EVALUATION OF RUTTING RESISTANCE OF SUPERPAVE AND HVEEM MIXTURES VOLUME II - IMPACT OF AGGREGATE GRADATIONS

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EVALUATION OF RUTTING RESISTANCE OF SUPERPAVE AND HVEEM MIXTURES

VOLUME II

IMPACT OF AGGREGATE GRADATIONS

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INTRODUCTION

This report represents the second in a series of four reports documenting the overall evaluation of rutting resistance of Superpave and Hveem mixtures. Specifically this report documents the evaluation of the impact of aggregate gradation on the permanent deformation resistance of HMA mixtures using the RSCH test. This experiment was developed using materials from NDOT contracts 2751 and 2827, which were originally constructed in the falls of 1996 and 1997, respectively and are fully described in Volume I of the reports series (1). Both contracts included test sections using a Hveem and a Superpave designed mixture to compare their performance under similar traffic and environmental loading conditions.

Contract 2751 was constructed in 1996 on SR 278 in Eureka County, Nevada. Contract 2827 was constructed in 1997 on US 93 in White Pine County (see Volume I report for full descriptions).

The experiment used the gradations of the field projects (Hveem and Superpave) and two other aggregate gradations, which fell between the existing Hveem and Superpave mixtures. One gradation was designed to meet both the Superpave 19 mm nominal maximum size and NDOT Type II gradation specifications while passing over the restricted zone. The second gradation was designed to meet the Superpave 19 mm nominal maximum size control points while at the same time pass through the restricted zone and satisfy NDOT Type II gradation specifications.

Therefore, for each contract four different gradations were fabricated using a single aggregate source and mixed with a single asphalt binder. Using the developed gradations, complete Superpave volumetric mix designs were performed to determine each mixture's optimum asphalt content.

The mixtures resistance to permanent deformation was determined using the Superpave

Shear Tester Repeated Shear at constant height test (RSCH). Further information associated with the RSCH test procedure are presented in Volume I report (1).

In summary, the experiment used percent plastic strain after 5000 load cycles as the response variable and had a single qualitative factor (mix type) with four levels. Each mixture type had 3 replications to ensure that mean comparisons could be performed. Table 1 outlines the test matrices for the aggregate gradation study documented in this report.

MATERIALS AND MIX DESIGNS

The following sections detail materials and mix design results obtained during the gradation study experiment for NDOT contracts 2751 and 2827. It is critical to note that field marinated aggregates were used to fabricate all specimens in both contracts. That is, all aggregates were sampled from lime treated stockpiles. Although not an ideal situation, due to the fact that the projects were sampled after marination had taken place, no other option existed but to continue with the assumption that all aggregate were uniformly marinated.

Gradation Development for Contract 2751

A single aggregate source was used to fabricate all blends. The aggregate source is located in Eureka County and consists of coarse aggregate, crusher fine, and natural sand stockpiles. Along with these stockpiles, 2.5% hydrated lime was used in all gradations as per NDOT marination specifications (1).

As outlined in the experimental design, both Hveem and Superpave gradations had already been established in 1996 as part of an NDOT field project (Volume I report). The Hveem gradation was designed by the NDOT Materials Division as a NDOT Type II gradation and did not satisfy the Superpave 19 mm nominal maximum size gradation specifications. It is important to note that the NDOT test procedure does not consider lime when calculating the combined gradation of the mixture. This step was adjusted in order to maintain true replication of the mixtures. The Hveem gradation was adjusted to include the 2.5% lime that was present in the mixture. The inclusion of lime to the combined gradation caused the material passing the No. 200 sieve to rise from 6.8% as determined using the NDOT procedure to 8.6%. A comparison of the Hveem gradation before and after the adjustment to include lime is shown in Table 2.

The Superpave "coarse" mixture was originally designed in 1996 by the University of Nevada Pavements/Materials Program (Volume I report). This mixture satisfied all the Superpave 19mm nominal maximum size gradation requirements except that the lower control point on the 2.36 mm (No. 8) sieve was slightly violated. One must recall that the goal of the test section was to compare the difference in performance between a typical NDOT Hveem mixture to that of a "coarse" Superpave mixture. Using the supplied aggregate stockpiles, the slight violation of this control point could not be avoided by designers when developing the Superpave "coarse" gradation.

The third gradation was developed to satisfy both NDOT Hveem Type II and Superpave 19mm nominal maximum size gradation requirements while passing over the restricted zone. This blend was referred to as the Superpave "over the restricted zone" gradation.

The fourth gradation was designed to pass through the restricted, which violates Superpave gradation requirements. This blend was referred to as the "through the restricted zone" gradation. Table 3 presents a summary of all four gradations. Figure1 graphically presents all four gradations on the Superpave 19mm 0.45 power chart.

Table 4 presents a summary of Superpave aggregate tests performed at the time of the original construction of the project.

Gradation Development for Contract 2827

A single aggregate source was used to fabricate all blends. The source is located in White Pine County and consisted of coarse aggregate, 3/8" chips, and crusher fine stockpiles. Along with these stockpiles, 1.5% hydrated lime was used in all gradations as per NDOT marination specifications and as previously stated was present on the aggregates at the time of sampling.

As outlined in the experimental design, both Hveem and Superpave gradations were previously established in 1997 as part of a NDOT test section (Volume I report). The Hveem blend was designed by the NDOT Materials Division as a NDOT Type II gradation and did not satisfy the Superpave 19mm nominal maximum size gradation specifications.

Again as in contract 2751, it is important to note that the NDOT test procedure does not include lime when calculating the combined gradation of the mixture. This procedure was again modified as was the case in the 2751 contract. The inclusion of lime in the combined gradation caused the material passing the No. 200 sieve to rise from 5.9% as determined using the NDOT procedure, to 7.0% with the adjusted method. A comparison of the Hveem gradation before and after the adjustment to include lime is shown in Table 5.

The Superpave "coarse" mixture was designed by a local consultant and submitted to NDOT by the project contractor for acceptance prior to the beginning of the test section construction in 1997. A verification of this mixture was performed by the NDOT Materials Division at which time discrepancies were observed between the NDOT developed optimum asphalt binder content and that of the original mix design. Due to these discrepancies in optimum asphalt contents, it was concluded that for the gradation study, both solvent extraction and muffle furnace tests performed by NDOT during the construction of the actual test section in 1997 would be utilized to determine the gradation to be used in this study. A total of 3 solvent extractions and 12 muffle furnace quality control tests were performed during the projects construction. The lab mixed lab compacted (LMLC) gradation was taken as the average of these 15 tests as shown in Table 6. This average gradation did satisfy all the Superpave 19 mm nominal maximum size gradation requirements.

The third gradation was developed to satisfy both NDOT Type II and Superpave 19 mm nominal maximum size gradation requirements while passing over the restricted zone. This blend was referred to as the Superpave "over the restricted zone" gradation.

The fourth gradation was designed to pass through the restricted zone, which violates

Superpave gradation requirements. This blend was referred to as the "through the restricted zone" gradation. Table 7 presents a summary of all four gradations. Figure 2 graphically presents all four gradations on the Superpave 19 mm 0.45-power chart. Table 8 presents a summary of Superpave aggregate tests performed at the time of the original construction of the project.

Asphalt Binder Selection

For both contracts, the Superpave performance grade binder tests were used to perform verification tests on each asphalt binder. All testing was performed in accordance with current AASHTO specifications at the time of construction of each project, which may have been modified since the time of original testing.

A PG 64-28 asphalt binder was selected for the 2751 project using the Superpave performance binder grade specifications along with historical climatic data in the area where the project was constructed. A verification grading of the binder is shown in Table 9.

A PG 64-34 asphalt binder was selected for the 2827 project using the Superpave performance binder grade specifications along with historical climatic data in the area where the project was constructed. A verification grading of the binder is shown in Table10.

Mix Designs for Contract 2751

Utilizing the developed gradations, complete Superpave volumetric mix designs were performed on each blend. The traffic volume was estimated to be between 0.3 and 1 million ESALs and an average design high air temperature was determined to be less than 39°C. Using these parameters in AASHTO TP4-93, the following was obtained regarding the number of gyrations required for the compaction and volumetric analysis process (2):

- $N_{initial}$ - 7
- N_{design} - 76
- $N_{maximum}$ - 117

It should be noted that for the Superpave "coarse" mixture, the design developed during construction (Volume I report) was utilized and thus a new or repeat analysis was not performed. For this mixture, the optimum asphalt binder content occurred at 6.3% by total weight of mix at which all Superpave volumetric requirements were satisfied. A summary of the volumetric properties of the Superpave "coarse" mixture is presented in Table 11 at the lab optimum asphalt content of 6.3% and at the field asphalt content of 5.4%. The reason for showing the field asphalt content will be discussed later.

From the original Hveem mix design performed by NDOT in 1996, the laboratory optimum asphalt binder content was estimated as 5.7% by total weight of mix (6.0 by dry weight of aggregate). It should be noted that the Hveem mix design estimated optimum asphalt binder content was used to fabricate test specimens for permanent deformation testing. The main purpose of conducting the Superpave volumetric analysis on the Hveem designed mixture was to compare the volumetric properties of the Hveem mixtures as they are compacted with the kneading and Superpave gyratory compactors. Using the Hveem optimum as a reference point, samples were mixed and compacted in the Superpave gyratory compactor at asphalt binder contents of 4.8%, 5.2%, 5.7%, 6.1%, and 6.5% by total weight of mixture. Upon visual inspection, it was immediately evident that in the Superpave gyratory compactor, the Hveem mixture was over asphalted at asphalt binder contents above 5.6% by total weight of mix. All specimens above this value exhibited a large amount of bleeding and appeared over compacted. This visual observation was confirmed by the results of the volumetric analysis, which indicated that at an asphalt binder content of 5.7%, there were only 2.2% air-voids left in the mixture. The Superpave mixture design specification identifies the optimum asphalt binder as the one corresponding to 4% air-voids. The optimum asphalt binder content was estimated at 4.9% by total weight of mix. This asphalt binder content was 0.8% lower than that obtained from the Hveem mix design. A comparison of volumetric properties at asphalt binder contents of 4.9% and 5.7% using the Superpave volumetric calculations at N_{design} are shown in Table 12.

The third or Superpave "over the restricted zone" gradation was mixed and compacted using the Superpave gyratory compactor at asphalt binder contents of 4.3%, 4.8%, 5.3%, 5.8%, and 6.3% by total weight of mixture. A summary of all Superpave volumetric mix design properties is shown in Table 13. The optimum asphalt content of this mixture occurred at 5.0% by total weight of mix at which all Superpave volumetric requirements were satisfied.

The fourth or "through the restricted zone" gradation was mixed and compacted using the Superpave gyratory compactor at asphalt binder contents of 4.1%, 4.6%, 5.1%, 5.6%, and 6.1% by total weight of mixture. A summary of all Superpave volumetric mix design properties is shown in Table 14. The optimum asphalt content of this mixture occurred at 4.8% by total weight of mix. At this asphalt binder content, all Superpave volumetric requirements were satisfied except for the VMA which was 12.7%, falling below the minimum required value of 13%. It was assumed that because the gradation passed though the restricted zone and followed the maximum density line, meeting the VMA requirement was going to be difficult. Furthermore, the precision of the VMA calculation itself may not be able to measure a difference of 0.3% accurately, thus it was concluded that the mixture would be accepted for the permanent deformation phase of the study.

Mix Designs for Contract 2827

Utilizing the developed gradations, complete Superpave volumetric mix design was performed on each gradation. For this project, the traffic volume was estimated to be between 1 and 3 million ESALs and an average design high air temperature was determined to be less than 39°C. Using these parameters in AASHTO TP4-93, the following was obtained regarding the number of gyrations required for the compaction and volumetric analysis process (2):

- $N_{initial}$ - 7
- N_{design} - 86
- $N_{maximum}$ - 134

The Superpave "coarse" gradation was mixed and compacted using the Superpave gyratory compactor at asphalt binder contents of 4.1%, 4.6%, 5.0%, 5.5%, and 5.9% by total weight of mixture. For this mixture, the optimum asphalt binder content occurred at 5.6% by total weight of mix at which all Superpave volumetric requirements were satisfied. A summary of the volumetric properties of the Superpave “coarse” mixture is presented in Table 15 for the lab optimum asphalt binder content of 5.6% and also the field asphalt content of 5.0%. The reason for showing the field asphalt content will be discussed later. From the original Hveem mix design developed by NDOT in 1997, the laboratory optimum asphalt binder was estimated as 7.0% by total weight of mix (7.5 by dry weight of aggregate) (Volume I report). At his point it should be stated that for permanent deformation testing, the Hveem mixture design estimated optimum asphalt binder content would be used to fabricate test specimens. The main purpose of conducting the Superpave volumetric analysis on the Hveem designed mixture was to compare the volumetric properties of the Hveem mixtures as they are compacted with the kneading and Superpave gyratory compactors. Using the Hveem optimum as a reference point, samples were mixed and compacted using the Superpave gyratory compactor at asphalt binder contents of 5.7%, 6.1%, 6.5%, and 7.0% by total weight of mixture. A visual inspection indicated that in the Superpave gyratory compactor, the Hveem mixture was over asphalted at asphalt binder contents above 6.5% by total weight of mix. All specimens above this value exhibited a large amount of bleeding and appeared over compacted. This visual observation was confirmed by the results of the volumetric analysis, which indicated that at an asphalt binder content of 7.0%, there was only 1.2% air-voids left in the mixture. The Superpave mixture design specification identifies the optimum asphalt binder as the one corresponding to 4% air-voids. The optimum asphalt binder content was estimated at 5.7% by total weight of mix. This asphalt binder content was 1.3% lower than that obtained from the Hveem mixture design. A comparison of volumetric results at asphalt binder contents 5.7% and 7.0% using the Superpave volumetric calculations at N_{design} are shown in Table 16. It is important to note that in both the 2751 and 2827 contracts, mixtures at the Hveem’s estimated optimum binder contents exhibited a large amount of bleeding when compacted in the gyratory compactor. This is a good indicator that the Superpave gyratory compactor and the Hveem kneading compactor compact similar mixtures significantly different.

The third or Superpave "over the restricted zone" gradation was mixed and compacted using the Superpave gyratory compactor at asphalt binder contents of 5.0%, 5.5%, 6.0%, 6.5%, and 7.0% by total weight of mixture. A summary of all Superpave volumetric mix design properties is shown in Table 17. The optimum asphalt content of this mixture occurred at 6.3% by total weight of mix at which all Superpave volumetric requirements were satisfied.

The fourth or "through the restricted zone" gradation was mixed and compacted using the Superpave gyratory compactor at asphalt binder contents of 4.5, 5.0%, 5.5%, 6.0%, and 6.5% by total weight of mixture. A summary of all Superpave volumetric mix design properties is shown in Table 18. The optimum asphalt content of this mixture occurred at 5.5% by total weight of mix. Again, all Superpave volumetric requirements were satisfied at this optimum.

RESULTS OF THE REPEATED SHEAR CONSTANT HEIGHT TESTS

This section presents the performance of the various mixtures for both contracts in the repeated shear at constant height test (RSCH).

Contract 2751

As stated in the experimental design, the Superpave Shear Tester (SST) RSCH test was used to measure the mixtures resistance to permanent deformation. Using the SHRPbind Version 2.0 binder selection program, a test temperature of 51.6°C was determined at a depth of 50mm below the surface of the pavement (3). For each mixture, 3 specimens were tested in the SST RSCH test, which resulted in a total of 12 tests per contract. All specimens were mixed and compacted to 3± 0.75% air-voids at their laboratory optimum asphalt binder contents. Hence for the Hveem designed mixture, the optimum asphalt binder content determined in the original Hveem design was used to prepare the specimens tested in the RSCH test.

Reflux extraction tests were performed on Superpave "coarse" field mixtures sampled at the time of construction of the test section in 1996. Test results indicated that the field asphalt binder content was estimated to be 5.4% by total weight of mix, which was approximately 0.9%

below the laboratory designed optimum content of 6.3%. Table 11 presents Superpave volumetric properties of the lab gradation mixture at the field optimum asphalt content of 5.4%. Due to the large deviation in asphalt binder contents, it was decided to mix the field asphalt binder content with the laboratory developed gradation to observe how the change in binder content would impact the permanent deformation resistance of the mixture. The addition of this new mixture increased the total number of test specimens for the study to 15. A summary outlining asphalt contents used to prepare specimens for the RSCH test for each gradation is shown in Table 19.

For each mixture, 3 replicate specimens were tested and the average plastic strain was calculated at the completion of 5000 shear load cycles. The three samples coefficient of variation ranged from 11% to 23% when reviewing all mixtures in the study as shown in Table 20. It is interesting to note that the Superpave "coarse" mixture at both field and lab optimums appeared to have significantly larger values of variability than observed with the finer mixtures as measured by standard deviations and coefficients of variations. One possible reason for this increased variability may be the tendency of coarser graded mixtures to exhibit "aggregate interlock" more than finer mixes. Aggregate interlock in the shear direction could cause dilation as the aggregates want to roll over each other when sheared. Coarse-graded mixes having lager and more angular aggregates will lock up and then release periodically throughout the duration of the RSCH test. All samples, even if they have identical volumetric properties, do not have the same aggregate distribution throughout their volume. This difference in aggregate distribution can cause different degrees of aggregate interlock, which directly result in increased variability in total deformation observed in the shear direction.

Table 21 presents the RSCH test results in terms of the percent plastic strain and average air-void content for all specimens tested. Table 22 and Figure 3 present average percent plastic strain as a function of load cycles for each mixture evaluated in the study.

Upon review of Table 22 and Figure 3, it was clearly evident that the Superpave "coarse" mixture fabricated at the laboratory optimum asphalt content of 6.3% performance was significantly worse than all other mixtures evaluated in the study. Furthermore, when the same gradation was mixed at the field binder content (5.4%), the shear resistance of the mixture increased by more than 50%. The phenomena of "lubrication" at higher asphalt binder contents outlined by Sousa appeared to be present in this mixture (4). Other than the poor performance of the Superave "coarse mixture" at the laboratory optimum asphalt content, there does not appear to be any noticeable differences among all other mixtures. Using the resistance to plastic shear strains as the ranking method, the mixture performance in the RSCH test from best to worst ranked as follows:

1. Through the Restricted Zone
2. Superpave "Over the Restricted Zone"
3. Hveem
4. Superpave at Field Asphalt Content
5. Superpave at Laboratory Optimum Asphalt Content

Results from mean comparisons contrasting percent plastic strain after 5000 load cycles for all mixtures are shown in Tables 21 and 23. A significance level of 0.05 was selected for all mean comparisons that corresponds to a confidence level of 95%. When reviewing Table 5.23, if the response values were statistically the same, "same" will be noted and conversely if they were different, "diff." will be noted. It should be stated that there appeared to be an unequal variance problem in data, which was corrected using a box-cox transformation. In summary, Tables 21 and 23 indicate that the "through the restriction zone" mixture appeared to perform statistically the same as Hveem and Superpave "over the restriction zone" mixtures, but was statistically different than both the Superpave "coarse" mixtures. Furthermore, there was no significant statistical difference in performance in the RSCH test results among the Hveem, Superpave "over the restriction zone", and Superpave "coarse" at the field optimum asphalt binder content mixtures. Also, the mean comparisons indicated that the Superpave "coarse" mixture prepared at the laboratory optimum binder content had a response that is statistically different from all other mixtures in the study.

Engineering judgement and the statistical analysis both suggest that the Superpave "coarse" mixture at the higher binder content appear to be more susceptible to permanent deformation than all other mixtures evaluated in this study. This observation agreed with conclusions obtained from the WesTrack project which indicated that coarser graded mixtures appeared to be considerably more susceptible to permanent deformation than finer graded mixtures placed at the test track (5).

Contract 2827

In a similar procedure employed in contract 2751, a test temperature of 49.3°C was calculated at a depth of 50mm below the surface of the pavement using the SHRPbind Version 2.0 binder selection program. Again for each mixture, 3 specimens were tested in the SST RSCH test, which resulted in a total 12 tests to complete the experiment. All specimens were mixed and compacted to 3± 0.75% air-voids at their laboratory optimum asphalt binder content. Hence for the Hveem designed mixture, the optimum asphalt binder content determined in the original Hveem design was used to prepare the specimens tested for RSCH testing.

Solvent extraction and muffle furnace tests were performed on the Superpave “coarse” field mix sampled at the time of construction of the test section in 1997. Test results indicated that the field asphalt binder content was 5.0% by total weight of mix. This value was approximately 0.6% below the laboratory-designed optimum content of 5.6%. Table 15 presents the Superpave volumetric properties of the lab gradation mixture at the field asphalt content of 5.0%. As with the Superpave “coarse” mixture in contract 2751, a significantly lower asphalt binder content was utilized during the construction of the project than that obtained during the laboratory mixture design. It would appear that in both contracts, one can only speculate on why the asphalt binder content was lowered. Possible factors for this reduction may have been asphalt binder drain down, differences in gradation between the lab and field, bleeding in the mat, or compaction difficulties. Again, any or all of these factors may have caused field personnel to reduce the asphalt content at the time of construction. As with the 2751 contract, due to the large deviation in the asphalt binder contents, it was decided to mix the field optimum asphalt binder content with the laboratory developed gradation to observe how the change would impact the permanent deformation resistance of the mixture. The addition of this new mixture increased the total number of test specimens for the study to 15. A summary outlining asphalt contents used to prepare specimens for the RSCH test for each gradation is shown in Table 24.

For each mixture, 3 replicate specimens were tested and an average plastic strain calculated at the completion of 5000 shear load cycles. The coefficient of variation (COV) for the 3 samples ranged form 7% to 25% when reviewing all mixtures in the study as illustrated in Table 25. As in the 2751 contract, the coarse graded Superpave mixtures appeared to have significantly larger amount of variability than that observed in the finer graded mixtures. This repeated differences in variability observed in both contracts with two completely different aggregate sources, further reinforces the idea that "aggregate interlock" may be an actual problem associated with coarser graded mixtures evaluated in the SST. At the present time, studies are underway to investigate whether the sample height of 50 mm is sufficient for this test procedure. If one considers that a Superpave 19 mm maximum nominal size gradation can contain 19 mm (3/4") aggregate, orientation of these larger aggregates can significantly influence the resistance a mixture has to shear in the horizontal direction. Theoretically, a 19 mm aggregate can be long and slender, which means it may be upwards of 30 to 40 mm in length and still be able to pass through a 19 mm sieve opening. A sample height of 50 mm would not be adequate for these longer aggregates, thus increasing the height of the test specimen to 75 mm may be beneficial in reducing the amount of variation observed in coarser mixtures.

Table 26 presents the RSCH test results detailing the percent plastic shear strain and average air-void content for all specimens tested in the RSCH test. Table 27 and Figure 4 present average percent plastic strains as a function of load cycles for each mixture evaluated in the study.

Upon review of Table 27 and Figure 4, there did not appear to be any significant difference in performance among mixtures. Furthermore, when examining the Superpave "coarse" gradation, the change from laboratory to field optimum asphalt binder contents did not cause a significant change in the shear resistance of the mixtures. This observation would indicate that this Superpave gradation would appear to be "insensitive" to an asphalt content reduction upwards of 0.6%. However, even thought the change in percent plastic strain after 5000 cycles was less than contract 2751, the trend of increasing plastic strain with increasing asphalt content did exist. Using the resistance to plastic shear strains as the ranking method, the mixtures performance in the RSCH test from best to worst ranked as follows:

1. Superpave at Field Asphalt Content
2. Through the Restricted Zone
3. Superpave at Laboratory Optimum Asphalt Content
4. Superpave "Over the Restricted Zone"
5. Hveem

Mean comparisons that contrast percent plastic shear strains after 5000 load cycles for all mixtures are shown in Tables 26 and 28. As before, if the RSCH performances between two mixtures were statistically the same, "same" will be noted and conversely if they were different, a "diff." Will be noted. There did not appear to be any violations to the analysis of variance (ANOVA) assumptions and hence the data was analyzed without adjustment.

In summary, Tables 26 and 28 indicate that statistically, the Superpave over the restricted zone, Superpave "coarse" at both lab and field optimums, and through the restriction zone all performed the same in the RSCH test. Statistical differences in performance were noted between the Hveem and Superpave "coarse" at field optimum mixtures. Even though this difference was statistical significant, engineering judgments indicates that the Hveem mixture had similar performance compared to all other mixtures tested.

Comparison of Contracts 2751 and 2827

Upon review of contracts 2751 and 2827, there does not appear to be any trend regarding performance and aggregate gradation type. In the 2751contract, the Superpave "coarse" mixture at both field and laboratory optimum asphalt binder contents exhibited the worst performance. Conversely, in contract 2827, the Superpave "coarse" mixture at field binder content ranked as the best mixture in the study which indicates that the results are not totally a function of gradation of the mixture. As previously stated though, the trend of increasing plastic strain with increasing binder content was present in both contracts.

It appears in both contracts that the gradation passing through the restriction zone ranked in the top two of the five mixtures. This indicates that mixtures that follow the maximum density line appear to be more resistant to plastic deformation. However, it must be reiterated that mixtures that follow this line, tend to have problems meeting the minimum VMA criteria. In quality control/quality assurance (QC/QA) projects where contractors are penalized for not meeting volumetric criteria, these mixtures would not be favorable.

SUMMARY AND CONCLUSIONS

A gradation evaluation study was conducted on NDOT contracts 2751 and 2827. In each contract, 4 gradations were developed which ranged between a Hveem to a Superpave coarse grading. Complete Superpave volumetric mix designs were performed on each gradation and optimum asphalt contents were obtained. The Superpave RSCH tests were performed on all gradations to attempt to differentiate among performance characteristics of the mixtures.

In contract 2751, it was evident that the performance of the Superpave "coarse" mixture was significantly inferior to that observed in all other mixtures analyzed in the study. However in contract 2827, there did not appear to be any substantial difference among the tested mixtures.

Based on the performance of the various mixtures (contracts 2751 and 2827) in the RSCH test, it can be concluded that typical "Hveem type" mixtures performed as well or better than Superpave "coarse" mixtures. Although these mixtures appear to have very good permanent deformation characteristics, fatigue and moisture sensitivity testing must be performed in order to evaluate the overall characteristics of the mix.

REFERENCES

1. Sebaaly, P.E., McNamara, W.M., and Epps, J.A., "Evaluation of Rutting Resistance of Superpave and Hveem Mixtures - Volume I: Introduction and Background," Research Report Number 1393-2, Nevada DOT, Crason City, Nevada, June, 2000.

2. American Association of State Highway and Transportation Officials, "June 1997 Interim Edition - AASHO Provisional Standards," Provisional Standard TP4-93[1], American Association of State Highway and Transportation Officials, Washington D.C, 1994.

2. SHRPbind Software, Version 2.0, Deighton and Associates, May 1995.

2. Sousa, J.B., Tayebali, A., Harvey, J.H, Hendricks, P., and Monismith, C.L., "Sensitivity of Strategic Highway Research Program A-003A Testing Equipment to Mix Design Parameters for Permanent Deformation and Fatigue", Transportation Research Board 1384, Transportation Research Board, Washington D.C., 1993.

2. Hand, A., "Relationship Between Laboratory Measured HMA Material and Mixture Properties and Pavement Performance at WesTrack," Dissertation of Doctor of Philosophy, University of Nevada, Reno, 1998.

Table 1 Gradation Study Test Matrix for NDOT Contracts 2751 and 2827.

Contract	Binder Type	Gradation Type	Source of Optimum Asphalt Content	Design Method Used to Determine Optimum Asphalt Content
2751	PG 64-28	Superpave "coarse"	Laboratory/Field	Superpave/Field Extractions
		Superpave Over the Restriction Zone	Laboratory	Superpave
		Through the Gradation	Laboratory	Superpave
		Hveem	Laboratory	Hveem
2827	PG 64-34	Superpave "coarse"	Laboratory/Field	Superpave/Field Extractions
		Superpave Over the Restriction Zone	Laboratory	Superpave
		Through the Gradation	Laboratory	Superpave
		Hveem	Laboratory	Hveem

Table 2 2751 Hveem Gradation With and Without Lime.
Correction

Sieve Size	% Passing		% Difference
	NDOT Uncorrected	UNR Corrected	
1"	100	100.0	0.0
3/4"	100	100.0	0.0
1/2"	90.9	91.1	-0.2
3/8"	75.6	76.2	-0.6
# 4	52.4	53.6	-1.2
# 8	35.7	37.3	-1.6
# 16	24.4	26.2	-1.8
# 30	17.2	19.2	-2.0
# 50	11.9	14.0	-2.1
# 100	8.7	10.7	-2.0
# 200	6.8	8.6	-1.8
Pan	0.0	0.0	0.0

Table 3 Percent Passing Each Sieve for All Gradations in Contract 2751.

Sieve	Gradation Type			
Size (mm)	Hveem	Superpave Coarse	Superpave Over R.Z	Through R.Z
25	100	100	100	100
19	100	100	100	100
12.5	91.1	90	89.9	89.9
9.5	76.2	60.4	75.6	76.2
4.75	53.6	27.3	52.3	45.2
2.36	37.3	19.3	36.3	35.2
1.18	26.2	14.2	30.1	25.3
0.6	19.2	8.7	21.2	18.9
0.3	14	7.2	14.1	13.9
0.15	10.7	5.5	9.5	8.3
0.075	8.6	4.6	4.6	4.4
0	0	0	0	0

Table 4 Contract 2751 Superpave Aggregate Test Results.

Aggregate Properties		
Property	Measured	Specification
Coarse Aggregate Angularity, (%)	87 / 83	>/= 65/-
Fine Aggregate Angularity, (%)	54	>/= 40
Flat and Elongated Particles, (%)	0.6	< 10
Sand Equivalent, (%)	43	>/= 40

Table 5 2827 Hveem Gradation With and Without Lime. Correction

Sieve Size	% Passing		% Difference
	NDOT Uncorrected	UNR Corrected	
1"	100	100.0	0.0
3/4"	98.7	98.7	0.0
1/2"	84.9	85.1	-0.2
3/8"	74.2	74.6	-0.4
# 4	61.8	62.4	-0.6
# 8	39.4	40.3	-0.9
# 16	23.3	24.4	-1.1
# 30	14.8	16.1	-1.3
# 50	10.0	11.3	-1.3
# 100	7.6	8.8	-1.2
# 200	5.9	7.0	-1.1

Table 6 Solvent Extraction and Muffle Furnace Tests Used to Obtain 2827 Superpave Lab Gradation.

Test Method	% Asphalt by TWM	Percent Passing - Sieve Size (mm)										
		25	19	12.5	9.5	4.75	2.36	1.18	0.6	0.3	0.15	0.075
S1	4.4	100	99	80	58	38	26	17	12	8	6	5.4
S2	4.4	100	96	72	52	32	23	16	12	9	7	4.7
S3	5.4	100	100	81	57	36	24	16	12	9	7	5.6
M1	5.6	100	99	82	62	38	25	17	12	9	7	5.1
M2	5.6	100	99	83	60	37	25	17	12	9	7	5
M3	5.3	100	99	77	55	36	22	14	10	7	6	4.8
M4	5	100	99	74	52	31	20	13	9	6	5	4.3
M5	5.5	100	99	77	55	36	21	15	9	8	6	5.2
M6	5.1	100	98	70	50	33	19	14	8	7	5	4.4
M7	6.2	100	99	76	60	45	30	19	13	10	8	5.7
M8	5.3	100	99	73	56	39	23	17	10	8	6	4.9
M9	5.6	100	98	81	62	41	26	16	11	8	6	4.5
M10	4.8	100	100	73	52	35	23	15	10	7	5	4
M11	5.7	100	100	81	66	48	29	17	11	7	5	4.4
M12	5	100	98	72	55	39	25	15	10	7	5	3.9
Mean	5.26	100.00	98.80	76.80	56.80	37.60	24.07	15.87	10.73	7.93	6.07	4.79
Std. Dev.	0.490	0.000	1.014	4.296	4.523	4.548	3.035	1.552	1.438	1.100	0.961	0.550

Table 7 Percent Passing Each Sieve for All Gradations in Contract 2827.

Sieve	Gradation Type			
Size (mm)	Hveem	Superpave Coarse	Superpave Over R.Z	Through R.Z
25	100	100	100	100
19	98.7	98.8	98.8	98.7
12.5	85.1	76.8	83.6	87.2
9.5	74.6	56.8	73.6	70
4.75	62.4	37.6	61.5	46.2
2.36	40.3	24.1	37.1	36.3
1.18	24.4	15.9	29.5	25.2
0.6	16.1	10.7	21.2	18.2
0.3	11.3	8	14.1	13.7
0.15	8.8	6.1	7.5	9.1
0.075	7	4.8	4.7	4.6
0	0	0	0	0

Table 8 Contract 2827 Superpave Aggregate Test Results.

Aggregate Properties		
Property	Measured	Specification
Coarse Aggregate Angularity, (%)	100 / 99	>/= 75/-
Fine Aggregate Angularity, (%)	43	>/= 40
Flat and Elongated Particles, (%)	0	< 10
Sand Equivalent, (%)	67	≥ 40

Table 9 2751 Superpave Performance Grade Verification Results.

Binder Properties (PG64-28 Required)		
Property	Measured	Specification
Flash Point, (°C)	240	≥ 230
Mass Loss, (%)	0.33	≤ 1.0
Brookfield Viscosity, (Pa*s), @ 135°C	0.91	≤ 3.0
Original G*/(sin δ), (kPa), @ 64°C	1.4	≥ 1.0
RTFOT G*/(sin δ), (kPa), @ 64°C	2.6	≥ 2.2
PAV G*(sin δ), (kPa), @ 19°C	1.7	≤ 5000
Creep Stiffness, (MPa), @ -18°C	213	≤ 300
Slope (m), @ -18°C	0.31	≥ 0.30

Table 10 2827 Superpave Performance Grade Binder Verification Results.

Binder Properties (PG64-34 Required)		
Property	Measured	Specification
Flash Point, (°C)	266	≥ 230
Mass Loss, (%)	0.27	≤ 1.0
Brookfield Viscosity, (Pa*s), @ 135°C	0.412	≤ 3.0
Original G*/(sin δ), (kPa), @ 64°C	1.3	≥ 1.0
RTFOT G*/(sin δ), (kPa), @ 64°C	2.7	≥ 2.2
PAV G*(sin δ), (kPa), @ 22°C	1.6	≤ 5000
Creep Stiffness, (MPa), @ -24°C	213	≤ 300
Slope (m), @ -24°C	0.312	≥ 0.30

Table 11 Contract 2751 Superpave Volumetric Property Summary of Superpave "Coarse" Mixture at Lab Optimum and Field Asphalt Conents.

Property	Measured Volumetric Properties		Specification
	Laboratory Optimum Asphalt Content	Field Optimum Asphalt Content	
%Gmm at N_{design}	96.0	94.8	96
% AC (by twm)	6.3	5.4	n/a
% VMA at N_{design}	17.1	16.5	>13
% VFA at N_{design}	76.9	67.2	65-78
Filler to Effective AC Ratio at N_{design}	0.8	0.96	0.6-1.2
% Gmm at N_{intial}	86.2	84.7	<89
% Gmm at N_{max}	97.7	96.3	<98

Table 12 Contract 2751 Superpave Volumetric Property Summary and Comparison of Hveem and Superpave Design Optimum Asphalt Contents in the Gyratory Compactor.

Property	Measured Volumetric Properties		Specification
	Hveem Compactor Lab Optimum Asphalt Content	Gyratory Compactor Lab Optimum Asphalt Content	
%Gmm at N_{design}	97.8	96.0	96
% AC (by twm)	5.7	4.9	n/a
% VMA at N_{design}	12.3	12.3	13
% VFA at N_{design}	82.1	68.0	65-78
Filler to Effective AC Ratio at N_{design}	1.96	2.38	0.6-1.2

Table 13 Contract 2751 Superpave Volumetric Property Summary of the Superpave Over the Restricted Zone Mixture.

Property	Measured Volumetric Properties	Specification
%Gmm at N_{design}	96.0	96
% AC (by twm)	5.0	n/a
% VMA at N_{design}	13	13
% VFA at N_{design}	69.9	65-78
Filler to Effective AC Ratio at N_{design}	1.19	0.6-1.2
% Gmm at Nintial	88.2	<89
% Gmm at N_{max}	97.1	<98

Table 14 Contract 2751 Superpave Volumetric Property Summary of the Through the Restricted Zone Mixture.

Property	Measured Volumetric Properties	Specification
%Gmm at N_{design}	96.0	96
% AC (by twm)	4.8	n/a
% VMA at N_{design}	12.7	>13
% VFA at N_{design}	69.7	65-78
Filler to Effective AC Ratio at N_{design}	1.16	0.6-1.2
% Gmm at N_{intial}	87.5	<89
% Gmm at N_{max}	97.1	<98

Table 15 Contract 2827 Superpave Volumetric Property Summary of Superpave "Coarse" Mixture.

Property	Measured Volumetric Properties		Specification
	Laboratory Optimum Asphalt Content	Field Asphalt Content	
%Gmm at N_{design}	96.0	95.1	96
% AC (by twm)	5.6	5.0	n/a
% VMA at N_{design}	14.3	14.1	>13
% VFA at N_{design}	72.1	65.1	65-75
Filler to Effective AC Ratio at N_{design}	1.03	1.18	0.6-1.2
% Gmm at N_{intial}	85.6	84.5	<89
% Gmm at N_{max}	97.5	96.6	<98

Table 16 Contract 2827 Superpave Volumetric Property Summary and Comparison of Hveem and Superpave Design Optimum Asphalt Contents in the Gyratory Compactor.

Property	Measured Volumetric Properties		Specification
	Hveem Compactor Lab Optimum Asphalt Content	Gyratory Compactor Lab Optimum Asphalt Content	
%Gmm at N_{design}	98.8	96.0	96
% AC (by twm)	7.0	5.7	n/a
% VMA at N_{design}	13.6	13.4	>13
% VFA at N_{design}	91.3	68.1	65-75
Filler to Effective AC Ratio at N_{design}	1.30	1.71	0.6-1.2
% Gmm at N_{intial}	89.0	86.2	<89
% Gmm at N_{max}	99.7	97.5	<98

Table 17 Contract 2827 Superpave Volumetric Property Summary of the Superpave Over the Restricted Zone Mixture.

Property	Measured Volumetric Properties	Specification
%Gmm at N_{design}	96.0	96
% AC (by twm)	6.3	n/a
% VMA at N_{design}	14.8	>13
% VFA at N_{design}	72.8	65-75
Filler to Effective AC Ratio at N_{design}	0.97	0.6-1.2
% Gmm at N_{intial}	87.5	<89
% Gmm at N_{max}	97.4	<98

Table 18 Contract 2827 Superpave Volumetric Property Summary of the Through the Restricted Zone Mixture.

Property	Measured Volumetric Properties	Specification
%Gmm at N_{design}	96.0	96
% AC (by twm)	5.5	n/a
% VMA at N_{design}	13.3	>13
% VFA at N_{design}	69.8	65-75
Filler to Effective AC Ratio at N_{design}	1.13	0.6-1.2
% Gmm at N_{intial}	87.3	<89
% Gmm at N_{max}	97.2	<98

Table 19 Optimum Asphalt Contents for All Gradations Used for RSCH Testing in Contract 2751.

Gradation Type	Asphalt Content By Total Weigh of Mixture (%)	Method Used to Determine Optimum
Hveem Type II	5.7	Hveem Mix Design
Superpave Coarse (LAB)	6.3	Superpave Mix Design
Superpave Coarse (Field)	5.4	Extraction of Field Mixture
SP Over the Restriction Zone	5	Superpave Mix Design
Through the Restriction Zone	4.8	Superpave Mix Design

Table 20 Contract 2751 Gradation Study RSCH Test Results.

Mix Type	Specimen ID	Percent Plastic Strain at 5000 cycles	Average	St. Dev.	COV (%)
Hveem	HV1	0.654	0.842	0.16	19.35
	HV2	0.931			
	HV3	0.941			
Over R.Z	OV2	0.632	0.707	0.12	16.61
	OV3	0.842			
	OV4	0.646			
Through R.Z	TH1	0.603	0.555	0.06	11.06
	TH5	0.577			
	TH6	0.486			
SP Coarse Field (5.4% AC)	SP1	1.251	1.004	0.24	23.67
	SP2	0.984			
	SP3	0.777			
SP Coarse Field (6.3% AC)	SP1	2.482	2.526	0.58	23.07
	SP3	3.130			
	SP4	1.967			

Table 21 Summary of Plastic Strain and Air Voids of RSCH Tested Specimens for Contract 2751.

Mix Type	Specimen ID	Air Voids (%)	Percent Plastic Strain at 5000 cycles	Mean Grouping
Hveem	HV1	3.46	0.654	B, C
	HV2	3.05	0.931	
	HV3	2.96	0.941	
Average		3.16	0.84	
St. Dev.		0.27	0.16	
COV		8.44	19.35	
Over R.Z	OV2	2.64	0.632	B, C
	OV3	2.75	0.842	
	OV4	2.64	0.646	
Average		2.68	0.71	
St. Dev.		0.06	0.12	
COV		2.37	16.61	
Through R.Z	TH1	2.66	0.603	B, C
	TH5	2.61	0.577	
	TH6	2.67	0.486	
Average		2.65	0.56	
St. Dev.		0.03	0.06	
COV		1.21	11.06	
SP Coarse Field (5.4% AC)	SP1	3.55	1.251	B
	SP2	3.08	0.984	
	SP3	3.46	0.777	
Average		3.36	1.00	
St. Dev.		0.25	0.24	
COV		7.42	23.67	
SP Coarse Field (6.3% AC)	SP1	2.72	2.482	A
	SP3	3.38	3.130	
	SP4	3.51	1.967	
Average		3.20	2.53	
St. Dev.		0.42	0.58	
COV		13.22	23.07	

* Any Mixture with Same Letter Indicates RSCH Performance is Statistically the Same

Table 22 Contract 2751 Gradation Study RSCH Test Results (Plastic Strain as Function of Load Cycles)

Number of Cycles	Average % Plastic Strain				
	Hveem	SP Over R.Z	Through R.Z	Superpave @ 6.3% AC	Superpave @ 5.4% AC
1	0.058	0.067	0.042	0.296	0.170
20	0.120	0.128	0.086	0.559	0.279
30	0.148	0.157	0.105	0.665	0.319
50	0.188	0.196	0.134	0.805	0.379
80	0.234	0.240	0.162	0.955	0.445
100	0.257	0.263	0.178	1.029	0.470
200	0.340	0.335	0.233	1.279	0.573
300	0.394	0.380	0.268	1.433	0.630
400	0.433	0.414	0.294	1.538	0.672
500	0.471	0.439	0.315	1.616	0.703
600	0.497	0.460	0.333	1.683	0.727
800	0.541	0.490	0.358	1.784	0.766
1000	0.573	0.517	0.379	1.863	0.797
1247	0.607	0.547	0.401	1.942	0.825
1500	0.635	0.564	0.420	2.014	0.849
1747	0.659	0.583	0.436	2.069	0.866
2000	0.681	0.597	0.448	2.120	0.886
2247	0.702	0.613	0.462	2.162	0.901
2500	0.718	0.625	0.471	2.202	0.914
2748	0.731	0.637	0.482	2.239	0.924
2997	0.746	0.647	0.496	2.277	0.937
3200	0.760	0.657	0.503	2.304	0.947
3400	0.769	0.663	0.510	2.339	0.952
3600	0.778	0.670	0.516	2.359	0.959
3800	0.789	0.675	0.523	2.389	0.968
3997	0.797	0.677	0.529	2.411	0.975
4200	0.807	0.683	0.533	2.434	0.983
4500	0.823	0.691	0.540	2.476	0.992
4998	0.842	0.707	0.555	2.526	1.004

Table 23 Contract 2751 Gradation Study Mean Comparison Results

	Hveem	SP Over R.Z	Through R.Z	Superpave @ 6.3% (LAB)	Superpave @ 5.4% (Field)
Hveem	X	Same	Same	Diff.	Same
SP Over R.Z	Same	X	Same	Diff.	Same
Through R.Z	Same	Same	X	Diff.	Diff.
Superpave @ 6.3%	Diff.	Diff.	Diff.	X	Diff.
Superpave @ 5.4%	Same	Same	Diff.	Diff.	X

* Significance Level of 0.05 Used in All Comparisons

Table 24 Optimum Asphalt Contents for All Gradations Used for RSCH Testing in Contract 2827.

Gradation Type	Asphalt Content By Total Weigh of Mixture (%)	Method Used to Determine Optimum
Hveem Type II	7.0	Hveem Mix Design
Superpave Coarse (LAB)	5.6	Superpave Mix Design
Superpave Coarse (Field)	5.0	Extraction of Field Mixture
SP Over the Restriction Zone	6.3	Superpave Mix Design
Through the Restriction Zone	5.5	Superpave Mix Design

Table 25 Contract 2827 Gradation Study RSCH Test Results.

Mix Type	Specimen ID	Percent Plastic Strain at 5000 cycles	Average	St. Dev.	COV (%)
Hveem	HV1	1.047	1.011	0.08	7.52
	HV2	0.924			
	HV4	1.063			
Over R.Z	OV1	0.823	0.896	0.15	16.24
	OV2	0.802			
	OV4	1.064			
Through R.Z	TH1	0.743	0.787	0.05	6.68
	TH3	0.845			
	TH4	0.772			
SP Coarse Field (5.4% AC)	SP1	0.485	0.603	0.10	17.39
	SP2	0.686			
	SP3	0.637			
SP Coarse Field (6.3% AC)	SP2	0.574	0.806	0.20	24.96
	SP3	0.908			
	SP4	0.935			

Table 26 Summary of Plastic Strain and Air Voids of RSCH Tested Specimens for Contract 2827.

Mix Type	Specimen ID	Air Voids (%)	Percent Plastic Strain at 5000 cycles	Mean Grouping
Hveem	HV1	3.74	1.047	A
	HV2	2.86	0.924	
	HV4	2.49	1.063	
Average		3.03	1.011	
St. Dev.		0.64	0.08	
COV		21.19	7.52	
Over R.Z	OV1	3.17	0.823	A, B
	OV2	3.28	0.802	
	OV4	3.11	1.064	
Average		3.19	0.896	
St. Dev.		0.09	0.15	
COV		2.71	16.24	
Through R.Z	TH1	2.73	0.743	A, B
	TH3	3.49	0.845	
	TH4	3.75	0.772	
Average		3.32	0.787	
St. Dev.		0.53	0.05	
COV		15.95	6.68	
SP Coarse Field (5.4% AC)	SP1	2.46	0.485	A, B
	SP2	2.89	0.686	
	SP3	2.79	0.637	
Average		2.71	0.603	
St. Dev.		0.23	0.10	
COV		8.29	17.39	
SP Coarse Field (6.3% AC)	SP2	2.29	0.574	A, B
	SP3	2.64	0.908	
	SP4	2.60	0.935	
Average		2.51	0.806	
St. Dev.		0.19	0.20	
COV		7.63	24.96	

* Any Mixture with Same Letter Indicates RSCH Performance is Statistically the Same

Table 27 Contract 2827 Gradation Study RSCH Test Results (Plastic Strain as Function of Load Cycles)

Number of Cycles	Average % Plastic Strain				
	Hveem	SP Over R.Z	Through R.Z	Superpave @ 5.0% AC	Superpave @ 5.6% AC
1	0.102	0.085	0.073	0.040	0.083
20	0.186	0.169	0.137	0.083	0.160
30	0.227	0.202	0.165	0.101	0.194
50	0.285	0.252	0.204	0.129	0.243
80	0.345	0.309	0.248	0.161	0.292
100	0.373	0.336	0.269	0.176	0.318
200	0.471	0.430	0.344	0.236	0.401
300	0.527	0.487	0.395	0.276	0.451
400	0.567	0.524	0.433	0.305	0.489
500	0.607	0.551	0.462	0.330	0.516
600	0.639	0.570	0.487	0.347	0.541
800	0.681	0.608	0.527	0.380	0.580
1000	0.720	0.636	0.561	0.405	0.605
1247	0.761	0.665	0.588	0.430	0.631
1500	0.789	0.696	0.618	0.450	0.656
1747	0.812	0.717	0.638	0.469	0.675
2000	0.833	0.739	0.658	0.486	0.689
2247	0.855	0.756	0.673	0.500	0.703
2500	0.873	0.777	0.688	0.513	0.717
2748	0.891	0.790	0.702	0.525	0.730
2997	0.908	0.804	0.714	0.536	0.740
3200	0.918	0.815	0.726	0.545	0.749
3400	0.931	0.826	0.736	0.551	0.757
3600	0.944	0.840	0.742	0.560	0.763
3800	0.952	0.850	0.748	0.567	0.770
3997	0.963	0.858	0.755	0.573	0.775
4200	0.975	0.864	0.764	0.581	0.781
4500	0.992	0.877	0.772	0.590	0.791
4998	1.011	0.896	0.787	0.603	0.806

Table 28 Contract 2827 Gradation Study Mean Comparison Results.

	Hveem	Over R.Z	Through R.Z	Superpave @ 5.0%	Superpave @ 5.6%
Hveem	X	Same	Same	Diff.	Same
Over R.Z	Same	X	Same	Same	Same
Through R.Z	Same	Same	X	Same	Same
Superpave @ 5.0%	Diff.	Same	Same	X	Same
Superpave @ 5.6%	Same	Same	Same	Same	X

* Significance Level of 0.05 Used in all Comparisons

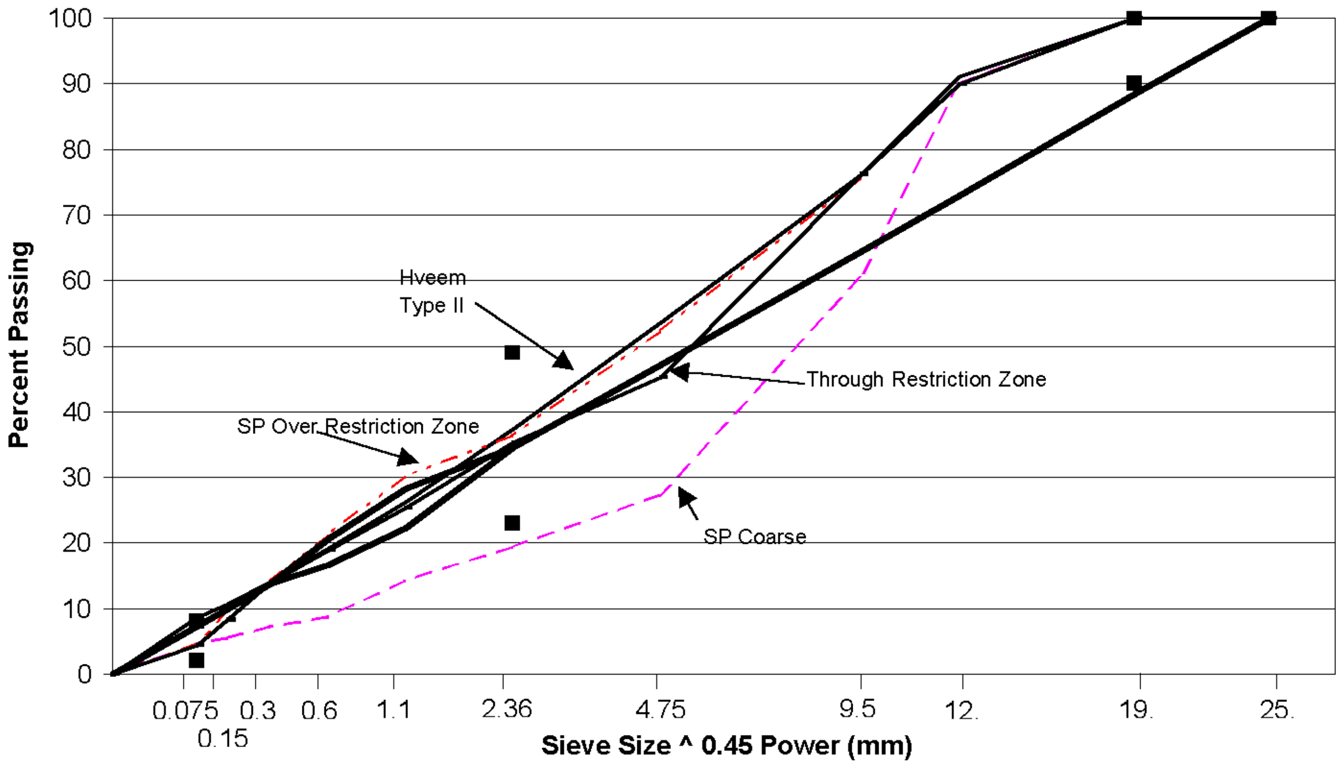

Figure 1 Plot of gradations used in contract 2751 on the 0.45 power chart.

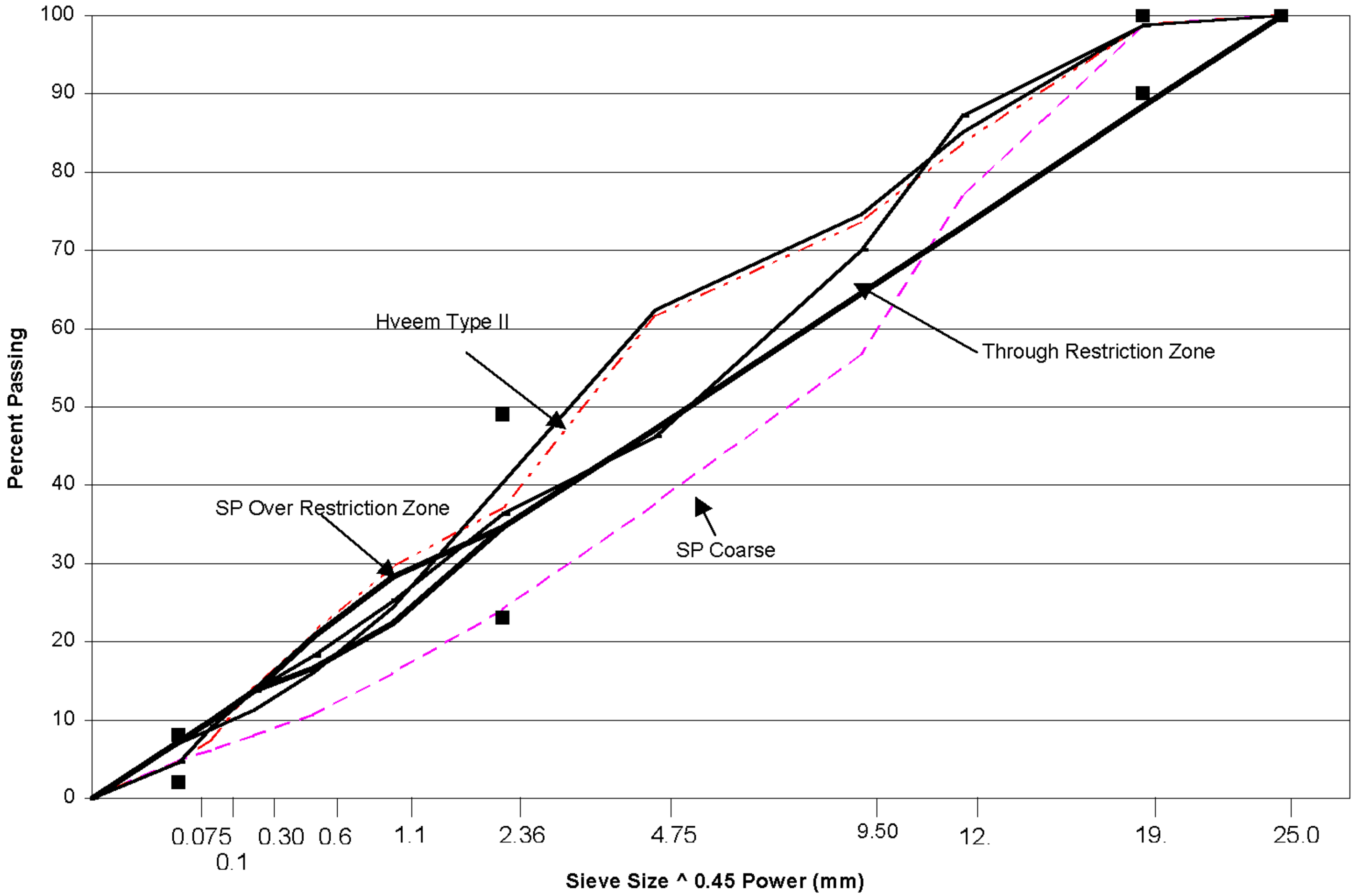

Figure 2 Plot of gradations used in contract 2827 on the 0.45 power chart.

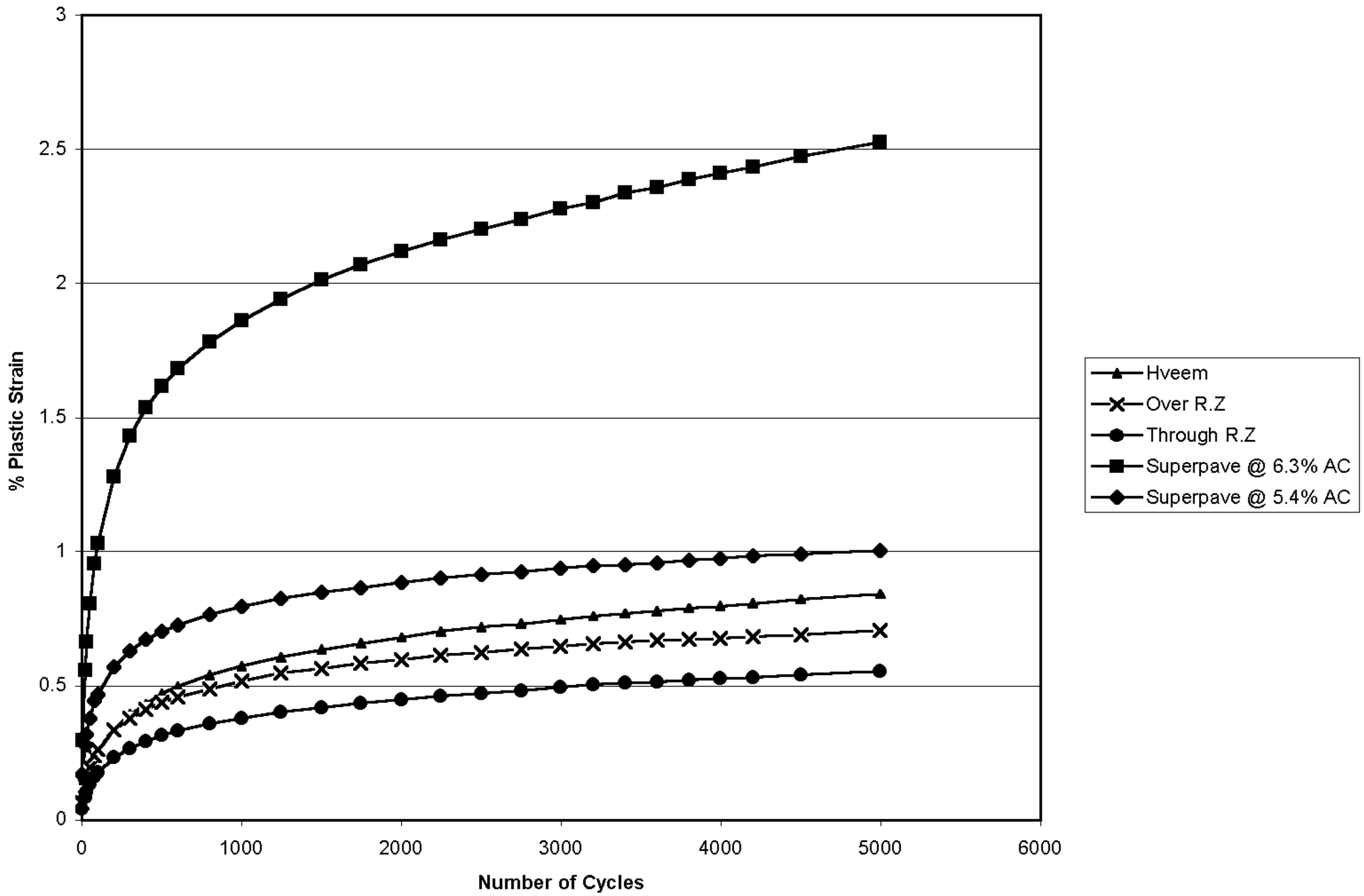

Figure 3 Contract 2751 percent plastic strain vs. load cycles for all gradations as measured in RCSH Test.

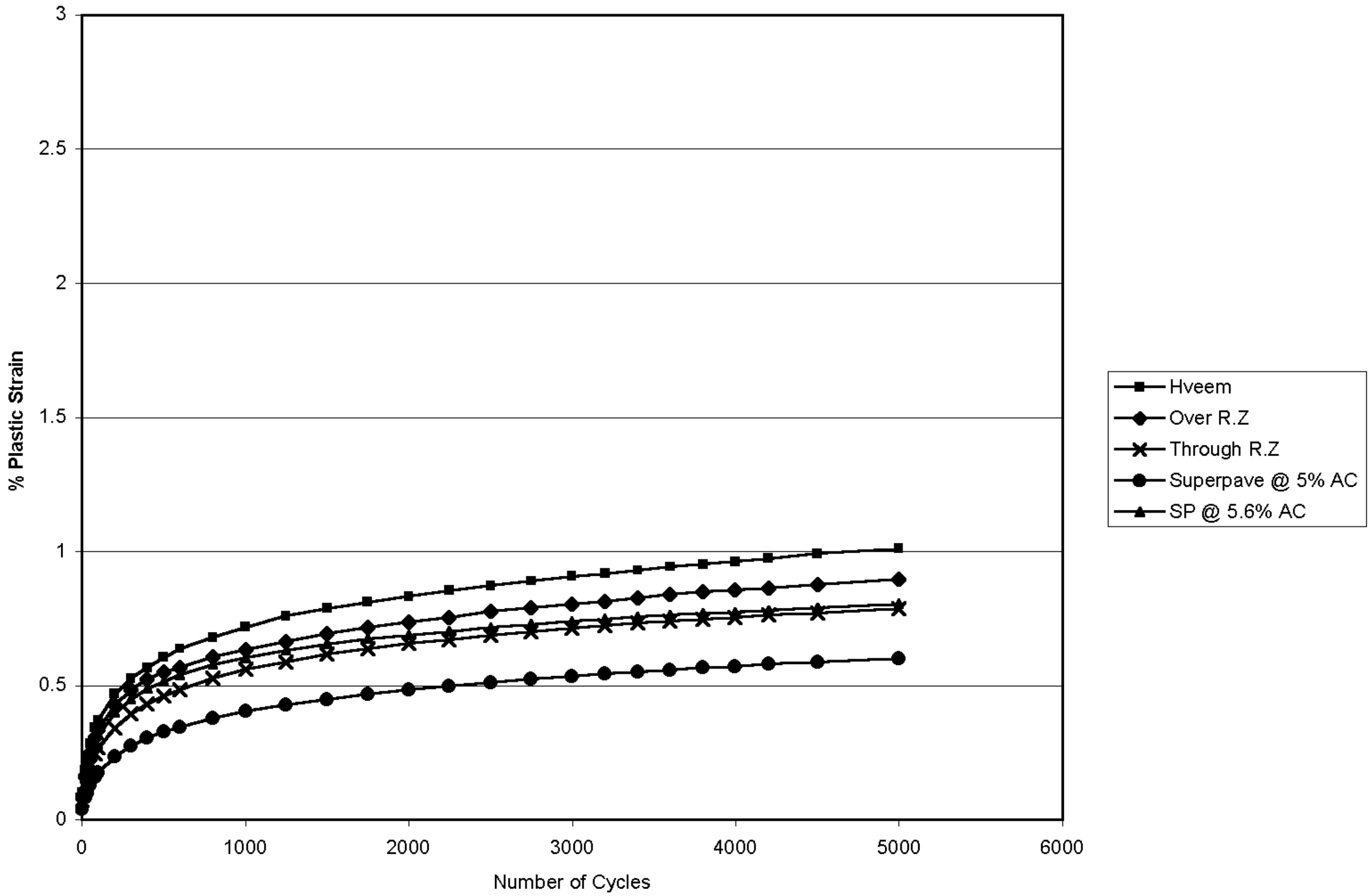

Figure 4 Contract 2827 percent plastic strain vs. load cycles for all gradations as measured by RSCH Test.