect, decreasing the N_{des} by 30 gyrations raised the air voids content by 1%. Thus, the research team decided there was no need to further consider N70 in the experiment.



SLIDE 9

Mixture Designs

Category 3, 9.5-mm

	N100	N70	N50	N30
P_b, %	5.9	5.9	6.0	6.0
P_{be}, %	4.6	4.6	4.6	4.7
V_a, %	4.1	5.1	4.9	5.3
VMA, %	15.0	16.0	15.8	16.3
VFA, %	72.9	67.9	68.9	67.6

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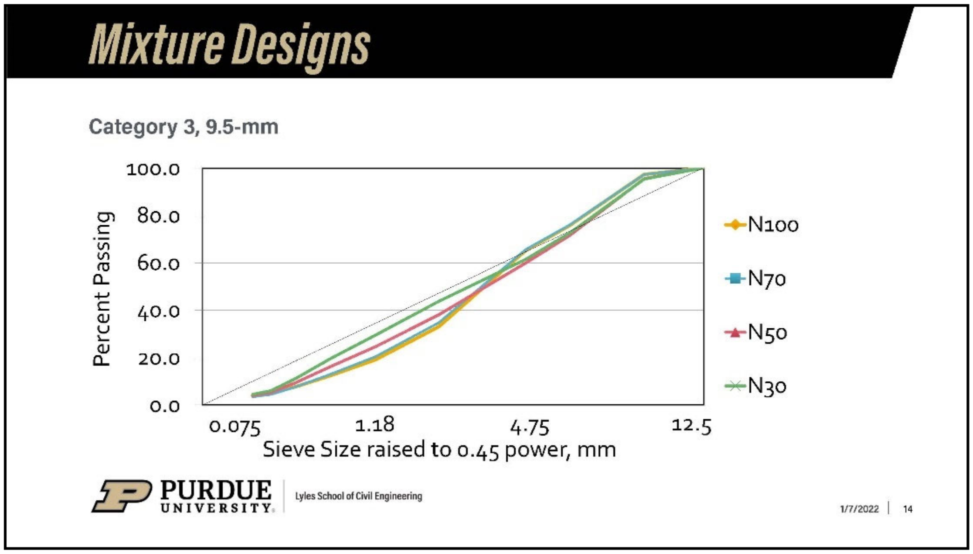
SLIDE 10



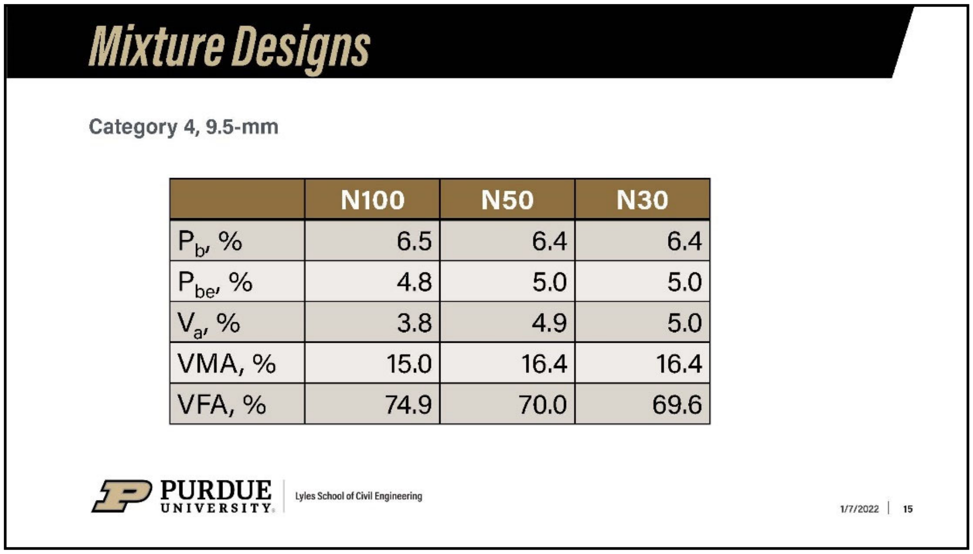
SLIDE 11

The volumetric information from the three Category 4, 9.5-mm mixtures (Slide 12) shows the effective binder content of the three mixtures staying relatively constant, while the air voids and VMA of the Superpave5 mixtures increase. In this case, the binder content of the two Superpave5 mixtures slightly decreased. Again, the changes were accomplished by varying the mixture gradations as the compaction effort changed.

The changes in mixture gradation were again slight as shown in Slide 13.

Dynamic modulus and flow number testing were completed according to standard AASHTO test methods using the asphalt mixture performance tester (AMPT) (Slide 14).

In Slide 15, the dynamic modulus results for the Category 4, 19.0-mm mixtures show the Superpave5 mixtures have higher modulus values through all frequencies than does the Superpave4 N100 mixture. This indicates the Superpave5 mixtures should have as good, or better rutting performance as the Superpave4 mixture.



Mixture Designs

Category 4, 9.5-mm

	N100	N50	N30
P_b, %	6.5	6.4	6.4
P_{be}, %	4.8	5.0	5.0
V_a, %	3.8	4.9	5.0
VMA, %	15.0	16.4	16.4
VFA, %	74.9	70.0	69.6

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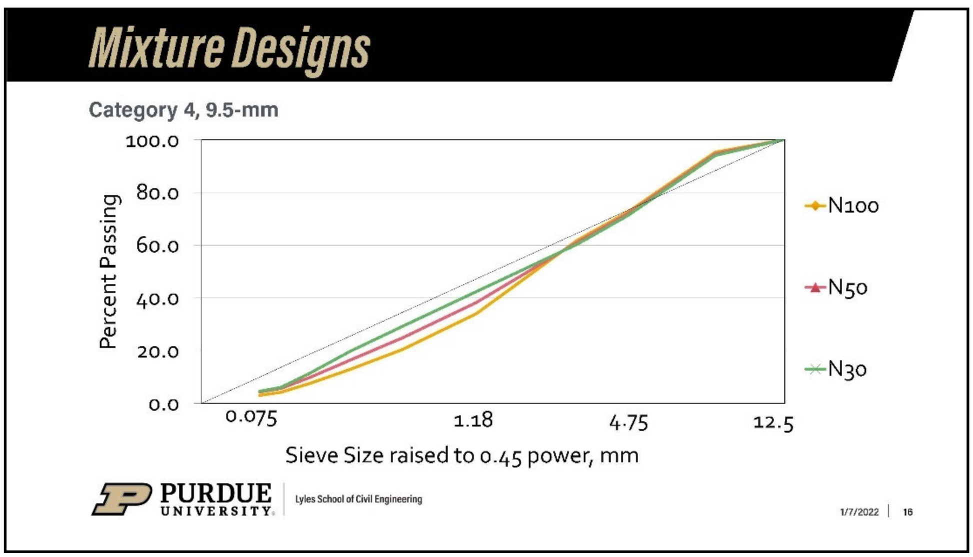
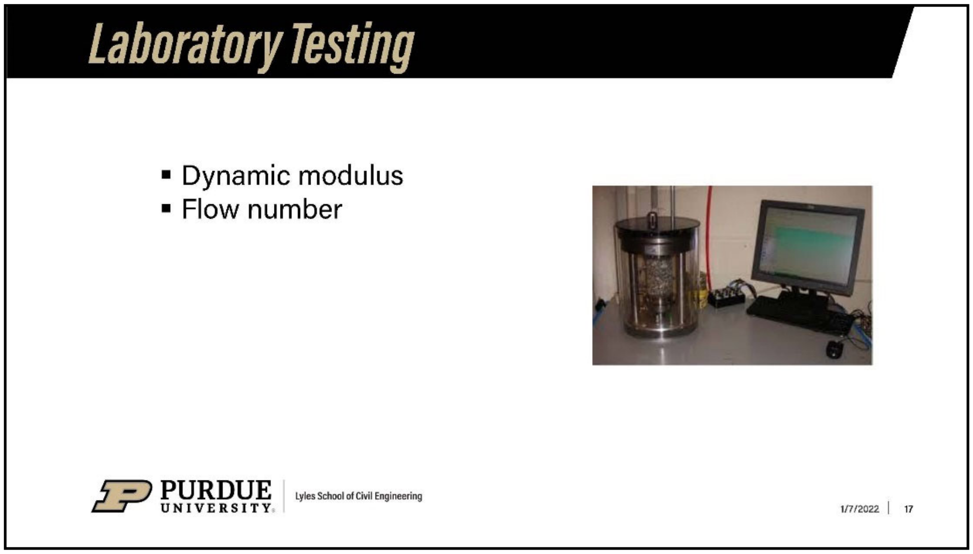
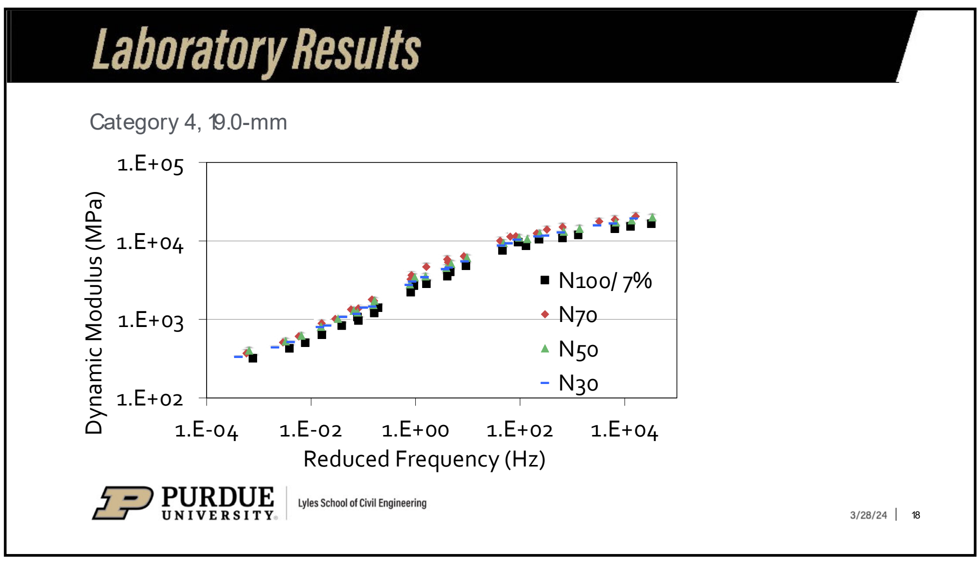
SLIDE 12



SLIDE 13



SLIDE 14



SLIDE 15

In agreement with the dynamic modulus results for the Category 4, 19.0-mm mixtures the Superpave5 mixtures have higher average flow values and lower average strains at flow number than does the N100 mixture (Slide 16). Again, this indicates the Superpave5 mixtures should have as good, or better rutting performance as the N100 Superpave4 mixture.

Laboratory Results

Category 4, 19.0-mm

Gyrations	Average Flow Number	Average Strain at FN (µm)
100	162	23,983
70	386	18,269
50	348	19,882
30	185	22,090

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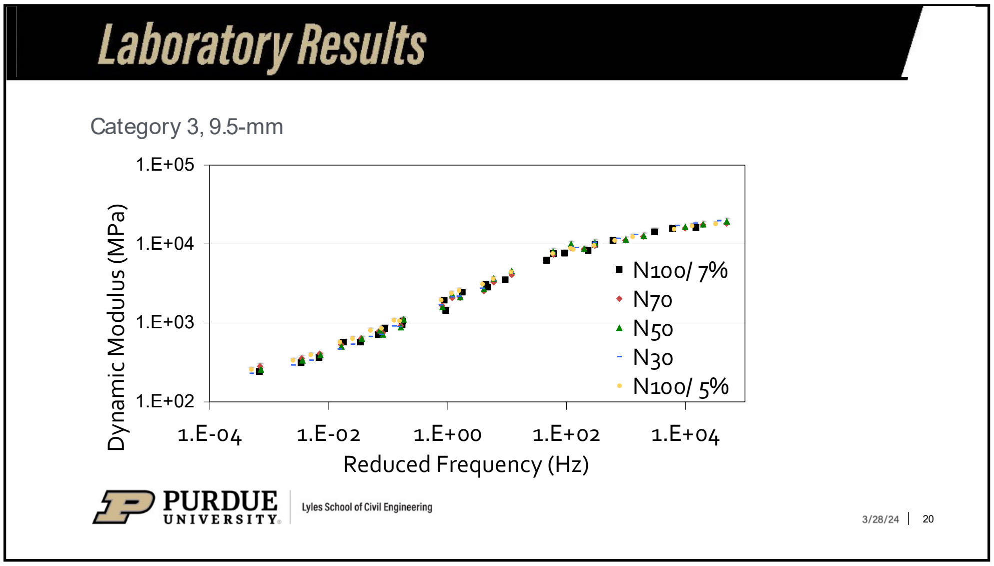
SLIDE 16

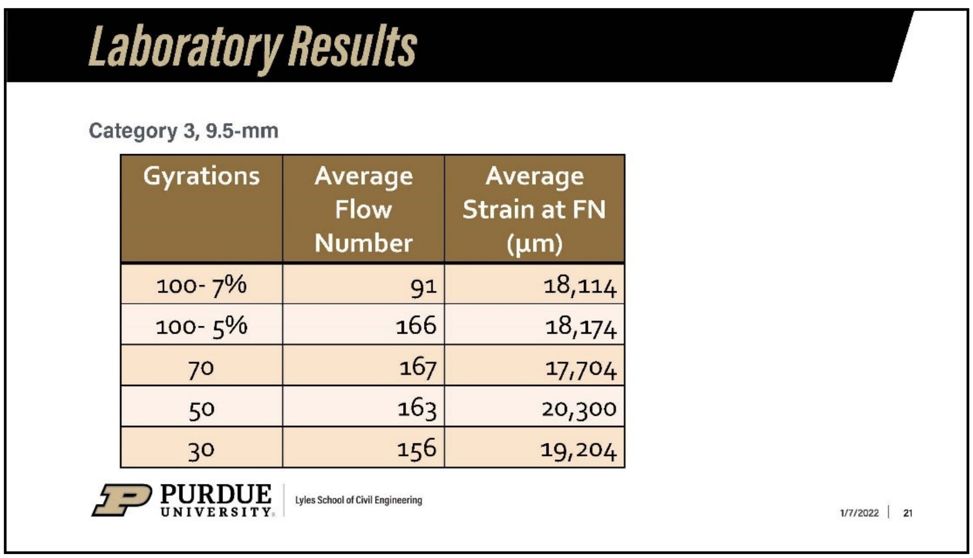
In Slide 17, the dynamic modulus results for the Category 3, 9.5-mm mixtures show the Superpave5 mixtures have modulus values through all frequencies comparable to the Superpave4 N100 mixture. This indicates the Superpave5 mixtures should have as good, or better rutting performance as the Superpave4 mixture.

In this instance, N100 design specimens were also produced at 5% air voids, and tested, to see how the results would compare. In general, the results were about the same as the other four mixtures, with the N100 at 5% specimens having a little higher modulus at the lower frequencies.

In agreement with the dynamic modulus results for the Category 3, 9.5-mm mixtures, the Superpave5 mixtures have higher average flow values and lower average strains at flow number than does the N100 mixture (Slide 18). Again, this indicates the Superpave5 mixtures should have as good, or better rutting performance as the N100 Superpave4 mixture. Also, the N100 at 5% data suggest it should have as good or better rutting performance as the Superpave5 mixtures.



SLIDE 17



Laboratory Results

Category 3, 9.5-mm

Gyrations	Average Flow Number	Average Strain at FN (µm)
100- 7%	91	18,114
100- 5%	166	18,174
70	167	17,704
50	163	20,300
30	156	19,204

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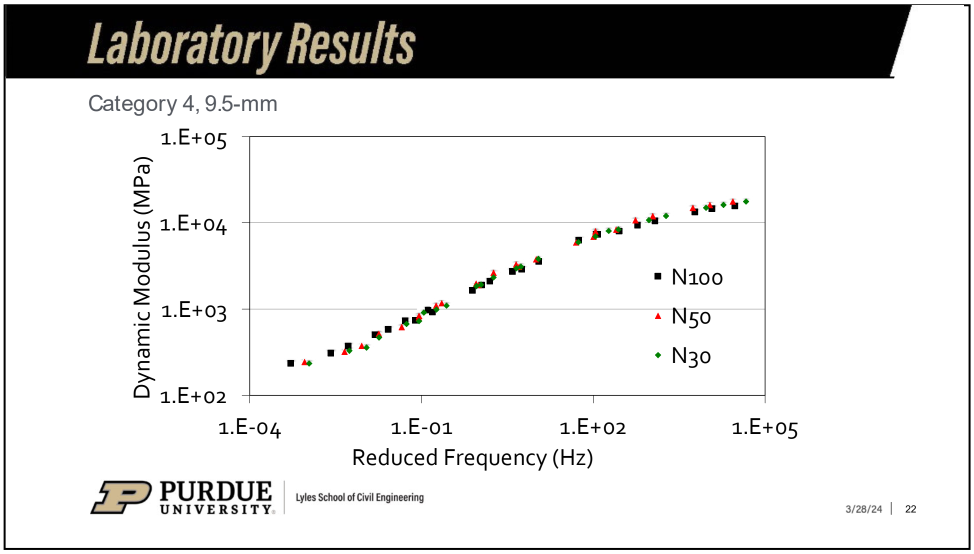
SLIDE 18

In Slide 19, the dynamic modulus results for the Category 4, 9.5-mm mixtures show the Superpave5 mixtures again have modulus values through all frequencies that are equal or higher to the Superpave4 N100 mixture. This indicates the Superpave5 mixtures should have as good, or better rutting performance as the Superpave4 mixture.

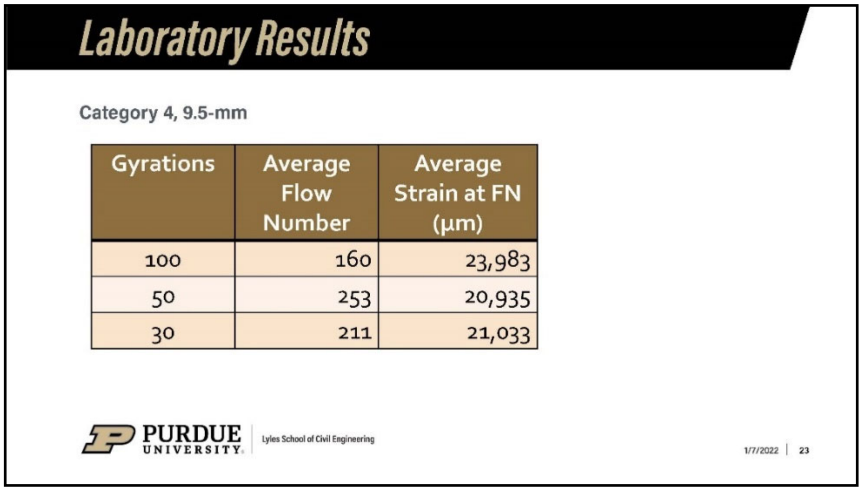


SLIDE 19

In agreement with the dynamic modulus results for the Category 4, 9.5-mm mixtures, the Superpave5 mixtures have higher average flow values and lower average strains at flow number than does the N100 mixture (Slide 20). Again, this indicates the Superpave5 mixtures should have as good, or better rutting performance as the N100 Superpave4 mixture.

In Slide 21, the modulus values at two frequencies and 50°C of the Category 4, 19.0-mm mixture were plotted as a function of the compaction effort. The data again show all three Superpave5 mixtures (N30, N50, N70) have as high or higher modulus values than does the Superpave4 (N100) mixture, again indicating that at this high temperature, the Superpave5 mixtures should have as good or better rutting performance than the Superpave4 mixture.

The modulus values at two frequencies and 6°C of the Category 4, 19.0-mm mixture were also plotted as a function of the compaction effort (Slide 22). The data again show all three Superpave5 mixtures (N30, N50, N70) have as high or higher modulus values than does the Superpave4 mixture.

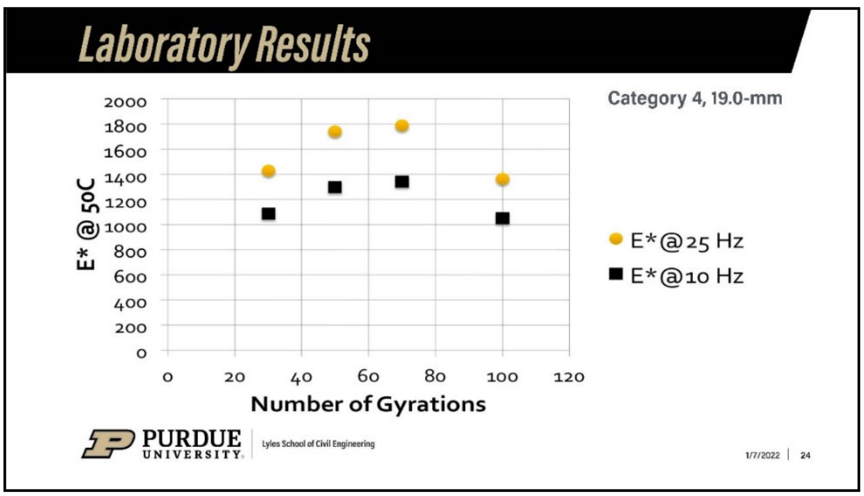


Laboratory Results

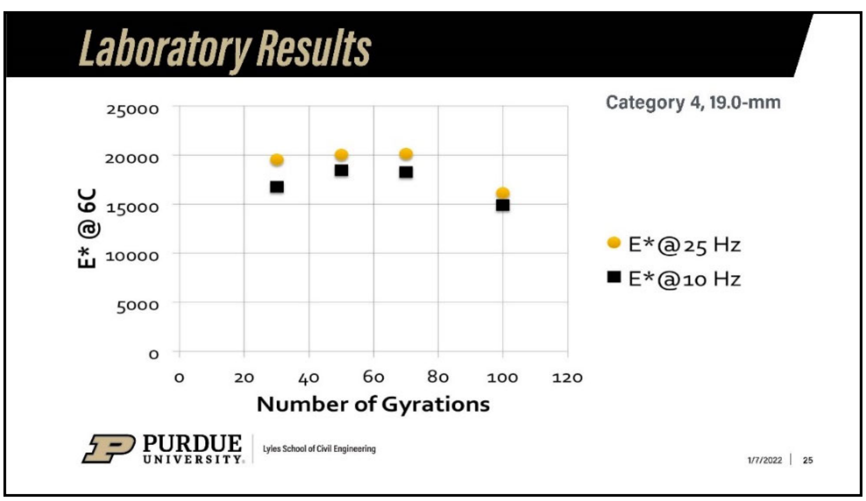
Category 4, 9.5-mm

Gyrations	Average Flow Number	Average Strain at FN (µm)
100	160	23,983
50	253	20,935
30	211	21,033

SLIDE 20



SLIDE 21



SLIDE 22

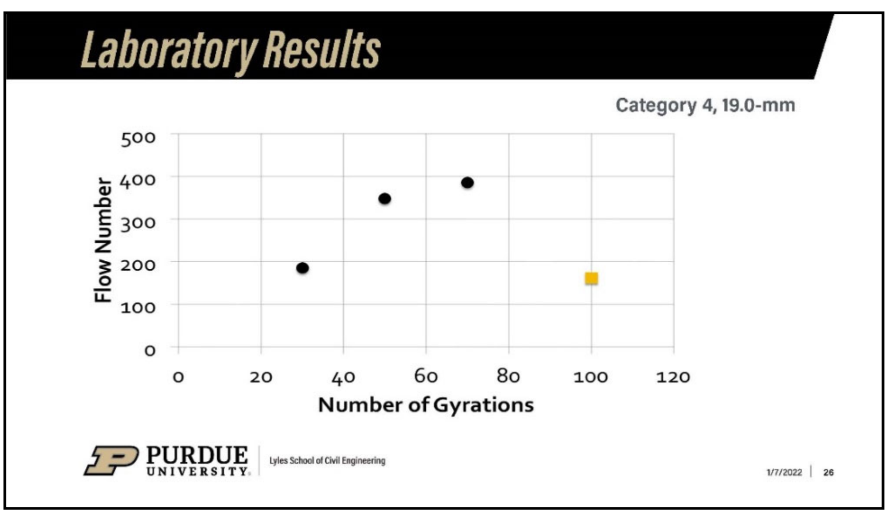
The flow number of the Category 4, 19.0-mm mixture were plotted as a function of the compaction effort (Slide 23). This data also show all three Superpave5 mixtures (N30, N50, N70) should have as high or higher rutting performance than the Superpave4 mixture.

These three data plots in Slides 21 to 23 of the Category 4, 19.0-mm mixture are used as representative results. The data from the two 9.5-mm mixtures show the same trends.

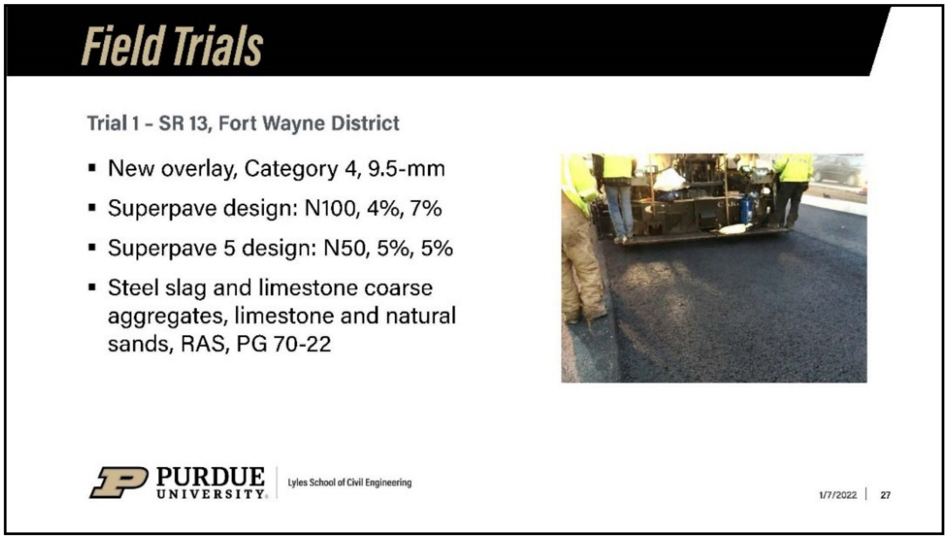
Given the data, at this point, a lengthy discussion was had about the correct N_{des} number for Superpave5 mixtures. There was some hesitation on the part of INDOT to accept an N_{des} of 30 gyrations, although the data indicate it should produce well-performing mixtures. It was decided to place two small field trials using an N_{des} of 50 gyrations and collect additional data.

The first field trial (Slide 24) was completed on SR-13 in the Fort Wayne District (northeast Indiana). The test section was part of a larger project that included a Superpave4, Category 4, 9.5-mm mixture, which allowed for comparisons. This overlay project included the use of recycled asphalt shingles (RAS) and a PG 70-22 binder in both the Superpave4 and Superpave5 mixtures.

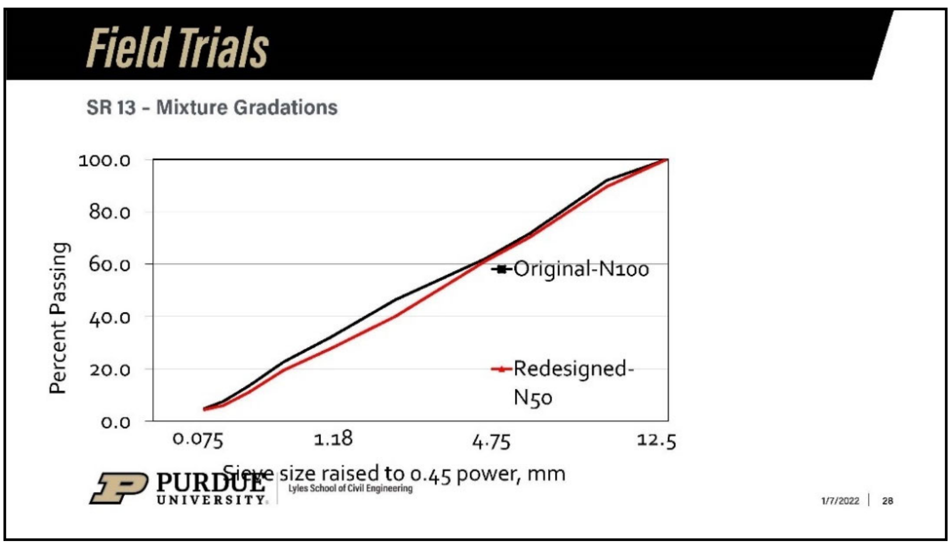
As seen in Slide 25, the gradations of the Superpave4 and Superpave5 mixtures were slightly different, but different enough for the Superpave5 mixture to have 5% air voids content at optimum binder content and 1% higher VMA than the Superpave4 mixture. The P_{be} in both mixtures was essentially the same.



SLIDE 23



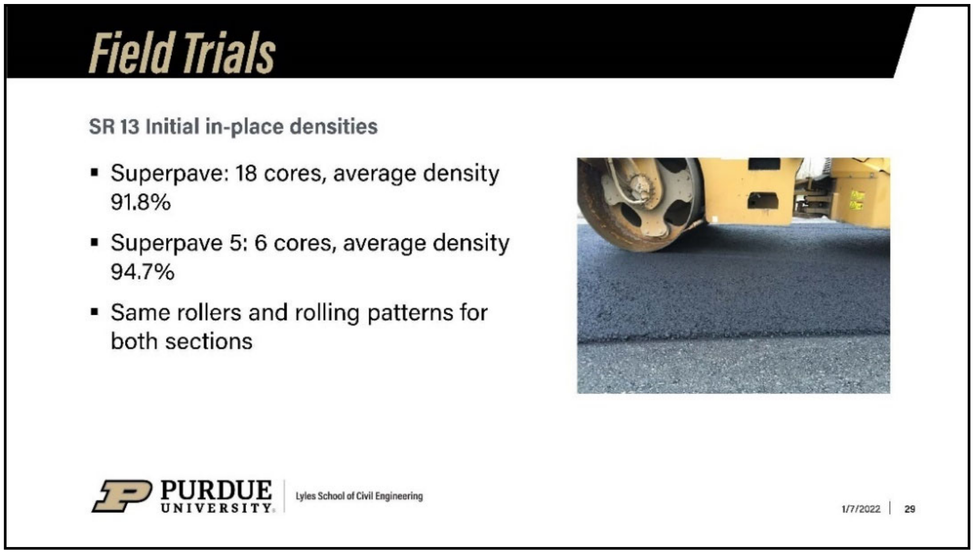
SLIDE 24



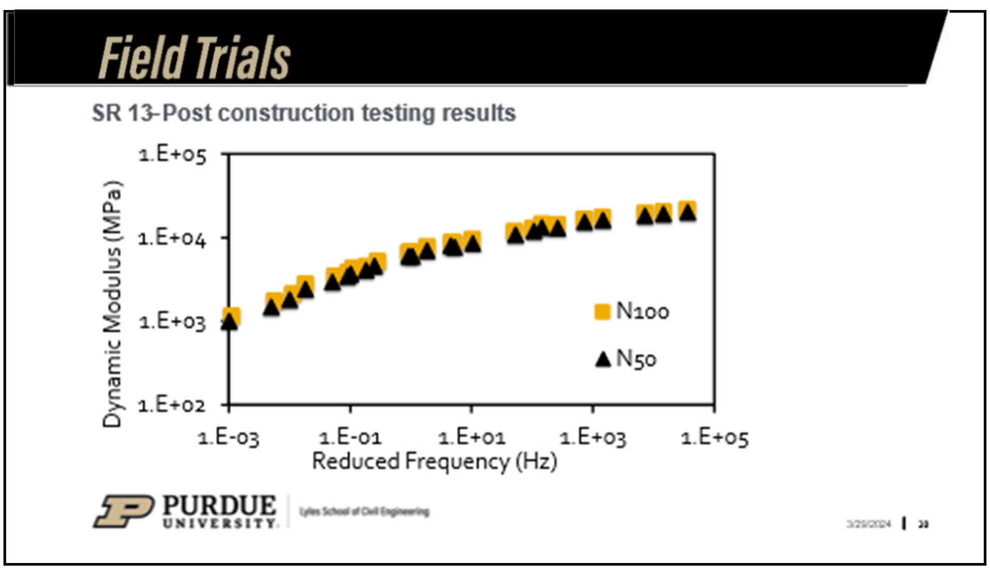
SLIDE 25

The initial in-place mat densities from the SR-13 trial project yielded promising results (Slide 26). The average density in the Superpave4 section was 91.8% of G_{mm}, which is perhaps slightly lower than what might be commonly found in Indiana. However, the average density of the 6 cores taken from the much smaller Superpave5 section was 94.7% of G_{mm}, essentially the 95% of G_{mm} sought. The average Superpave5 density was 3% higher than the Superpave4 mixture, even though the same rollers and rolling patterns were used for both mixtures.

The dynamic modulus data for the SR-13 project are shown in Slide 27. The data indicate the Superpave4 and Superpave5 mixtures have comparable dynamic modulus curves over the range of frequencies used in the testing. These results were encouraging again.



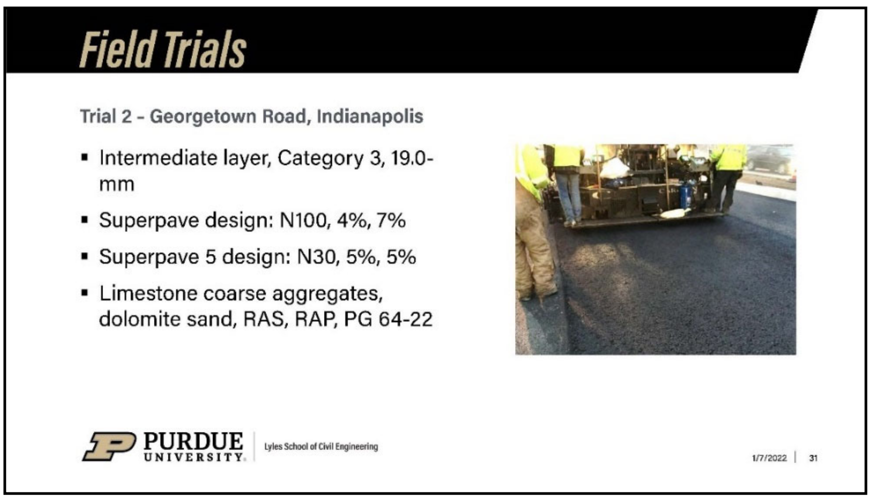
SLIDE 26



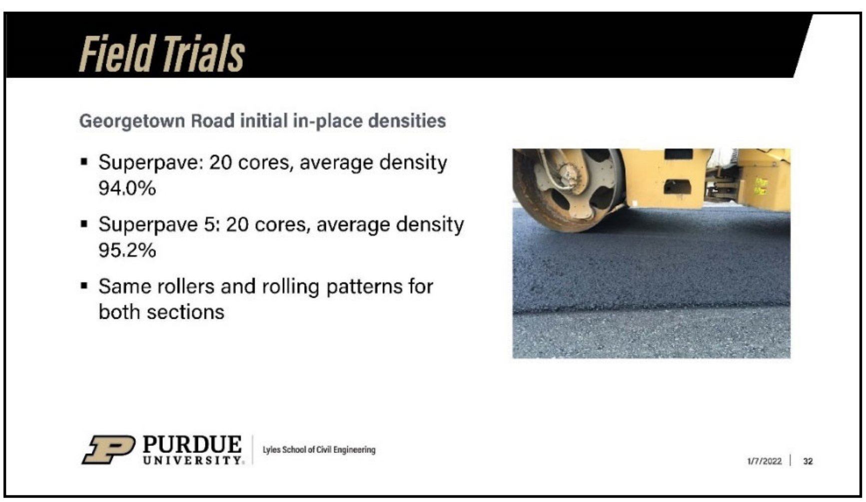
SLIDE 27

The second trial project was placed on Georgetown Road in Indianapolis (Slide 28). Rather than a surface mixture, this time an intermediate asphalt mixture was produced and placed. The Superpave5 mixture was designed using 30 design gyrations, given the project was placed on a city street. Both the Superpave4 and Superpave5 mixtures made use of RAS, reclaimed asphalt pavement (RAP), and a PG 64-22 binder.

The initial in-place mat densities from the Georgetown Road trial project again yielded promising results (Slide 29). The average density in the Superpave4 section was 94.0% of G_{mm}, an excellent density for such a mixture. The average density of the Superpave5 section was 95.2% of G_{mm}, essentially the 95% of G_{mm} sought. The average Superpave5 density was 1% higher than the Superpave4 mixture, even though the same rollers and rolling patterns were used for both mixtures.



SLIDE 28

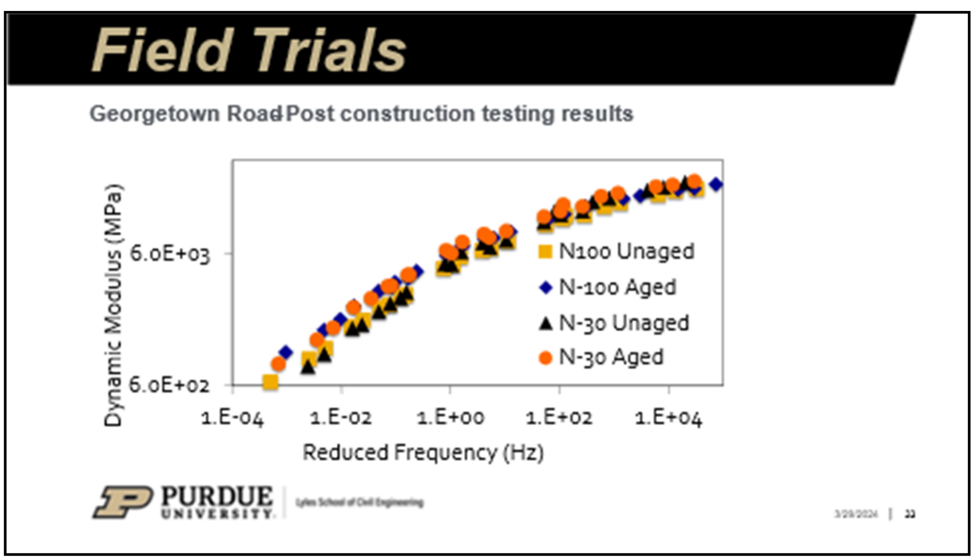


SLIDE 29

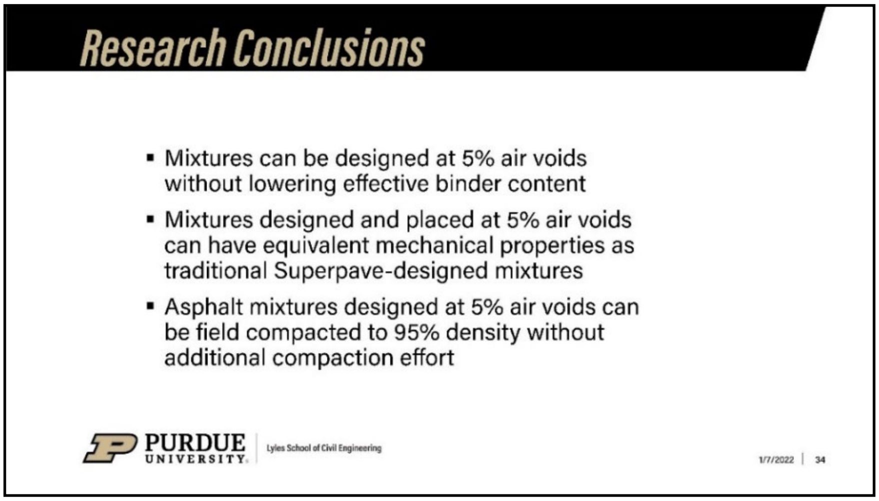
The dynamic modulus data for the Georgetown Road project are shown in Slide 30. This time, both the Superpave4 and Superpave5 mixtures were tested in unaged and aged conditions, then tested to determine modulus values. The standard AASHTO R30 aging protocol of 5 days at 85°C was used to age specimens. The data indicate the Superpave5 mixture perhaps has a slightly higher dynamic modulus curve than does the Superpave4 mixture. The data may also indicate less aging in the Superpave5 mixtures, which was an anticipated result of increasing initial in-place mat densities.

Given both the laboratory research and field trials results, it was concluded (Slide 31) that asphalt mixtures could be designed at 5% air voids content using the Superpave mixture design method without lowering the effective binder content (P_{be}). This was done by changing the gradations of the Superpave5 mixtures. These changes in the mixture design procedures yield asphalt mixtures that have mechanical properties equivalent to or better than Superpave4 mixtures produced using the same mixture components. Finally, it was shown in the field trials that Superpave5 mixtures could be field compacted to 95% of G_{mm} without using additional compaction effort.

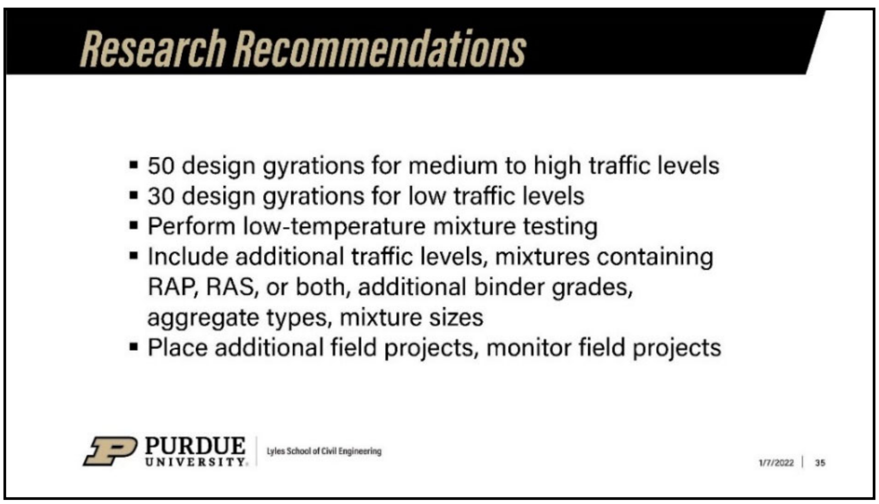
Recommendations were made (Slide 32) to use 30 design gyrations for low-volume traffic levels and 50 design gyrations for medium- to high-volume traffic levels. Additionally, more field trials should be placed and monitored. These sections should extend the work to include additional binder grades, aggregate types, mixture sizes, and recycled contents.



SLIDE 30



SLIDE 31



SLIDE 32

SUMMARY

Overall, the use of Superpave5 mixtures has been successful in Indiana. The specifications for its use have been in place for five years and, anecdotally, everyone believes the change has had a positive effect on asphalt pavement performance. In addition to mixture design method changes, INDOT has also made changes to Pavement ME asphalt mixture inputs, to reflect the differences between Superpave5 and Superpave4 mixture properties.

REFERENCE

Prowell, B.D., and Brown, E.R., *NCHRP Web-Only Document 96:Appendixes to NCHRP Report 573: Superpave Mix Design: Verifying Gyration Levels in the N_{design} Table*, Transportation Research Board of the National Academies, Washington, DC, 2006.

Performance of Superpave5 Trial Sections

GERRY HUBER

Heritage Research Group

The purpose of this section is to compare field performance of the Superpave5 trial sections with the regular Superpave specifications encoded in the standard specifications of INDOT. As such, the first important point is to understand what comparison is being made. INDOT specifications for asphalt mixtures, including those for Superpave mixture specifications, closely match those published by AASHTO.

The Superpave mix design system needs to be adjusted to achieve air voids which are the same during design and after compaction. Research discussed in the previous section focused on determining the laboratory compactive effort to design mixtures at 5% air voids such that they can be compacted to a final density of 95% Gmm, at a lift thickness of four times Nominal Maximum Particle Size (NMPS) using the same rolling effort (roller size, weight and number of passes) as currently used. These research results indicate that mixtures previously designed at 125, 100, or 75 gyrations should be compacted with 70, 50, or 30 gyrations respectively.

Based on findings from the research, INDOT adjusted their current specification to become Superpave5. Design air voids were increased from 4.0% to 5.0%. Design VMA was increased by 1.0% meaning the effective asphalt volume (V_{be}) remains the same in Superpave5 mixtures as in regular Superpave mixtures.

Final compaction on the road was targeted to be 5.0% air voids (95% Gmm) instead of 7.0% air voids (93% Gmm). In summary INDOT made the following changes to their specifications:

- Laboratory compaction effort was changed from 100 gyrations to 50 gyrations (INDOT had already discontinued use of 125 gyrations) and from 75 or 50 gyrations to 30 gyrations.
- Design air void content was increased from 4.0% to 5.0%.
- Design VMA requirements for each of the nominal maximum size mixtures were increased by 1.0%.

- Design VFA requirements were adjusted to recognize the new VMA and air void specifications.
- All other requirements were unchanged.

In 2013 the first trial project in Indiana (Slide 1) was built using the adjusted Superpave mix design, dubbed Superpave5. In 2018, cores were taken, and an evaluation was done to compare the performance and the state of being of the Superpave5 mixture compared to the regular mixture (Superpave4) after 5 years of service.

The first trial section was part of an existing project located in northeast Indiana near Middlebury, on State Route 13 (SR13). The entire project is 6.1 miles long and the trial section is 2.2 miles long in the southbound lane, about one-sixth of the entire project. Mixture in the northbound lane adjacent to the trial is considered the control section. The project had an average annual daily traffic (AADT) of 13,400 in 2012 with 19% heavy trucks. The existing road is one lane in each direction with 11-foot lanes and 2-foot shoulders.

The existing pavement suffered from extensive transverse cracking but was structurally sound. The project called for milling the existing surface then placing 2 inches of intermediate mixture and 1.5 inches of 9.5-mm NMPS surface mixture designed for 3 to 10 million ESALs. The trial section included only the surface mixture.

The Superpave4 and Superpave5 designs contained the same constituent materials. The aggregate stockpiles, recycled material and asphalt binder grade were the same for each design. The recycled material content was kept the same for each design. The design effective asphalt content was targeted to be the same for both mixtures. The Superpave5 design was 0.2 percent higher in effective asphalt content and 0.3 percent higher in total asphalt content than the Superpave4 mixture (Wielinski et al., 2019).

SLIDE 1

The same rolling train (Slide 2) was used for the Superpave5 trial section as had been used for the control section (Superpave4). The research study done at Purdue University had been based on the premise that field compactive effort to achieve 5% in-place air voids for the Superpave5 mixture should be the same as for the compactive effort to achieve 7% in-place air voids for the regular Superpave mixture. As a result, the same rollers, same speed, same passes were used for the Superpave5 mixture as had been used for Superpave4 on the previous day.

A summary of the mix construction properties for both quality control (QC) testing and Quality Acceptance (QA) testing is shown in Slide 3. QC and QA tests for the Superpave4 asphalt content are near the design value of 5.1%. For the Superpave5 mixture, the QC asphalt content is slightly higher, and the QA results are slightly lower. The combined QC and QA testing matches the design content.

SLIDE 2

SR 13 Mix Construction Properties

	Superpave4			Superpave5		
	Design	QC	QA	Design	QC	QA
Asphalt, %	5.1	5.1	5.0	5.4	5.5	5.2
Air Voids, %	4.0	3.5	4.1	5.0	4.5	4.0
Density, $\%G_{mm}$	-	-	91.6	-	94.7	96.9

SLIDE 3

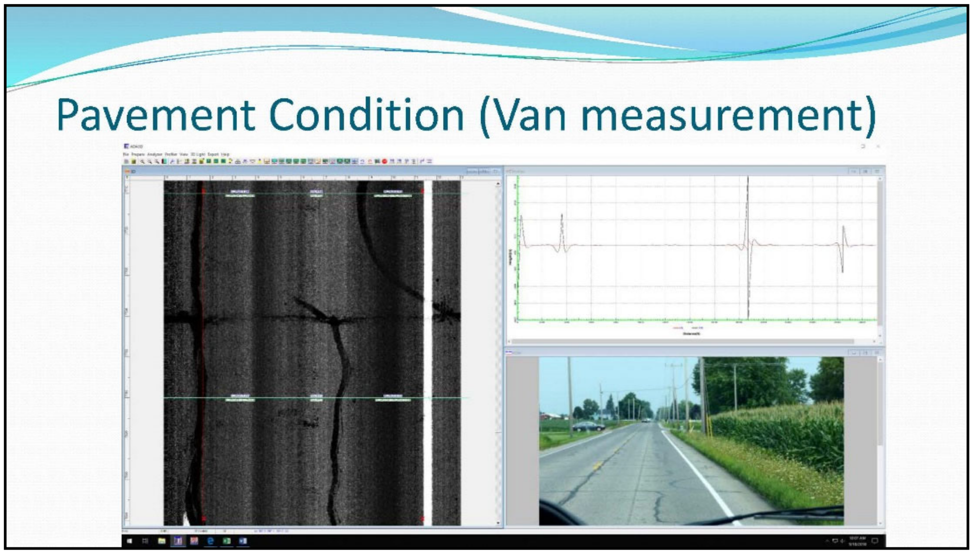
For Superpave4 air voids, the QC results, 3.5%, are slightly lower than the target of 4.0% and the QA results are approximately equal, 4.1%. For Superpave5 both the QC and QA results are lower than the design of 5.0%. The QC results are 0.5% lower, and the QA results are 1.0% lower.

QA results for Superpave4 compaction show an average density of 91.6%. There are no QC test results available for the Superpave4 mixture. The expected value for density is slightly higher than 93%. For Superpave5 the compaction target is 95.0%. QA results—96.9% are higher than the target. QC results—94.7% are near the target. There is no obvious reason for the higher compaction density of the QA results.

After 5 years in service, a performance assessment was conducted (Slide 4). Three sampling locations were selected in the southbound lanes (Superpave5) and three locations were selected in the northbound lanes (Superpave4). At each location six cores were taken between the wheel paths. A suite of tests done on cores included bulk specific gravity, maximum specific gravity, asphalt content, gradation, air voids, permeability, asphalt binder recovery, and grading.

Surface condition data were collected using an automated van system (WayLink PaveVision 3D)—pavement smoothness, International Roughness Index (IRI), and rut depth (mm) in each of the wheel paths. Automated crack detection software categorized transverse, longitudinal, and pattern cracking. A typical display is shown in Slide 5 for a 10-foot pavement length. A summary for the three Superpave4 locations and three Superpave5 locations is shown in Slide 6. The Superpave4 and Superpave5 sections are similar, and all sections are rated acceptable for smoothness and rut depth.

SLIDE 4



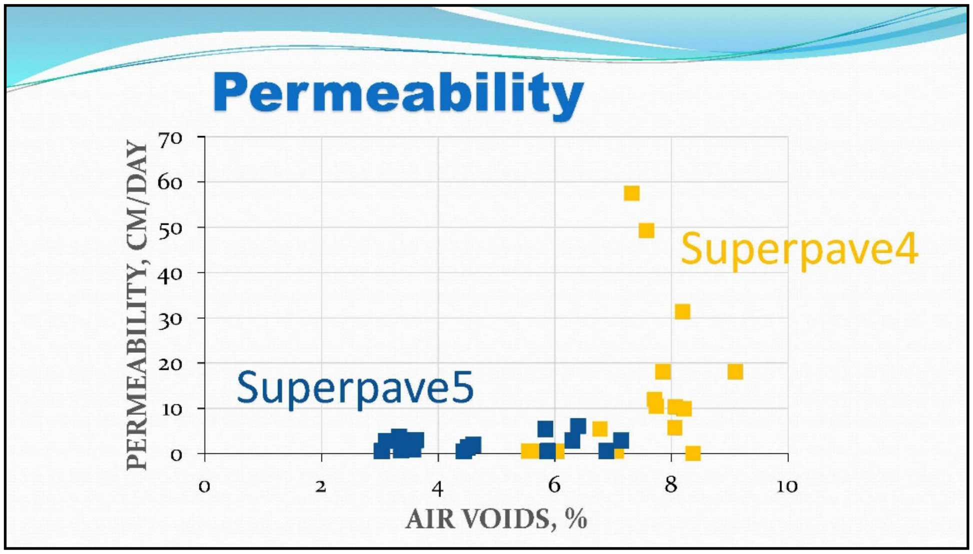
SLIDE 5

Smoothness and Rut Depth

	Superpave4				Superpave5			
	IRI (in/mi)		Rut Depth (in)		IRI (in/mi)		Rut Depth (in)	
	LWP	RWP	LWP	RWP	LWP	RWP	LWP	RWP
Average Three Locations	43	91	0.22	0.31	28	120	0.14	0.22
Entire Project	47	119	0.13	0.26	53	206	0.14	0.26

SLIDE 6

Since gradation was only slightly different between the Superpave4 and Superpave5 mixtures, permeability (Slide 7) of the two mixtures was influenced only by density (in-place air voids). As with most asphalt mixtures there is an in-place void content below which permeability is low and is relatively insensitive to air voids. Above the threshold air void content permeability increases rapidly. For this mixture the threshold air void level was about 7%. As shown in Slide 7, when air voids were below 7% permeability was very low.



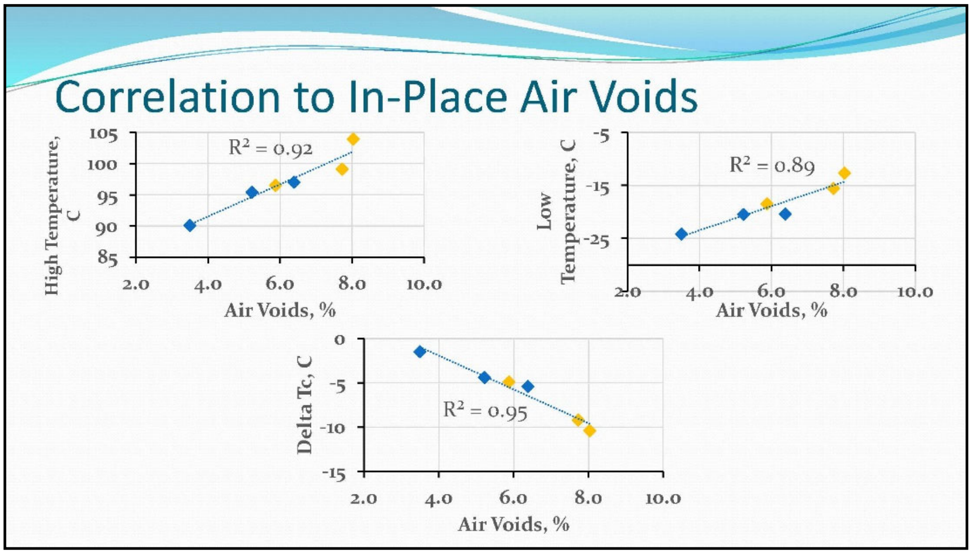
SLIDE 7

Target density for Superpave4 is about 7% in-place air voids and for Superpave5 the target is about 5%. The permeability data shown in Slide 7 includes all 18 cores (six from each of three locations) from the Superpave4 mixtures and 18 cores (again, six from each of three locations) from the Superpave5 mixtures. Of note in this data, the highest air void Superpave5 location had between 6% and 7% air voids. The lowest Superpave4 air void location had between 5.5% and 7% air voids.

Asphalt binder was recovered from each of the three Superpave4 locations and three Superpave5 locations. The recovered asphalt binder was graded for high temperature and low temperature grade. The results for each of the sample locations are shown in Slide 8.

Recovered asphalt binder properties, specifically PG high temperature grade, PG low temperature grade, and delta T_c are very strongly related to in-place air voids. Note that each location had the same composite of new PG 70-22 asphalt binder and reclaimed asphalt binder from recycled material. It would be reasonable to expect that in July 2013 all the locations had the same asphalt binder properties.

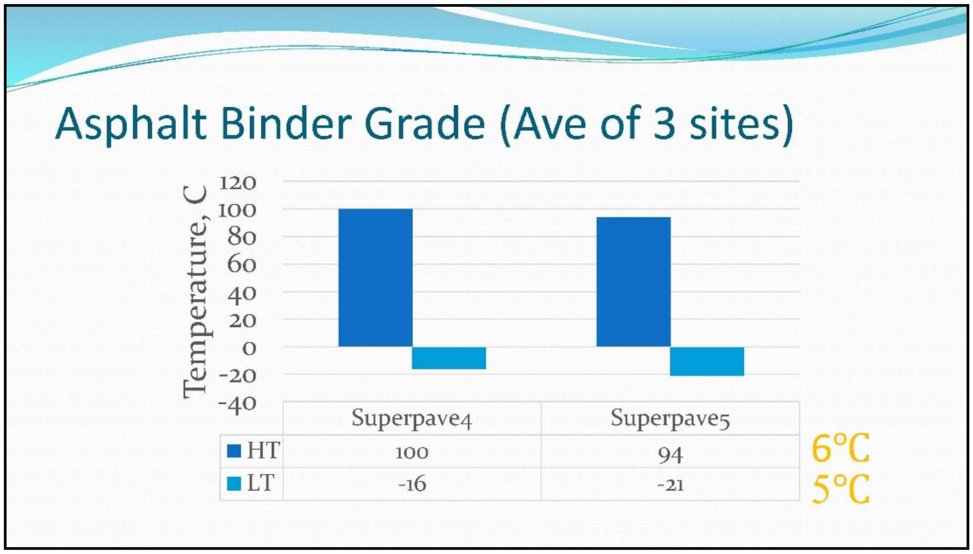
After 5 years in service, the high temperature grade for all sections ranged from 90.1°C to 103.9°C, more than two high temperature grades. The low temperature grade ranged from -12.7°C to -25.7°C, more than two grades.



SLIDE 8

The Superpave5 data are shown as blue diamonds, while the Superpave4 data are shown as yellow diamonds. Note overlap between the sets of data. The lowest air void Superpave4 location has lower air voids than the highest air void Superpave5 location. These data suggest that the 0.3% higher asphalt content in the Superpave5 design is not the reason for reduced in-service aging. In-place air voids (permeability) is controlling the aging. The data in Slide 8 show aging is directly related to in-place air voids. The difference, and reason for reduced aging of the Superpave5 mixtures, is because of higher compaction (lower in-place air voids).

As shown in Slide 9 the three Superpave5 sampling locations have an average grade of PG 94-21 and the three Superpave4 locations have an average grade of PG 100-16. There is a difference of six degrees (one whole temperature grade) in the high temperature grade and five degrees (almost one whole temperature grade) in the low temperature grade.



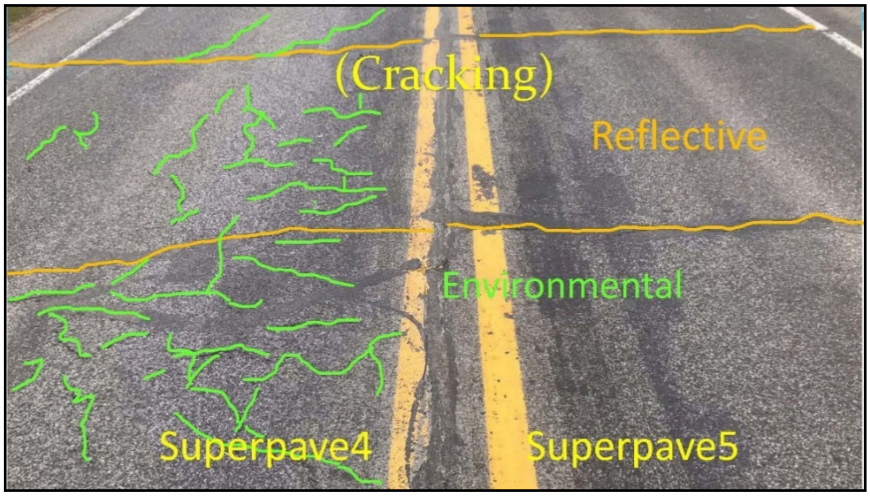
SLIDE 9

Slide 10 shows the difference in cracking performance. Cracking measurements from the automated condition van data showed no difference between the Superpave4 and Superpave5 sections. The van detected transverse reflective cracks but was unable to identify short fine cracks that existed in the surface. Fine surface cracking was identified visually at the time of coring. In Slide 10 reflective cracks are shown in orange and environmental cracks are shown in green. This cracking pattern was typical at each of the core sample locations.

The second Superpave5 project (Slide 11) was done on a 19.0-mm intermediate mixture. This project included a small (1,000 ton) portion of the project converted from Superpave4 to Superpave5. As shown in Slide 11, this was a reconstruction project of a major collector street in Indianapolis. Like the first trial project, there was insufficient mixture to allow for setting up of a rolling pattern. Instead, using the same principle as in the SR13 project, the same rolling train was used for the Superpave5 mixture.

Asphalt binder content and air void results are listed in Slide 12. The density is shown as well. The target density of 95% was achieved.

On Georgetown Road, Superpave5 was used only for an intermediate mixture. Superpave4 was used for the surface mixture throughout the project. When viewing the surface where the Superpave5 mixture was used for the intermediate layer, there is no visual difference in performance. Coring and follow-up evaluation of the Superpave5 mixture has not been possible.



SLIDE 10

SLIDE 11

Georgetown Road Mix Construction Properties

	Superpave4		Superpave5	
	Design	QA	Design	QA
Asphalt, %	4.6	4.7	4.8	4.6
Air Voids, %	4.0	4.4	5.0	4.5
Density, $\%G_{mm}$	-	92.2	-	95.8

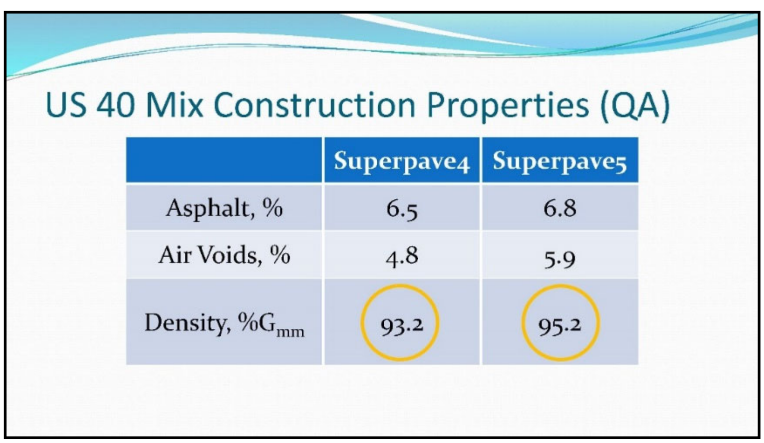
SLIDE 12

A third project was set up on U.S. 40 in Richmond, Indiana. As shown in Slide 13, this was a mill-and-fill project. The existing pavement is a jointed concrete pavement that has been previously overlayed with six inches of asphalt.

The project is located adjacent to I-70 near the eastern boundary of Indiana. This trial project was significantly larger than the SR13 or Georgetown Road trials. In addition to demonstrating the ability to construct and compact Superpave5 mixtures, the objective was to quantify variability of the properties INDOT uses for acceptance and compare them to variability of the same properties in Superpave4 mixtures.

Mixing, placing, and compacting the Superpave5 mixture was again successful. Average quality assurance values are listed in Slide 14. Asphalt content for the Superpave5 mixture is slightly higher than the Superpave4 mixture. Air voids were slightly higher than the target value for both mixtures (0.8% for the Superpave4 and 0.9% for the Superpave5), and compaction was near the target of 93% and 95% respectively.

SLIDE 13



	Superpave4	Superpave5
Asphalt, %	6.5	6.8
Air Voids, %	4.8	5.9
Density, $\%G_{mm}$	93.2	95.2

SLIDE 14

A visual evaluation of the field performance was done after 5 years. There were locations where cracking had occurred, although much of the project did not have cracking. Slide 15 shows longitudinal wheel path cracking in the Superpave4 lane and not in the Superpave5 lane. Slide 16 shows another location where mid-lane longitudinal cracking exists in the Superpave4 lane and not in the Superpave5 lane.

SLIDE 15

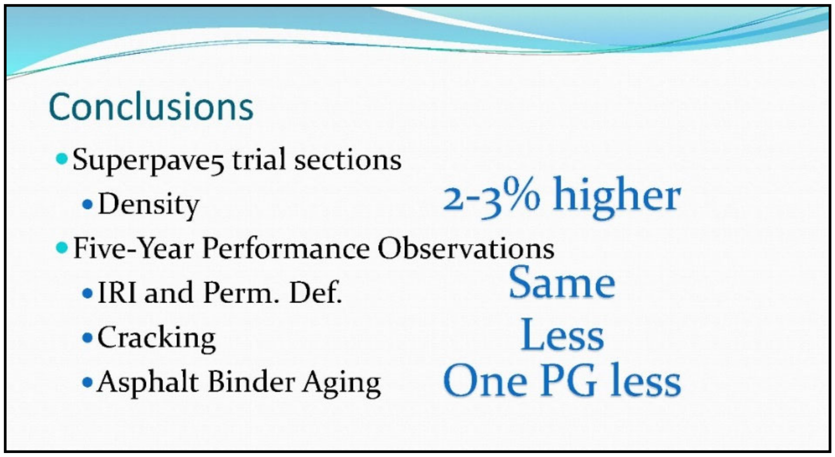
SLIDE 16

Since this project is a mill and fill, reflective cracking is expected. Reflective cracking is locally specific to existing cracks before overlaying. Since existing cracks were not mapped before the mill and fill, it is not possible to know if the distribution of existing cracks is similar for the Superpave5 areas and for the Superpave4 areas.

Slide 17 provides some field evidence of Superpave4 crack resistance compared to Superpave5. The photo, taken standing on the curb, shows Superpave5 mixture in the first lane, and Superpave4 in the next two lanes. There is a reflective crack typical of a concrete joint deep in the pavement. The crack traverses the two lanes of Superpave4 mixture and stops at the Superpave5 mixture. In the foreground, against the concrete curb, there are short cracks typical of D-cracking.

Based on the three trial sections, the density (%G_{mm}) of Superpave5 mixtures is 2% to 3% higher than for Superpave4 mixtures (Slide 18). Field performance observations comparing Superpave5 and Superpave4 show no difference in smoothness or rutting. Both mixtures provided acceptable performance. Superpave5 mixtures had more resistance to reflective cracking and less susceptibility to environmental cracking. With respect to asphalt binder aging, Superpave5 mixtures aged less than Superpave4 mixtures. After 5 years, the asphalt binder in Superpave5 mixtures was one PG grade less aged than asphalt binder in Superpave4 mixtures.

SLIDE 17



SLIDE 18

SUMMARY

The Superpave5 mix design system is designed with 5% air voids and intended for compaction to 95% density (5% in-place air voids). This paper has described the performance of three trial sections.

- Three trial sections were constructed between 2013 and 2016. Lessons learned from these sections include compaction with the same rolling pattern (equipment and number of passes) produced a final density of approximately 95%.
- Permeability was directly related to in-place air void content of the mixtures. Permeability of the Superpave5 mixture on the first trial section (State Route 13) was significantly lower than the Superpave4 mixture.
- Aging of asphalt binder in the mixture was directly related to permeability (indirectly to air void content). After 5 years the Superpave5 asphalt binder had aged less than the Superpave4 asphalt binder. High temperature grade was six degrees lower and low temperature grade was five degrees lower.
- Superpave4 mixtures on SR13 and U.S. Highway 40 had more cracking than the comparable Superpave5 mixtures.
- Delta T_c, a measure of cracking susceptibility, of the recovered asphalt binder on SR13 varied in direct proportion to the in-place air void content for both Superpave5 and Superpave4 mixtures.
- On SR13 the smoothness (IRI) and rut depth after 5 years are approximately equal for Superpave5 and Superpave4.

REFERENCE

Wielinski, J, Campbell, C., Beeson, M., and Huber, G., Superpave5: Effect of In-Place Air Voids on Asphalt Mixture Performance, Canadiana Technical Asphalt Association, 2019.

Superpave5 Implementation in Indiana

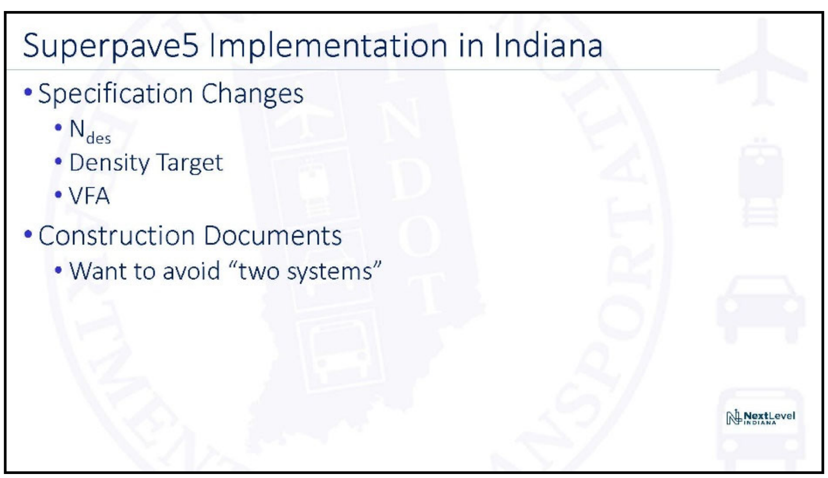
MATT BEESON

Indiana Department of Transportation

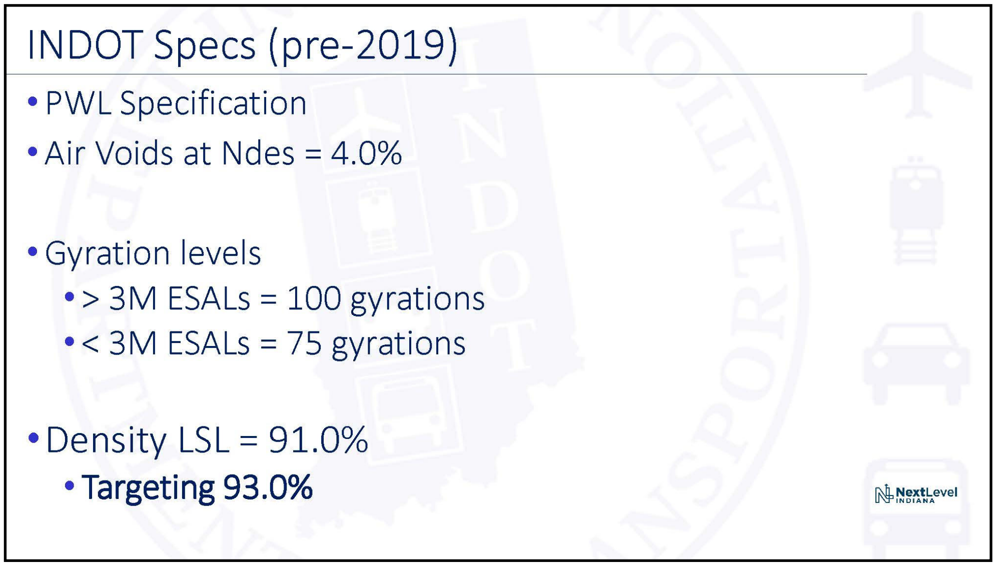
INDOT implemented Superpave5 in 2019 on a partial basis and in 2020 statewide. This presentation is a summary of what INDOT changed and the benefits realized from implementation.

Based on the results of the 5-year follow-up to the Superpave5 trial section as described by Gerry Huber, INDOT was ready to implement Superpave5 (Slide 1). We identified what specifications needed to change, which ultimately were minor in terms of the number of edits. We needed to edit the design gyration level, N_{des}, the field target density levels, and voids filled with asphalt, VFA. Also, INDOT wanted to avoid having a paving system where we required two different gyration levels and density targets, so we produced a construction memorandum allowing contractors to opt in to the new system on all contracts.

For background, Slide 2 shows the relevant INDOT HMA (hot mix asphalt) specifications prior to making the change to Superpave5 in 2019. INDOT utilizes percent within limits to calculate pay factors for acceptance. The mix design and production air void target was the standard Superpave value of 4.0%. INDOT utilized two design gyration levels, N_{des}, split by design ESALs: 100 gyrations for greater than 3 million ESALs, and 75 gyrations for less than 3 million ESALs. The lower specification limit for in-place density, $\%G_{mm}$, was 91.0%. Based on typical standard deviations, this effectively sets the in-place density target as 93.0% G_{mm}.



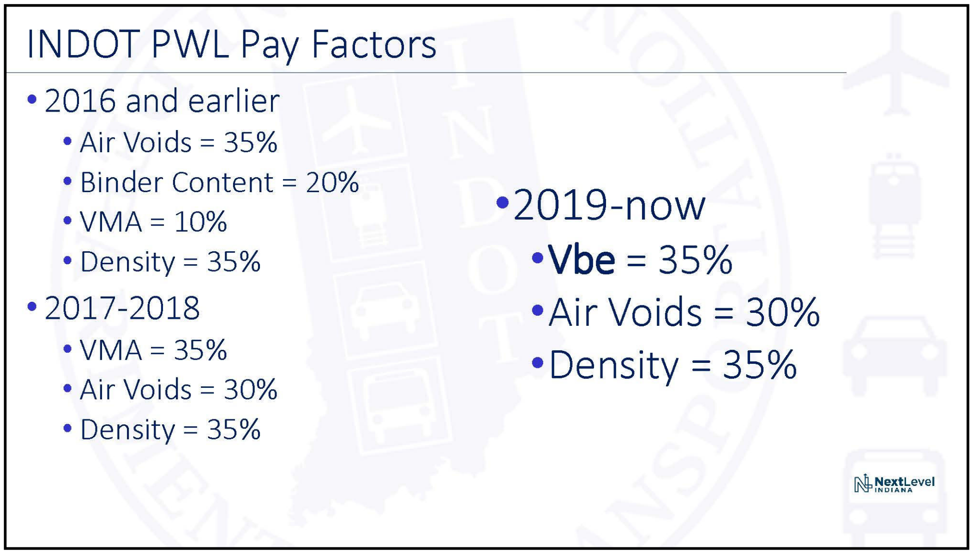
SLIDE 1



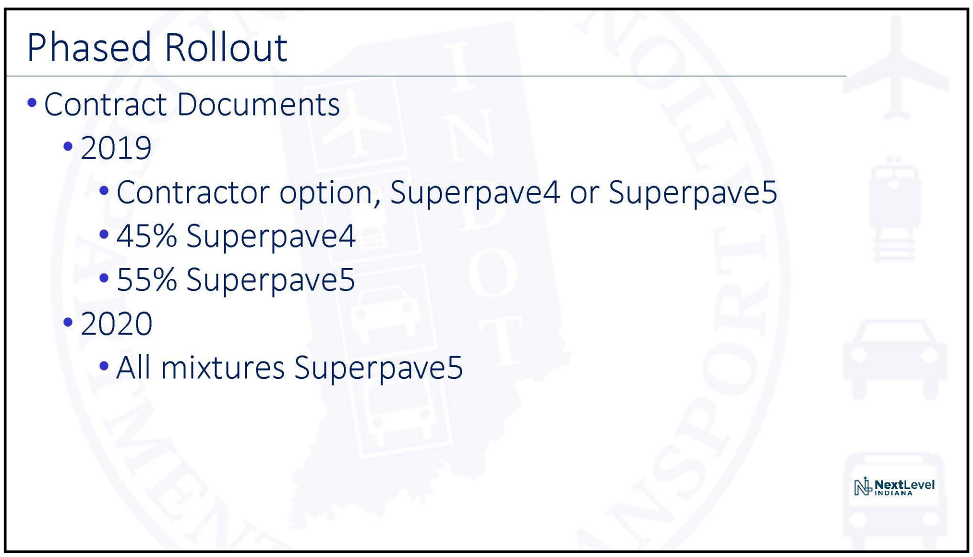
SLIDE 2

Slide 3 provides additional background information on how INDOT weighted HMA pay factors prior to and after Superpave5 implementation. This is not directly related to Superpave5 implementation but provides context on how INDOT values the various properties listed for acceptance. Prior to 2016, INDOT utilized four factors, air voids, binder content, VMA, and density. For 2 years, 2017 and 2018, INDOT removed binder content and put more emphasis on VMA. Beginning in 2019, INDOT replaced VMA with volume of effective asphalt, or V_{be}.

INDOT made the decision to change their standard specifications to implement Superpave5 in early 2019. Due to the lag in time between when specification changes are approved and when the changes are reflected in contract documents, Superpave5 was effectively not going to be required until the 2020 paving season. However, INDOT made the option available to contractors via a construction memorandum to change the design method to Superpave5 on all existing contracts. Approximately 55% of the mixture placed in 2019 on INDOT contracts was placed as Superpave5 due to contractors opting to make the change voluntarily (Slide 4).

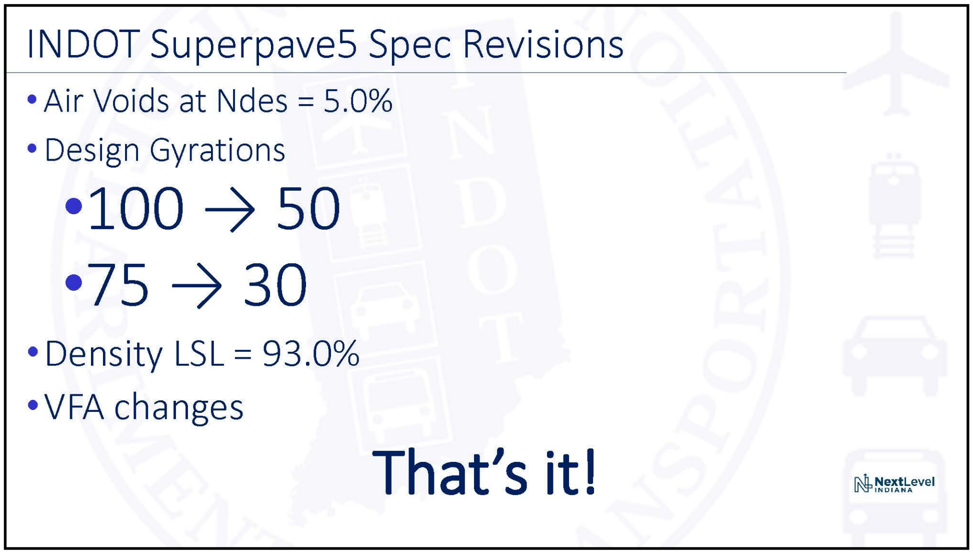


SLIDE 3



SLIDE 4

As discussed earlier, the changes to the text of the specifications were minimal (Slide 5). Target air voids at N_{des} changed from 4.0% to 5.0%. Mixture applications that had a design gyration level of 100 now had a design gyration level of 50, and mixture applications that had a design gyration level of 75 now had a design gyration level of 30. The lower specification limit for in-place density increased from 91.0% to 93.0%, leading to an intended target of 95.0% in-place density.

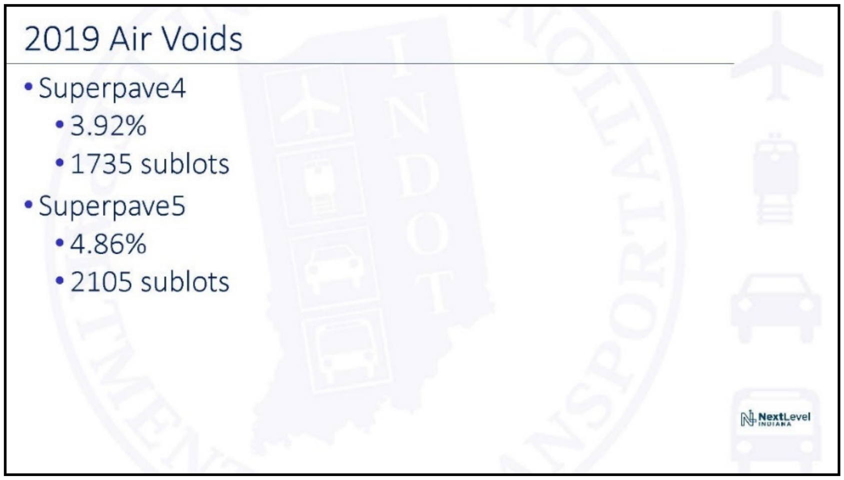


SLIDE 5

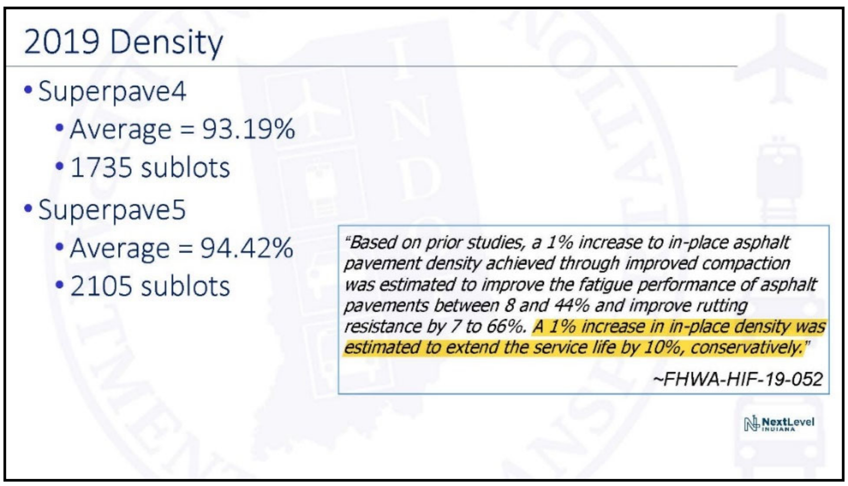
Slide 6 shows a summary of field sampled INDOT-tested gyratory air voids from 2019 acceptance samples. The data were separated by standard Superpave (referred to here as Superpave4) and Superpave5 to show the difference in gyratory air voids between the two. The results were as expected.

The ability to achieve the target air voids from gyratory compacted specimens was important, as shown on Slide 7, but the key was learning if that translated to in-place density. Slide 8 shows average %G_{mm} for INDOT mixtures placed in 2019 as measured from QA cores. The average density increased by approximately 1.2%. Per FHWA-HIR-19-052, a 1% increase in in-place density was estimated to extend the service life by 10% conservatively.

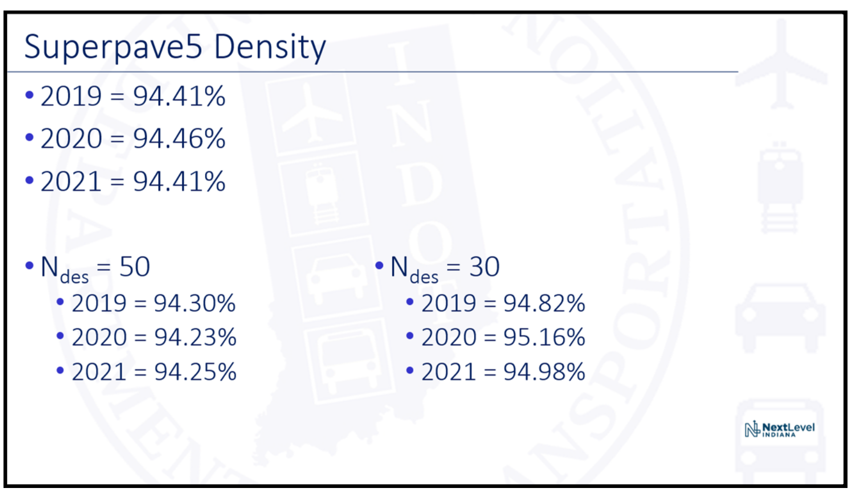
The average Superpave5 density values were consistent over the 5 years since implementation (Slide 8) at around 94.4% to 94.5% G_{mm} on a statewide average. Also shown are values split out by gyration level. The in-place density values are consistently higher on the 30 gyration mixtures.



SLIDE 6



SLIDE 7



SLIDE 8

Slide 9 shows the mixture average pay factors from 2019 through 2021. INDOT utilizes percent within limits to calculate pay factors for contracts with sufficient quantity. The first year, the pay factors for density for Superpave5 mixtures were a bit lower than the Superpave4 mixtures. It appears that over the next 2 years, contractors were able to improve consistency of in-place density and thus improve the density pay factors.

One concern that arose when implementing Superpave5 was regarding rutting. Would moving toward lower gyration levels lead to increased rutting? INDOT chose five mixes of each design type at random and performed Hamburg rutting testing per AASHTO T 324. The data shown on Slide 10 are rut depth (mm) after 20k passes. We found no appreciable difference between the two data sets.

Pay Factors

	Pay Factors				
	Air Voids	Vbe	Density	LCPF	Samples
2019 S4	1.00	0.98	1.00	0.991	1735
2019 S5	0.99	0.99	0.97	0.985	2105
2020	1.00	1.03	0.99	1.01	4377
2021	1.00	1.03	1.00	1.01	4136

SLIDE 9

Superpave5 Hamburg Comparison

- 5 mixtures of each chosen at random
- PG 64-22
- Rut depth (mm) at 20k passes at 50C

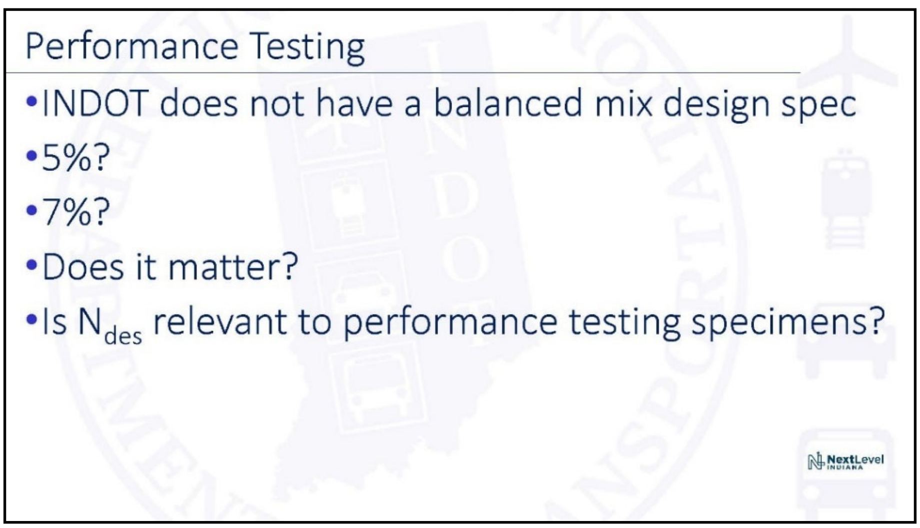
	Superpave4	Superpave5
1	3.22	3.17
2	2.86	2.9
3	3.41	2.34
4	2.92	4.14
5	3.26	3.71
Average	3.13	3.25

SLIDE 10

INDOT has additional unanswered questions regarding performance testing specimens (Slide 11). Now that we target 5% in-place air voids, should we also use 5% for performance testing specimens? Or should we use the more widely accepted target of 7% that many of the performance tests use? INDOT will continue to evaluate this as we move forward with performance testing.

SUMMARY

INDOT has continued to utilize Superpave5 mixtures since implementing in 2019 and has found the density improvement to be consistent in 2022 and 2023 as well. INDOT is embarking on a study to look at real-world performance benefits now that the first mixtures placed in 2019 have been in place 5 years.



SLIDE 11

Impact on Mix Design and Construction

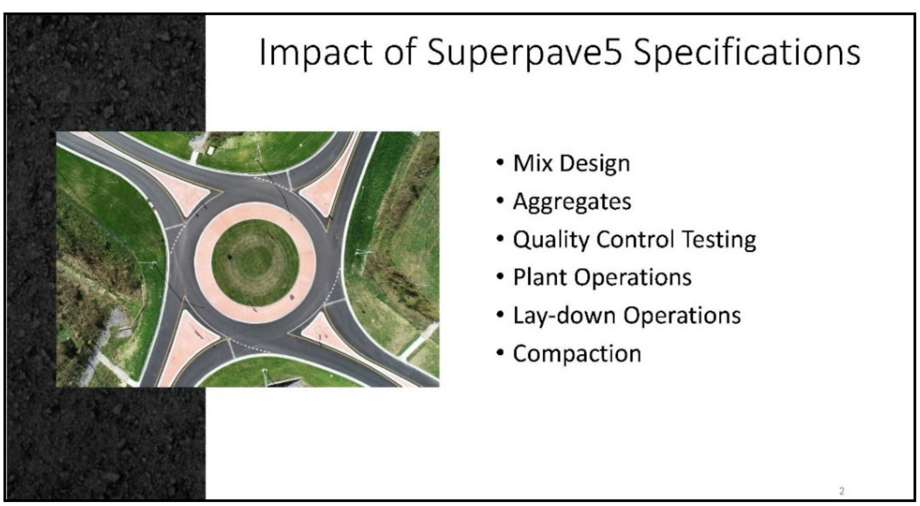
Elizabeth Pastuszka

Asphalt Pavement Association of Indiana

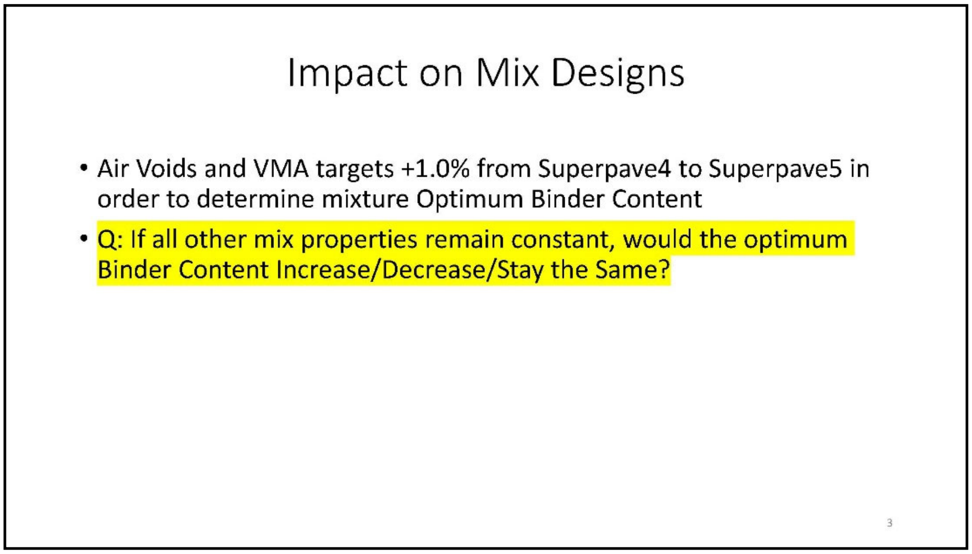
This section will provide an overview of a contractor's perspective on INDOT moving toward Superpave5 and the impact this change had on mix design and construction. At the time of the presentation, the author was working at E&B Paving, a heavy highway contractor in Indiana, but she is now working at the Asphalt Pavement Association of Indiana.

As shown in Slide 1, various considerations exist, such as mix design volumetric target requirements for mix submittals, aggregate needs that have been seen, what quality control tests are required, how the plant operations were changed, and lay-down and compaction changes that were needed in the field.

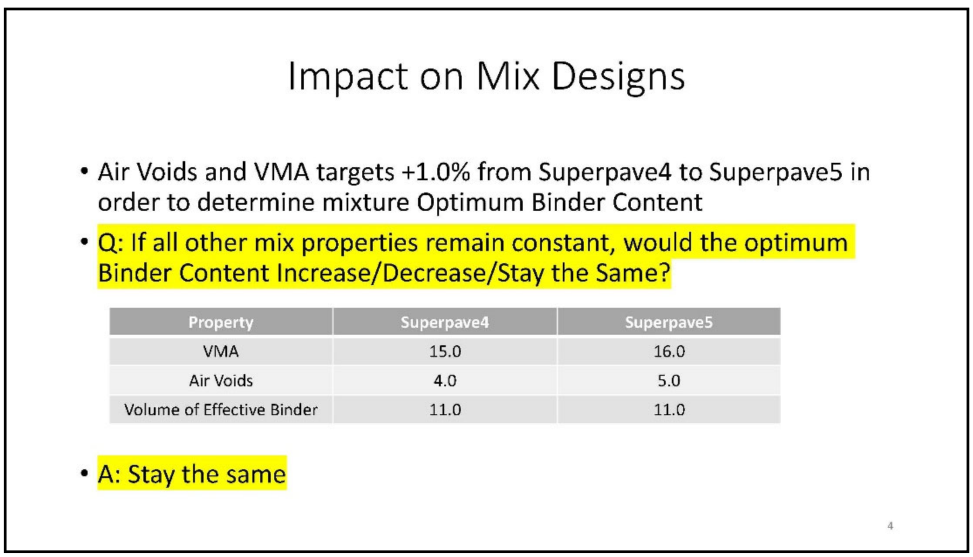
As discussed in previous sections, not only did the target percent air voids increase from 4.0% to 5.0%, but the minimum VMA requirements also increased by 1.0%. The question was asked (Slide 2) if the target air voids and minimum VMA requirements increasing by 1.0% changed the volume of effective binder (V_{be}) of the asphalt mixture. With the calculation of V_{be} being equal to VMA minus air voids, the answer is no, and the V_{be} stays the same. For the most part then, the total asphalt binder content of the mix should not vary if all other criteria stay the same (Slide 3).



SLIDE 1



SLIDE 2



SLIDE 3

The tables in Slide 4 show the volumetric requirements for the asphalt mix designs. The target percent air voids at optimum asphalt binder content were increased from 4.0% to 5.0% and the minimum VMA requirements for each size of asphalt mixture were increased by 1.0%. This ultimately kept the minimum V_{be} requirements for each mixture the same for the design. Some other aspects of the asphalt mix design specifications that did not change are the aggregate consensus properties and lift thickness requirements.

Impact on Mix Design

Air Voids (Dense Graded HMA)		
Property	**SP4 Target**	**SP5 Target**
Air Voids @ Opt. AC	4.0%	5.0%

VMA (Dense Graded HMA)		
Mix Size	**Minimum SP4**	**Minimum SP5**
4.75 mm	16.0	17.0
9.5 mm	15.0	16.0
12.5 mm	14.0	15.0
19.0 mm	13.0	14.0
25.0 mm	12.0	13.0

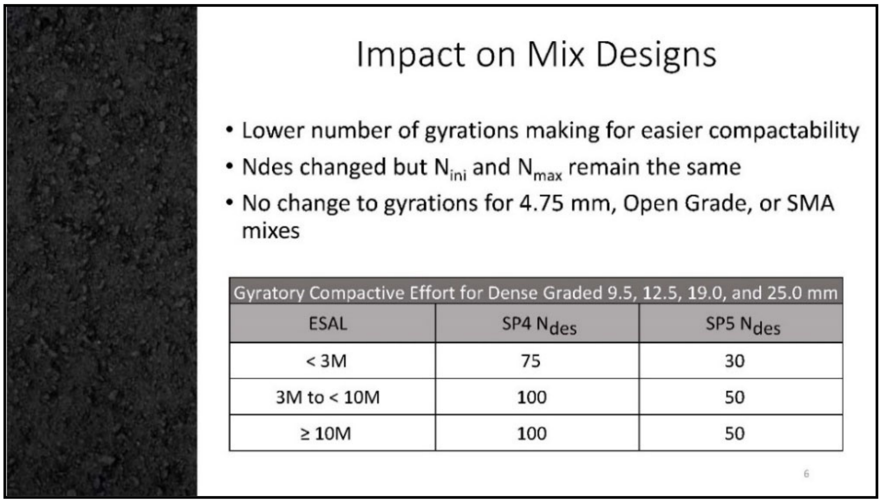
V_{be} (Dense Graded HMA)	
Mix Size	**Minimum**
4.75 mm	13.0
9.5 mm	11.0
12.5 mm	10.0
19.0 mm	9.0
25.0 mm	8.0

SLIDE 4

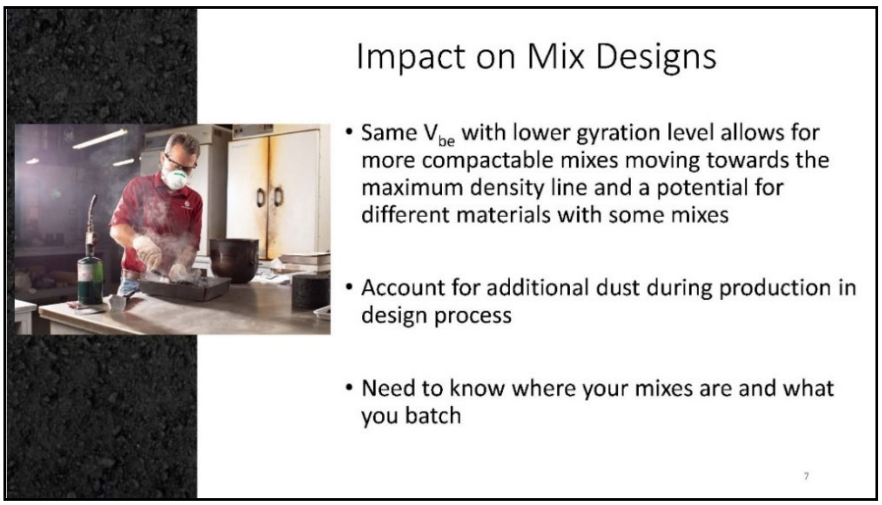
In addition to the percent air voids and VMA targets of the design changing, the number of gyrations for N_{des} was also lowered (Slide 5). The N_{ini} and N_{max} requirements remained the same along with the compactive effort for 4.75 mm, open graded, and SMA (stone mastic asphalt) mixtures. This allowed mix designers the ability to compact the mixtures a little easier as well as being able to move mixtures toward the maximum density line for a finer mix rather than primarily coarse graded.

As with any asphalt mix design, it is critical to understand the materials (Slides 6 and 7). Even though some of the Superpave5 mixtures can be made more toward the finer side than with Superpave4, dust is still a concern with maintaining volumetric properties. Too much dust will make the mixture more difficult to compact and lower the VMA. A mix designer should account for any additional dust during the design process and adjust the other materials as needed to still meet the volumetric requirements of the design.

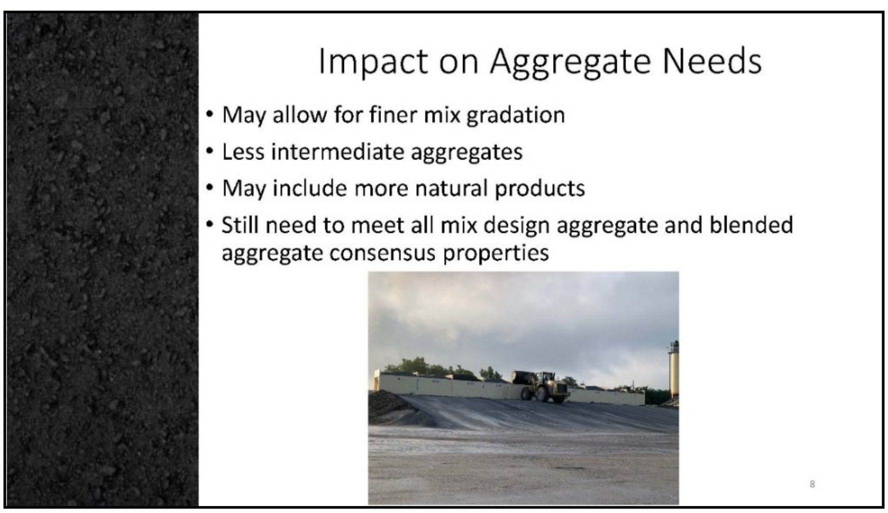
Many mixes saw a slight change in the gradation between the Superpave4 and Superpave5 designs. Most of the changes were that the designs could move on the finer side than what they currently were seeing. This allowed the use of less intermediate aggregate sizes—some designers saw up to 5% difference in certain mixtures—while still maintaining the target volumetrics. The use of less intermediate sized products alleviated the need from aggregate suppliers which are products that tend to be slower and more costly for quarries to produce yet was favorable in many Indiana asphalt mix designs as it tended to "open up" the mix making it easier to meet target VMA values.



SLIDE 5



SLIDE 6

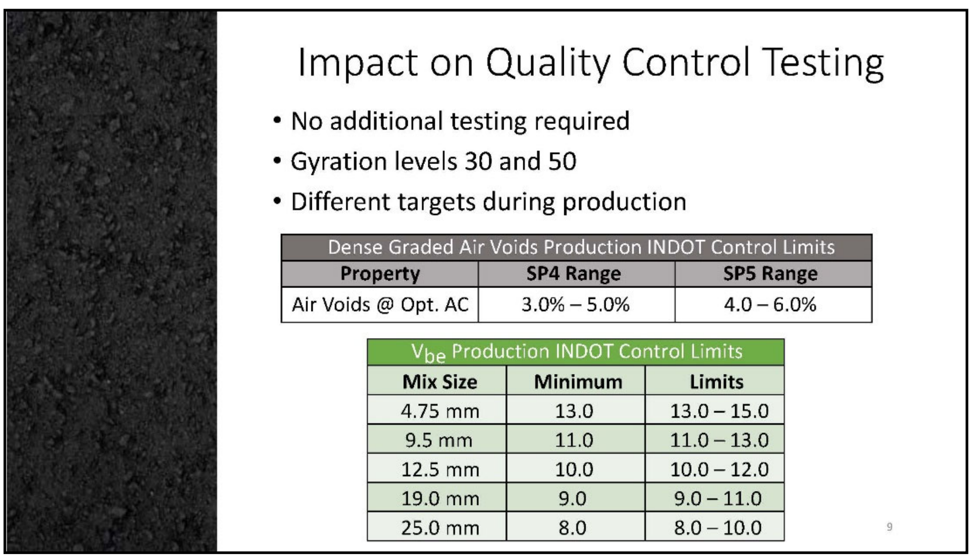


SLIDE 7

Some designers found they could utilize more local, natural products. This included gravel and natural sands to help the compactability, workability, and in some instances the cost of the mixture. Along with natural materials, the amount of recycled materials could potentially be increased by up to 5% as well, depending on the mixture and quality of the recycled material.

Even with less intermediate aggregates, more natural products, and increased recycled materials, the designers needed to maintain engineering judgment for the overall mix quality. With properties like aggregate consensus properties remaining the same, coarse aggregate and fine aggregate angularities needed to be maintained with the increase of natural materials along with other aggregate quality requirements for asphalt mixtures. The amount of recycled materials should be considered so the mixture meets not only the volumetric properties, but also the overall mixture quality and requirements.

As shown in Slide 8, the only changes to quality control testing were the different gyrations levels at N_{des}. It took some time for the laboratory technicians to get used to the new gyration levels. Training was provided to show where the new target air void, VMA, and V_{be} requirements were and what was now deemed as acceptable versus failing. Some of the values once considered to be at action limits were no longer the case, so there was some time needed for technicians to get used to the new values during production testing.

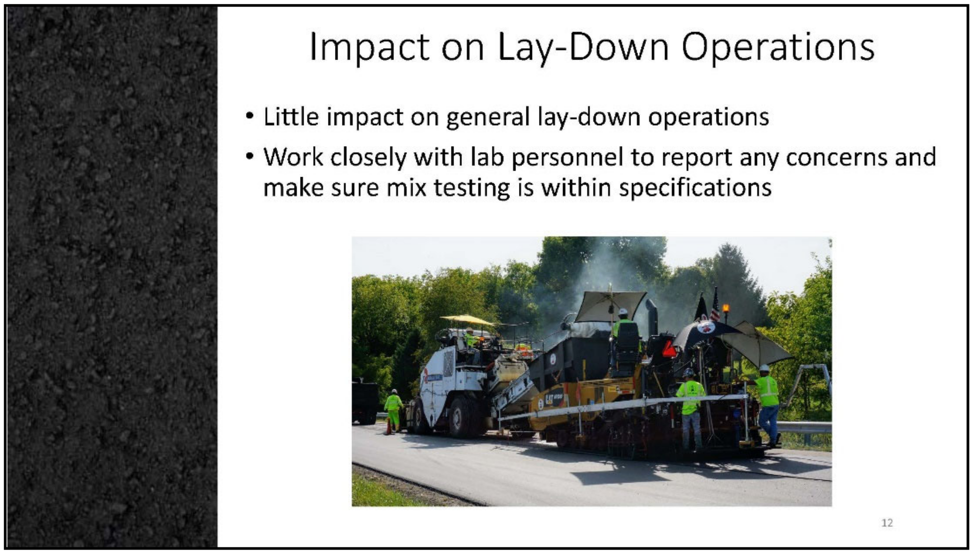


SLIDE 8

As discussed in Slide 9, there was essentially no impact to general plant operations, mix temperatures, trucking, or project planning. Scheduling, planning, trucking, and plant operation best practices should be continued regardless of whether a Superpave4 versus Superpave5 mix is used. Plant calibrations and mixture temperatures should be monitored to ensure a quality mix is produced and delivered to the project site.

As discussed in Slide 10, there were no significant changes in lay-down operations for Superpave5 mixes. The rolling pattern, number or type of rollers used, or the lay-down operations in the field were not impacted a great deal. All best practices for lay-down and compaction should be utilized. By doing so, the field was able to achieve around 95% of the G_{mm}, or 5% in-place air voids. It was also seen how important communication was with the plant and quality control laboratories regarding the asphalt mixtures with any production changes and current test results from cores and mixture samples. This helped maintain consistency during production as they quickly talked about what the field might be seeing placed on the roadway versus what was being tested at the plant in the lab.

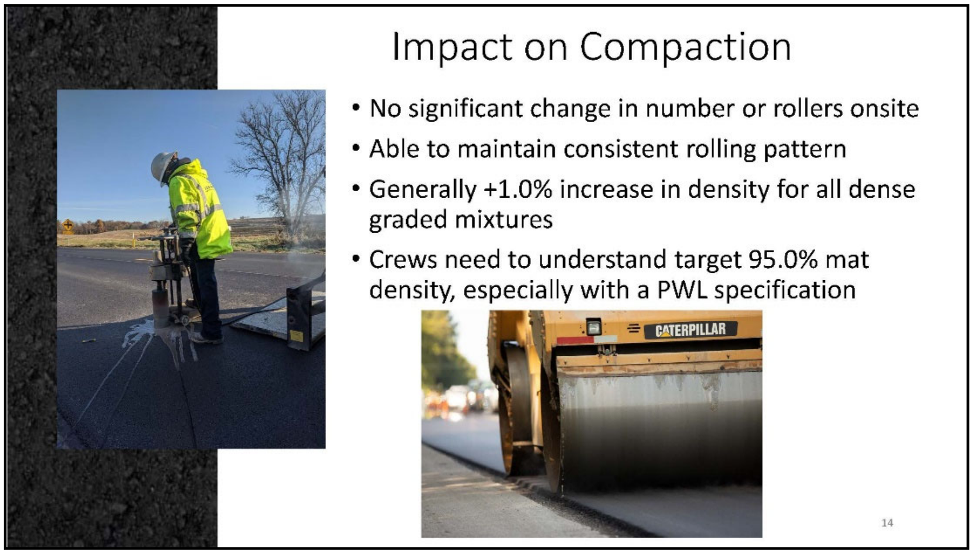
SLIDE 9



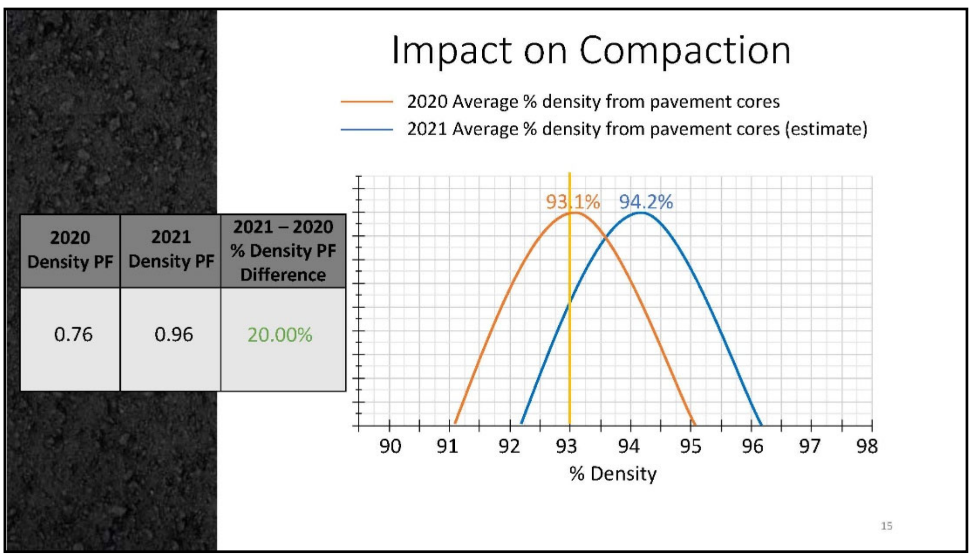
SLIDE 10

As discussed in Slide 11, density in the field was obtained without significant changes to the compactive effort. However, some crews found that, since they were achieving higher density values, around 95-96% of G_{mm}, they believed they could essentially back off the compactive effort to obtain around 93-94% density, where they were used to targeting. Training was needed for density gauge personnel, roller operators, foremen, superintendents, and project managers to explain that they should maintain compactive effort to achieve 95% density values in the field, otherwise your overall pay factor values will be significantly impacted, especially with percent within limits (PWL).

As presented in Slide 12, after a full year of Superpave5 implementation and seeing the density pay factors in some areas, data indicated there was considerable training needed for field personnel on how PWL works and why the compactive effort should target 95% density instead of 93% density. Comparing the first year of Superpave5 to the second and after considerable internal training, one case showed the pay factor for density alone increased by 20%, mainly by changing the target density in the field to 95%.



SLIDE 11

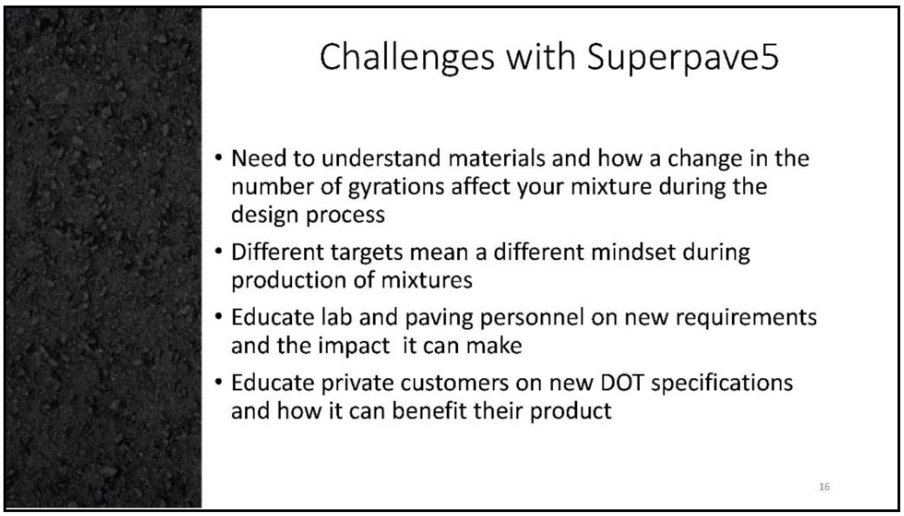


SLIDE 12

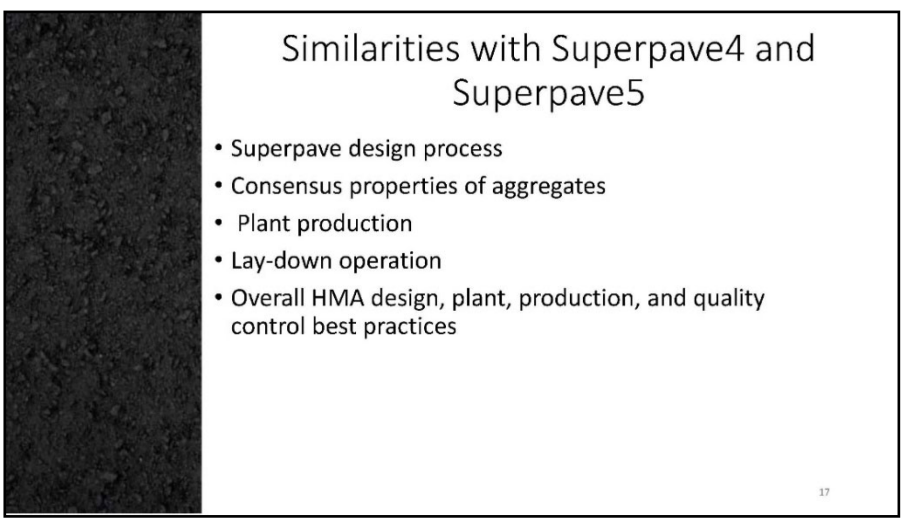
Some of the challenges contractors saw with superpave5 (Slide 13) were the importance of understanding the materials and how the mixtures reacted with the reduced number of gyrations during mix design. One of the largest challenges was getting laboratory and field personnel to understand the different target production values and what the limitations of the new specifications were. There was considerable internal training conducted over a couple of years to educate the personnel. With the data collected, showing the impact of pay factors and the improvement between year one and year two quickly convinced personnel the changes were worthwhile.

There were several municipalities that needed additional information and education on the benefits of Superpave5 and what it could do for the compaction of their roadways. Contractors conducted one-on-one meetings and several presentations to engineers and consultants to explain the advantage of moving to Superpave5 with little to no additional cost.

Some similarities between the Superpave4 and Superpave5 methods are listed in Slide 14. There are several aspects of the design, materials, plant, production, and the types of tests and frequency for quality control that show this design method can be easily implemented.



SLIDE 13



SLIDE 14