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Superpave Gyratory Compaction Guidelines

This digest summarizes the findings from NCHRP Project 9-9, "Refinement of the Superpave Gyratory Compaction Procedure," conducted by the National Center for Asphalt Technology at Auburn University. This digest was prepared by Dr. E. R. Brown and Mr. M. S. Buchanan of the National Center for Asphalt Technology as an Executive Summary of the full report.

INTRODUCTION

This digest summarizes key results of NCHRP Project 9-9, *Refinement of the Superpave Gyratory Compaction Procedure*. Of particular interest, it presents a recommended reduction in the N_{design} table in AASHTO PP28, *Practice for Designing Superpave HMA*, from the original 28 traffic and climate combinations to 4, provides specific N_{design} levels for base mixes, and recommends setting the Superpave short-term aging mix temperature equal to the equi-viscous compaction temperature.

The Superpave gyratory compaction procedure, developed under the Strategic Highway Research Program (SHRP), is the method required for all Superpave mix designs and mixture process control. The gyratory compactor must provide a density in the compacted laboratory specimen that closely approximates the ultimate density of the HMA mixture obtained in the pavement when subjected to traffic loads and climate conditions so that an appropriate optimum asphalt content can be selected during the laboratory mix design process.

There are three controls (vertical pressure, gyratory angle, and gyration rate [rpm]) on the Superpave gyratory compactor that must be set to estimate the ultimate field density. These control parameters were established by SHRP researchers and were not the subject of NCHRP Project 9-9. The number of gyrations (N) also has a significant effect on the laboratory density. SHRP has established, based on a limited set of data, a procedure for determining N_{design} for dense-graded mixtures, which is based on the design high air temperature of the paving location and the traffic level in terms of equivalent single-axle loads (ESALs). The current Superpave mixture design specification allows for 28 possible values of N_{design} (seven levels of ESALs and four levels of average high air temperature).

NOTICE TO READERS

The entire three-volume report for NCHRP Project 9-9 is available on the CD-ROM titled CRP-CD-1: *Bituminous Materials Research Series*, together with the final reports for NCHRP Projects 9-7, "Field Procedures and Equipment to Implement SHRP Asphalt Specifications" (also published as *NCHRP Report 409*, "Quality Control and Acceptance of Superpave-Designed Hot Mix Asphalt") and 9-8, "Designing Stone Matrix Asphalt Mixtures." Copies of the CD-ROM are available, for $10.00, from TRB Publications Sales, PO Box 289, Washington, DC 20055.

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Other factors that will affect the gyratory compactor results include aggregate properties (e.g., gradation, absorption, hardness) and short-term aging of mixtures. Additionally, non-dense-graded asphalt mixtures, such as gap-graded and large stone mixtures, which were not included in the SHRP program, need to be evaluated using the Superpave gyratory compactor to establish the proper compaction levels. Also not evaluated in the initial SHRP research was whether the levels of N_{design} should be reduced for binder and base mixtures.

The overall goal of this document is to provide guidance in specific areas related to the Superpave gyratory compaction of hot mix asphalt. Among the items for which guidance is provided are the following:

- Consolidation of the current N_{design} compaction matrix.
- Superpave mixture design procedures for large stone and gap-graded mixtures.
- The potential for using the mixture's compaction temperature as the short-term aging temperature.
- The appropriate design number of gyrations for mixtures as a function of depth.
- The necessity and appropriateness of the current density requirements at $N_{initial}$ and $N_{maximum}$.

Recommended N_{design} Levels

Currently there are a total of 28 possible N_{design} values specified in AASHTO PP 28 used for the compaction of Superpave mixtures. Some states have recognized that this number of values is excessive and confusing and have therefore reduced the number. Research results from NCHRP Project 9-9 have shown that the current N_{design} compaction matrix can be consolidated from 28 to 4 compaction values and still provide quality mix designs for all traffic categories. These traffic levels include low, medium, high, and very high. A recommended N_{design} table is provided in Table 1. There are four recommended N_{design} levels: 50, 70, 100, and 130 gyrations.

Gyratory Compaction of Large Stone Mixtures

Large stone mixtures (37.5 nominal size) can be compacted and designed in the Superpave gyratory compactor in the same manner as conventional mixtures. Large stone mixtures placed in the top 100 mm of the pavement structure should be designed using the suggested levels of N_{design} for dense-graded mixtures, shown in Table 1.

Gyratory Compaction of Gap-Graded Mixtures

The research data indicates that gap-graded mixtures can be designed without problems in the Superpave gyratory compactor. Many S-shaped, medium-gapped aggregate blends are currently being used in the Superpave system without major problems. The gap-graded mixtures evaluated were stone matrix asphalt mixtures.

It is recommended that the gap-graded mixtures, such as stone matrix asphalt (SMA), be designed using 100 gyrations as shown in Table 1. However, there are some cases where the design level should be decreased to 70 gyrations. The decision of the design gyration level should be based on the experience of the user agency. For higher traffic volume roadways, the designer should consider using 100 gyrations, while 70 gyrations could be used for lower volume roadways. Also, when designing mixtures with aggregates which tend to break down during lab compaction (i.e., Los Angeles Abrasion values greater than 30), the design number of gyrations should be 70.

Compaction Procedures for Base Mixtures

The research results from laboratory-prepared specimens showed that the number of gyrations for mixtures greater than 100 mm from the finished pavement surface may be reduced by approximately 28 percent to account for the reduced vertical pressure and lower temperatures at increased depths within the pavement structure. For mixtures greater than 200 mm from the finished pavement surface, the design number of gyrations may be reduced by a greater percentage.

For mixtures that are placed below 100 mm in the pavement structure, the design number of gyrations may be reduced one level from those shown in Table 1. When placed more than 200 mm into the pavement structure, the design gyrations may be reduced by two levels. However, if it is likely that these mixtures will be open to traffic for any significant period of time (more than 2-3 days) prior to the construction of the overlying mixture, the design number of gyrations for the mixtures should remain at the level used for surface course mixtures.

Short-Term Aging Procedure for Superpave Mix Design

It is recommended that the short-term oven-aging temperature used in the Superpave volumetric mix design process be changed from 135°C to the compaction temperature of the asphalt mixture as determined from the temperature-viscosity relationship of the asphalt binder. Based on the limited study with a low absorption aggregate (less than 2 percent water absorption), the Superpave mixture expert task group's (ETG) recommendation of a 2-hr short-term aging period for mixtures with low absorption aggregates is valid. However, additional research should be performed with aggregates having a range of absorption values to make further recommendations concerning the reduction of the short-term aging time from 4 to 2 hours.

TABLE 1 Recommended consolidation of the N_{design} compaction matrix

Design Traffic Level (million ESALs)[1,2]	Compaction Parameters			Typical Roadway Applications [4]
	$N_{initial}$	N_{design} [3]	$N_{maximum}$	
Less than 0.1	6	50	74	Applications would include roadways with very light traffic volumes such as local roads, county roads, and city streets where truck traffic is prohibited or at a very minimal level. Traffic on these roadways would be considered local in nature and not regional, intrastate, or interstate. Special purpose roadways serving recreational sites or areas would also be applicable to this level.
0.1 to 1	7	70	107	Applications would include many collector roads or access streets. Medium trafficked city streets and the majority of county roadways would be applicable to this level.
1 to 30	8	100	158	Applications would include many two-lane, multilane, and partially divided or completely controlled access roadways. Among these are medium to highly trafficked city streets, many state routes, U.S. highways, and some rural interstates. Use for Stone Matrix Asphalt.[5]
Greater than 30	9	130	212	Applications include much of the U.S. Interstate system, both rural and urban in nature. Special applications such as truck weighing stations or truck climbing lanes on two-lane roadways would also be applicable to this level.

Notes:

(1) Values shown are based on 20-year ESALs. For roadways designed for more or less than 20 years, determine the estimated ESALs for 20 years and choose the appropriate N_{design} level.

(2) When the mixture being designed is to be placed more than 100 mm from the finished surface the N_{design} requirement can be dropped one traffic level. When the mixture is more than 200 mm from the surface the N_{design} requirement can be dropped two traffic levels. However, if the mixture being designed at lower gyrations is exposed to significant traffic prior to being overlaid, significant stability problems may occur.

(3) It is recommended that Superpave mixtures be compacted to N_{design} gyrations.

(4) Typical applications as defined by *A Policy on Geometric Design of Highways and Streets,* AASHTO, 1994.

(5) When the Los Angeles Abrasion value for the aggregate used in Stone Matrix Asphalt exceeds 30 or when designing for less than 1 million ESALs, consider dropping to the next lowest compaction level (70 gyrations).

TABLE 2 Superpave design compactive effort and aggregate consensus property requirements

Estimated Design Traffic Level (million ESALs)[2]	Superpave Compaction Parameters			Percent G_{mm} at $N_{initial}$ Requirement	Aggregate Consensus Properties					
					Coarse Aggregate Angularity		Fine Aggregate Angularity[7]		Clay Content[8]	Flat and Elongated[9]
	$N_{initial}$	N_{design}[1]	$N_{maximum}$		≤ 100 mm	> 100 mm	≤ 100 mm	> 100 mm	All Mixtures	All Mixtures
< 0.1	6	50	74	< 91.5	55/-	-/-	-	-	40	
0.1 to < 1.0	7	70	107	< 90.5	65/-	-/-	40	-	40	
					75/- [3]	50/-	40	40	45	
					85/80 [4,6]	60/-	45	40	45	
1.0 to < 30.0	8	100[10]	158	< 89.0	95/90[5]	80/75	45	40	45	
≥30.0	9	130	212	< 89.0	100/100	100/100	45	45	50	< 10 percent

Notes:

(1) It is recommended that Superpave mixtures be compacted to N_{design} gyrations.

(2) Values shown are based on 20-year ESALs. For roadways designed for more or less than 20 years, determine the estimated ESALs for 20 years and choose the appropriate N_{design} level.

(3) Requirements apply to traffic levels from 1 to < 3 million ESALs.

(4) Requirements apply to traffic levels from 3 to < 10 million ESALs.

(5) Requirements apply to traffic levels from 10 to < 30 million ESALs.

(6) "85/80" denotes that 85 percent of the coarse aggregate has one fractured face and 80 percent has two or more fractured faces.

(7) Criteria are minimum presented as percent air voids in loosely compacted fine aggregate. Test to be run in accordance with AASHTO TP-33.

(8) No distinction is made between depth from surface. Test to be run in accordance with AASHTO T176.

(9) Criterion based on a 5:1 maximum to minimum ratio.

(10) Use for Stone Matrix Asphalt. However, when the Los Angeles Abrasion value for the aggregate used in SMA exceeds 30, consider dropping to the next lowest compaction level (70 gyrations).

Requirements for $N_{initial}$ and $N_{maximum}$

It appears that the requirement of percent G_{mm} at $N_{initial}$ of 89 percent for lower traffic volume roadways is too stringent. Fine-graded mixtures in the study which were comprised of crushed fine aggregate materials failed this requirement, especially at the lower N_{design} values. This requirement should be raised for the lower volume roadways, as shown in Table 2, to allow for more fine-graded mixtures to be used.

Generally, mixtures that were more likely to fail the density requirements at $N_{maximum}$ were the coarse-graded mixtures, not the fine-graded mixtures. Mixtures designed to have 4 percent air voids at N_{design} do not fail the $N_{maximum}$ density requirement. All the mixtures evaluated passed the $N_{maximum}$ requirement. The mixtures that came the closest to failing the requirement are considered to be the better mixtures.

Currently, the gyratory compaction procedure requires that specimens be compacted to $N_{maximum}$ and densities and volumetric properties be back-calculated at N_{design}. This causes an error in the calculated volumetric properties at N_{design}. Because the mixture is designed based on its volumetric properties at N_{design}, Superpave volumetric mix designs should be completed by compacting specimens to their respective N_{design} values, and not $N_{maximum}$ as currently exists. Once the optimum asphalt content of the mixture has been determined, triplicate specimens should be prepared at the optimum asphalt content and compacted to the respective $N_{maximum}$. The average specimen density should then be calculated and compared against the density requirement at $N_{maximum}$ of less than 98 percent of G_{mm}.

Adjustment of $N_{initial}$ and $N_{maximum}$ Values During Field Process Control

During quality control or quality assurance testing of a mixture's volumetric and densification properties, the specification values of density at $N_{initial}$ should be raised or lowered to account for the change in the mixture's air voids at N_{design}. The amount that the specification values are changed should be equal to the difference in the measured and design percent G_{mm} at N_{design}. For example, if the measured air voids in the field is 4.5 percent, then the requirements for $N_{initial}$ and $N_{maximum}$ should be decreased by 0.5 percent.

Interpretation of the Gyratory Compaction Slope

Based on the test results, the gyratory compaction slope does not appear to be a good indicator of the strength of the aggregate structure of the asphalt mixture. Mixtures designed at lower levels of N_{design} have higher compaction slopes than mixtures designed at higher N_{design} levels. However, the slope does recognize changes that occur in the mixture's asphalt content within a given N_{design} level, with gradation being constant. Therefore, the slope could possibly be used in the quality control or quality assurance testing of an asphalt mixture.

Aggregate Consensus Property Requirements for Revised N_{design} Levels

Although not specifically an objective of the research project, some adjusting of the aggregate consensus property requirements was necessary to match the revised N_{design} levels and to make for a standard or uniform table. Consensus property requirements are shown in Table 2. By observing Table 2, it is evident that the specification values used in the past remain approximately constant. It was not an objective of the research project to determine if these values are correct in their current form. Each N_{design} level specified has one set of consensus property requirements, with the exception of the N_{design} level of 100 gyrations. Because the range of ESALs at this N_{design} level was wide (1 to 30 million ESALs), aggregate property requirements were specified for three levels of ESALs: 1 to 3 million, 3 to 10 million, and 10 to 30 million ESALs.