TechBrief

The Asphalt Pavement Technology Program is an integrated, national effort to improve the long-term performance and cost effectiveness of asphalt pavements. Managed by the Federal Highway Administration through partnerships with State highway agencies, Industry and academia the program's primary goals are to reduce congestion, improve safety, and foster technology innovation. The program was established to develop and implement guidelines, methods, procedures and other tools for use in asphalt pavement materials selection, mixture design, testing, construction and quality control.

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SUPERPAVE MIX DESIGN AND GYRATORY COMPACTION LEVELS

This Technical Brief provides an overview of the intent of the Superpave volumetric mix design and a suggested process to evaluate effects of changes to the gyration levels.

Issues with N_{design}

Superpave mix design was first introduced in 1993 with the completion of the Strategic Highway Research Program (SHRP). This new design system was not an evolution in mix design but a revolution. The Superpave (Superior Performing Asphalt Pavements) system introduced a new compactor, the Superpave Gyratory compactor (Figure 1) for densifying mixes in the lab. In addition the new design system introduced aggregate and binder requirements and mixture compactive effort tied to traffic.

Currently the Superpave mixture design system is the predominately used system in the US. Since its introduction many miles of roadway, using the Superpave system have been placed across the country. There has been some concern by various highway agencies that the Superpave mixture design system produces asphalt mixes that are too dry (too low asphalt binder content) and may have resulted in durability issues. A National Cooperative Highway Research Program (NCHRP) project 9-9(1), Report 573 "Verification of Gyration Levels in the N_{design} Table," recommended a reduction in gyratory compaction levels based on studies of densification in the field. Though this study was quite extensive, the relationship in the study between gyratory compaction levels and densification in the field was not strong, as shown in Figure 2. Based on some general trends and statistical correlations the study produced a table that reduced the gyratory levels and recommended their use. The Federal Highway Administration's (FHWA) Asphalt Mixture & Construction Expert Task Group (Mix ETG) concluded after extensive evaluations that no general recommendation could be established for reductions of the gyratory levels. The ETG believed that the data has too wide a variability for a blanket national acceptance of the proposed N_{design} tables.

Figure 1: Examples of Superpave Gyratory Compactors (SGC).

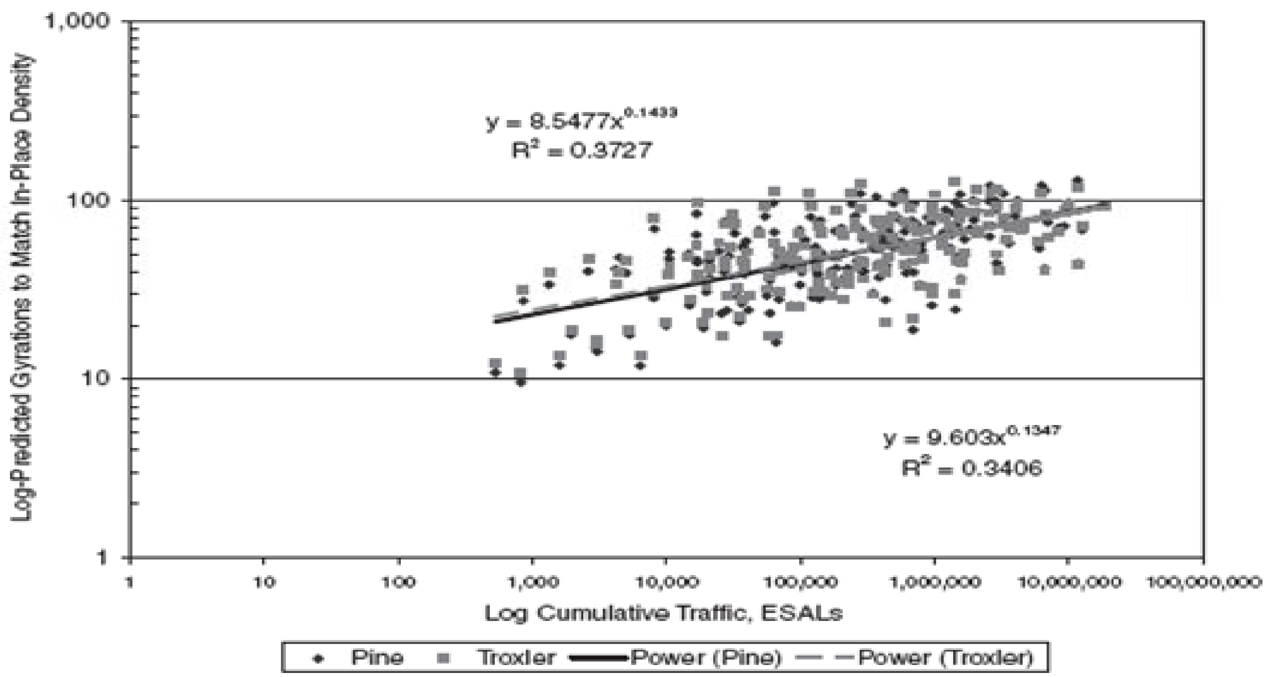

Figure 2: Plot from NCHRP 9-9(1) study, Report No. 573 showing predicted gyrations to match in-place density for all post construction sampling periods.

To address the issue of gyratory compaction levels, the FHWA Mix ETG recommends agencies perform an independent evaluation prior to making any adjustments in compaction levels from the AASHTO R 35 standards. The evaluation would evaluate the effect of the proposed changes in gyration level to performance for typical aggregates, binder, and mix designs. This technical brief provides suggestions on conducting the evaluations.

Background of Superpave Mix Design

The Superpave mix design maintained the basic volumetric properties used in the Marshall design system with a new compactor and more defined aggregate requirements based on traffic loading. These aggregate properties include AASHTO T 304, Uncompacted Void Content of Fine Aggregate; ASTM D 5821, Determining the Percentage of Fractured Particles in Coarse Aggregate; ASTM D 4791, Flat Particles, Elongated Particles, or Flat and Elongated Particles in Coarse Aggregate; and AASHTO T 176, Plastic Fines in Graded Aggregates and Soils by Use of the Sand Equivalent Test. The aggregate requirements are based on traffic levels, independent of gyratory compaction levels.

The Superpave mix design system evaluates the volumetric properties of the compacted samples. These properties include air voids (Va), voids in mineral aggregate (VMA) and voids filled with asphalt binder (VFA), and dust to binder ratio. The volumetric requirements for design are as follows: the criteria for Va is fixed (4 percent at N_{design}); the criteria for VMA is a function of nominal maximum aggregate size (NMAS); the criteria for VFA is a function of traffic level; and the criteria for dust to binder ratio is a function of NMAS. The volumetric properties of Va, VMA, and VFA together define the void structure and void requirements for an asphalt mix.

The mix design begins with the selection of an aggregate gradation by combining various aggregates stockpiles to meet the requirements that need to be achieved. The aggregates are then combined with asphalt binder and compacted in the gyratory compactor to the specified gyratory compaction effort, where the volumetric properties are then evaluated. The intent of the process is to evaluate how mix will consolidate to assure there is sufficient space for binder to provide long-term durability and sufficient aggregate structure to resist densification and plastic deformation by traffic in the field.

Gyratory Compaction Level and Binder Content

There is a misconception that the gyratory compaction level controls the voids and asphalt binder content of the mix. In truth, it is the gradation and aggregate properties and their resistance to compaction that controls the air voids and resulting binder content. In laboratory compaction, if the gradation is held constant changing the gyratory level will change the air voids and binder content, however, in actual practice the gradations are not held constant. Asphalt binder is the most expensive material in the mix. In the case of contractor mix designs, the contractor has to design the mix to provide the minimum binder content to be competitive in bidding. Typically contractors adjust the aggregate gradation within the required limits to provide a cost effective mixture utilizing lowest binder content.

The gyratory compaction level actually controls the aggregate interaction so a mix can be produced that will have at least the minimum specified void structure at the specified number of gyrations. If an agency elects to reduce the gyratory compaction level for a given traffic level, then a situation is created for a greater range of aggregate types and gradations to meet the minimum specified void levels resulting in lower mixture stiffness and increased susceptibility to plastic deformation.

It is the VMA requirements that actually control the binder content. The VMA controls the overall voids in the mixture and the air voids (Va) controls how much of the VMA is left over for the asphalt binder and free air. For example, a minimum 14% VMA and 4% air voids leaves 10% available for the binder by volume. Changing the gyration levels does not change the volumetric requirements. The new design will still be made to minimize VMA and therefore minimize binder volume by adjusting the gradation. Reducing the gyration compaction level allows weaker aggregate structures to be used meet the VMA and air void requirements.

If it is an agency's goal to increase the asphalt binder content in a mix, either the minimum VMA requirement should be increased or the air void requirement reduced. Otherwise gradations will eventually be adjusted again back to the original minimum VMA. Increasing the minimum VMA requirement or lowering the design air void content along with reduced gyratory compaction levels is not necessarilya bad approach, but it should not be done arbitrarily.

FHWA recommends the volumetric design requirements of AASHTO R 35, e.g., 4.0% for air voids and increasing the minimum VMA limits by 0.5 percent for each gyratory level to increase the binder content assuming the aggregate structure is sufficient for the traffic conditions.

Aggregate Material Properties Relation to Performance

Aggregate properties and gradations are the primary factors that affect VMA and air void properties of compacted gyratory specimens. Aggregate properties vary significantly across the US from extremely hard basalts to very soft limestones. Many aggregates can be used for the production of quality, long-lasting, asphalt mixes provided they do not degrade under environmental conditions, such as shale's and chert that are susceptible to significant degradation during the production and placement process. There are also other important issues such as polishing associated with friction and safety, which are not covered herein that needs to be considered in the mix design process.

The Superpave aggregate requirements were developed to minimize performance concerns such as rutting and fatigue. However, they are not intended to be definitive in assuring performance, but only to improve the probability of good performance. Mixture performance testing has always been considered the goal and final control on mix specifications.

Adjusting the Gyratory N_{design} Table

Before changes are made to the gyratory compaction levels in AASHTO R 35, a full evaluation should be made of existing mixes being used over the range of compaction levels in use. The existing AASHTO specification has five traffic levels with four gyratory design levels shown in Table 1. Comparisons should be made between mixes produced using the existing AASHTO specifications and any proposed gyration levels. Comparisons of binder content and VMA can be made of mixes produced at the different levels to determine if there is any real difference. These comparisons should be made between similar type mixes such as coarse mix compared to coarse and fine mixes compared to fine. This is because fine mixes have a larger surface area and will typically have higher binder contents than coarse mixes. Also, care must be followed to determine to what extent the aggregate properties actually do change from one gyratory level to another. Though the minimum aggregate requirements change from one gyration level to another in many locations due to availability and local conditions there may actually be only minor difference.

Table 1. AASHTO R 35Superpave Gyratory Compaction Effort

20-Year Design Traffic, ESALs (millions)	N_{design} (Number of Design Gyrations)
< 0.3	50
0.3 to < 3	75
3 to < 10	100
10 to < 30	100
$\geq$ 30	125

Figure 3 shows a plot of the gyratory compaction curves of two different 100 gyration mixes. The compatibility of these two mixes is quite different even though they both meet 4% air voids at 100 gyrations. One mix is much more sensitive to the gyration level than the other. In one case changing the gyration level will have much less effect on changes in binder content and VMA.

Comparisons Should Be Made Using Performance Testing

FHWA's primary concern with reducing gyratory compaction levels to increase binder content is the potential for increased rutting on the roadways. The perceived benefits of reducing the gyratory compaction levels just to increase the binder contents are not a valid assumption on its own. Rutting evaluations can be completed using any of several performance tests currently available. These include the Fn (Flow Number test) and E* (Dynamic Modulus test) performed on the Asphalt Mix Performance Tester (AMPT); the Hamburg Wheel Tracking Test;

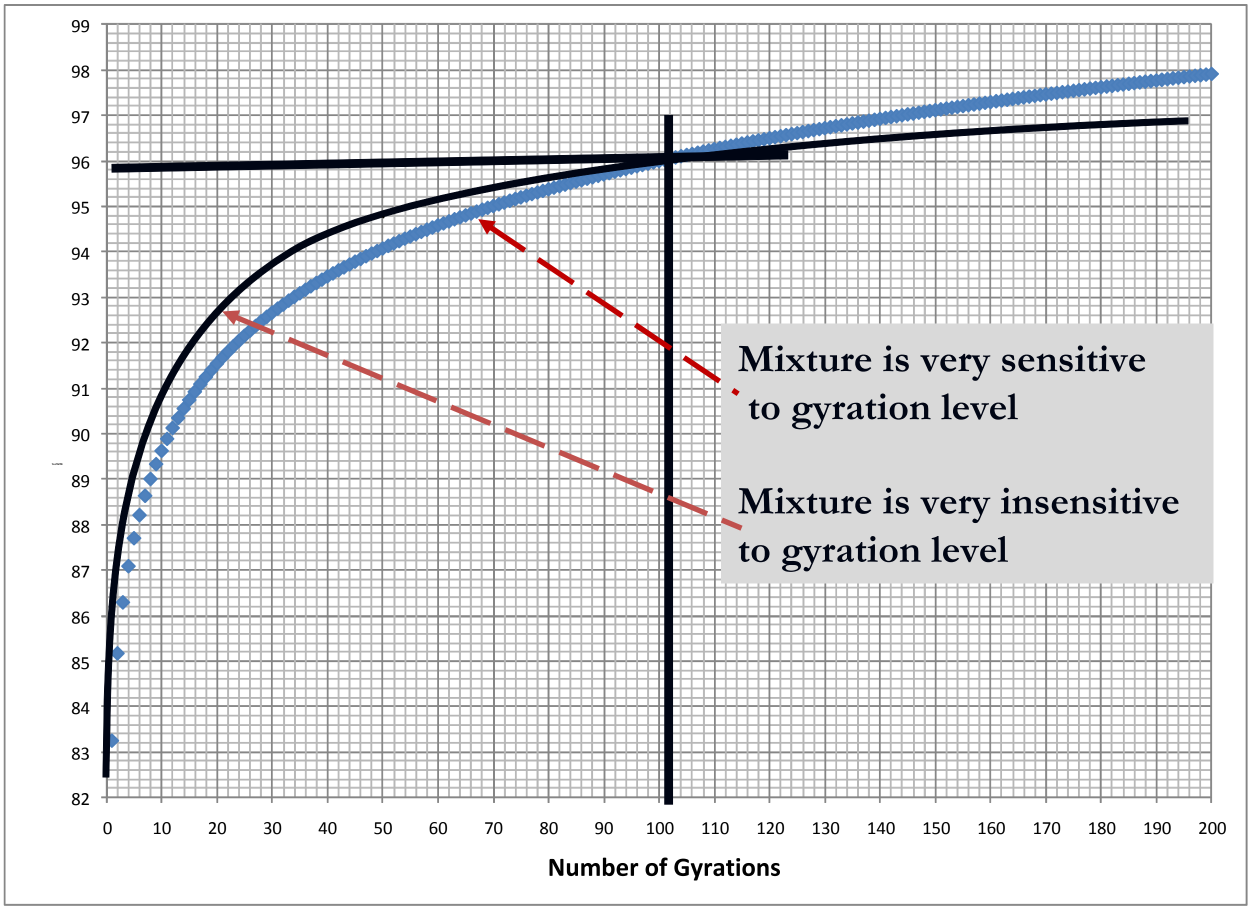

Figure 3: Plot of gyratory curves showing differences in compatibility of mixes to gyration levels.

the French Wheel Tracking Test, or the Asphalt Pavement Analyzer. Mixes from each of the different existing gyration levels with known field performance should be tested in two or more of these testers. The test results from the different gyration level mixes can then be compared to determine the typical variation in rut resistance between the mixes. This will result in the first indication if changing gyratory compaction levels will be a problem. If there is a large difference in the rut resistance of mixes at adjacent gyratory levels further possible changes could cause major problems in the mixture. If changing from one gyration level to another does not cause large changes in rutting response adjustments the gradation bands can be considered to be verified, and the mixes can be further investigated.

As a final step in the evaluation of changes to the gyratory compaction level, new mix designs should be developed with new gradations based on achieving the minimum VMA requirements. This is because in the field this is what will eventually occur. Again performance testing of the mixes is an important step to determine if there is any significant change in potential performance from the currently used mixes. If gyratory compaction level adjustments are subsequently made, a follow-up review of actual field performance and trends should be conducted.

Mixture Evaluation

A database of existing mixes based on gyration level, nominal maximum aggregate size, aggregate type and course or fine gradation should be developed. Mixes with known performance should be used. Direct comparisons can be made within and between mixes from the database to determine if there are real differences between gyratory levels. Comparisons between binder contents gradations and performance characteristics can then be made between mixes. To demonstrate this two different mixes are compared below.

The example compares two fine graded mixes designed at different gyration levels. The E1 mix is a 1 million ESAL mix designed at 60 gyrations. The E10 is a 10 million ESAL mix designed at 100 Gyrations. Both mixes were designed to meet all required materials and volumetric properties for their respective gyration levels. Both mixes met the minimum VMA requirements. The gradations, binder contents and gyration levels are given in table 2. The only real difference between the gradations is that the E1 mix uses more natural sand which is allowed for the lower gyration mix.

Table 2: Gradations for fine mixes designed for two different gyration levels.

Sieve Size, mm	E-1 Fine Mix	E-10 Fine Mix
19 mm	100	100
12.5 mm	92	94.2
9.5 mm	82	85.9
4.75 mm	62.3	66.6
2.36 mm	45.4	46.6
1.18 mm	36	33.9
0.60 mm	25.5	23.7
1.30 mm	16.6	16.6
1.15 mm	9.2	8.7
1.075 mm	5.1	4.1
Design Gyrations	60	100
Optimum percent Binder	5.30%	5.80%

Both mixes have very similar gradations except that the E1 mix has more natural sand which was made possible by the reduced gyrations levels. The increased natural sand and the slightly higher dust content allowed the E1 mix to meet VMA and air void requirements with lower binder content of 5.30% compared to the 5.80% for the E10 mix. Performance properties of the mixes should then be compared.

The Hamburg rut tester was used to compact both mixes at several different temperatures to determine the extent of difference in rutting potential between the mixes. The plot of the rut data is shown in Figure 4. In this case the E10 mix designed at 100 gyrations only exhibits approximately 3 mm of rutting at 64 ^{o}C. The E1 mix designed at 60 gyrations exhibits approximately 7 to 8 mm of rutting at 64 ^{o}C. In this case there is a substantial difference in rutting between the mixes. Reducing gyration levels could increase the rutting potential of the E10 mix. In this case the E10 mix also had the higher binder content which typically would have a higher fatigue life. Again lowering the gyration levels may produce mixes with lower binder content not higher due to the increased amount of fines that could be put in the mix at lower gyration levels.

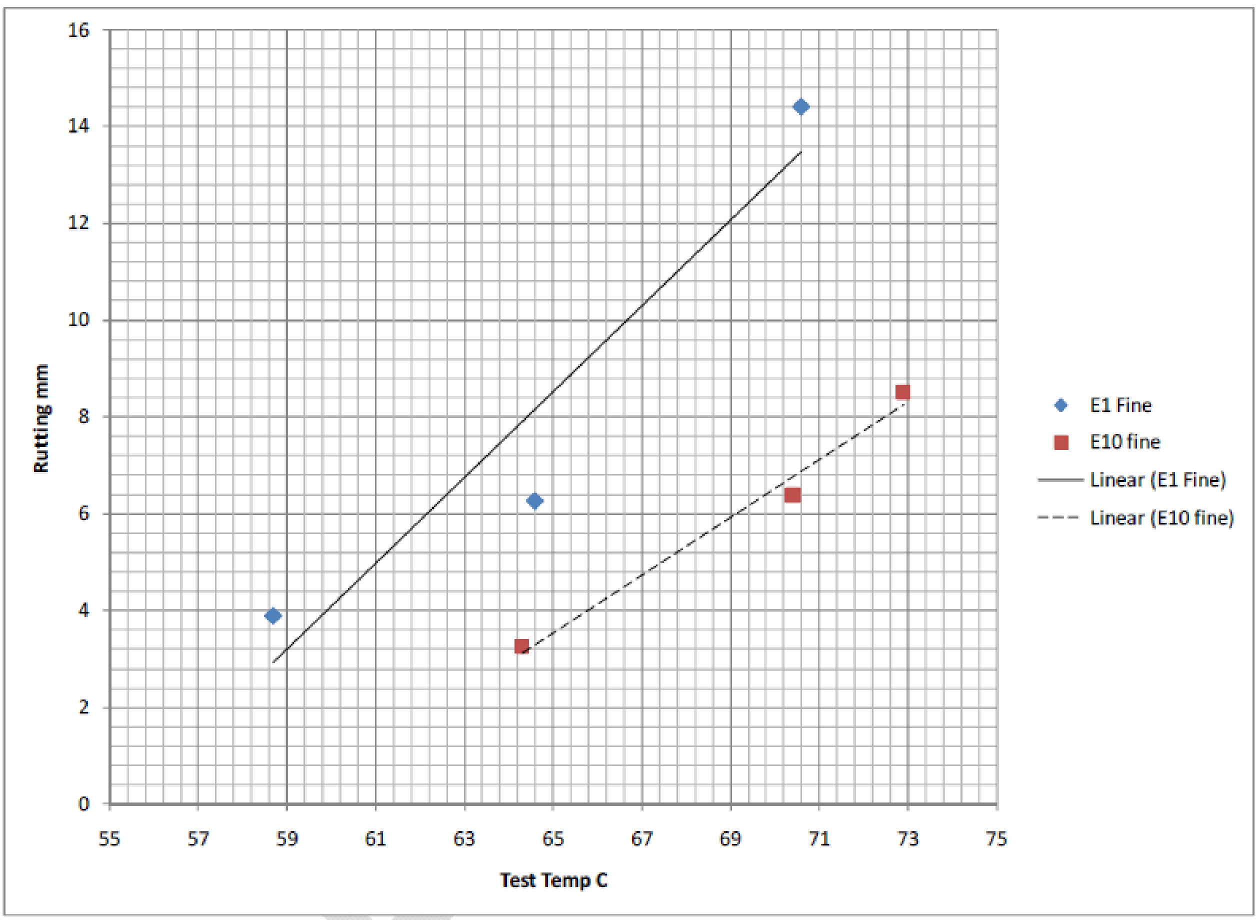

Figure 4: Plot of Hamburg rutting data for an E1 and E10 fine gradation mixes tested at different temperatures.

The continuation of the evaluation would be to evaluate both mixes for fatigue and low temperature cracking to determine the extent of any differences in these areas. If the initial evaluation had shown the mixes to be much more similar in performance then the further evaluation of actually doing the mix design at the lower gyration level and reevaluating the performance characteristics would be warranted. In this case for these aggregates and fine gradations would not be advisable to consider lowering the gyration levels.

Conclusion

Superpave asphalt mix design has been used in the US since 1993. Overall the general results from the new mixtures have been better performing, longer-lasting pavements. The Superpave system has evolved since its introduction with refined test procedures and material specifications. Each of these adjustments has been carefully evaluated before recommendations for change were made. The AASHTO Superpave gyratory compaction levels have proven to provide good-performing, constructible pavements in most cases. It is acknowledged that there are cases where the current requirements may be excessive and produce mixes that are hard to construct resulting in a less durable pavement.

FHWA recommends that before changes are made to the agency specifications careful evaluation should be conducted to understand the full extent and implications to the changes. The miss-understanding related to the relationship between gradation and aggregate properties to N_{design} and its affect on air voids and binder contents needs to be addressed and evaluated before arbitrarily changing the mix design requirements.

This Technical Brief provides an overview of the intent of the Superpave volumetric mix design and provided information on the process to follow to evaluate the potential effects of changes to the gyration level or volumetric requirements. The goal is to produce superior performing asphalt pavements at the lowest cost possible.

Further Information:

NCHRP Report 573: *Superpave Mix Design: Verifying Gyration Levels in the* N_{design} *Table*

NCHRP Report 97: Appendixes to NCHRP Report 573: Superpave Mix Design: Verifying Gyration Levels in the N_{design} *Table*

NCHRP Report 614: *Refining the Simple Performance Tester for Use in Routine Practice*

NCHRP Project 09-33: *A Mix Design Manual for Hot Mix Asphalt (Completed June 2010)*

Asphalt Institute Publication SP-2: *Superpave Level 1 Mix Design*

AASHTO M 323: Standard Specification for Superpave Volumetric Mix Design

AASHTO R 35: Superpave Volumetric Design for Hot-Mix Asphalt (HMA)

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