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1263 South Stewart Street
Carson City, Nevada 89712

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16. Abstract

To assess implementation and applicability of the Superpave mixture design method specifically for conditions in Nevada a cooperative research effort was undertaken by NDOT. A series of mixtures were designed for a range of traffic and environmental conditions typically encountered in Nevada using both the Superpave and Hveem mix design methods. The mixtures were then placed in the field to allow for direct performance comparisons under actual field conditions. Extensive laboratory evaluations were also conducted on the materials, pre-, during-, and post-construction. A suite of laboratory performance tests were performed on the project materials to evaluate rutting, fatigue and durability performance over time. Field performance was also monitored for up to five years after construction. Contrasting laboratory test results and field performance led to the refinement of materials selection and mixture design procedures that will be implemented by NDOT on a trial basis during the 2002 and 2003 construction seasons.

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INTRODUCTION

The road building industry has undergone considerable changes within the last decade with regards to hot mixed asphalt (HMA) mix design and laboratory performance testing. Even with the development of refined mix design procedures in recent years, designers still have limited capabilities of predicting the potential performance of mixtures under field loading conditions. The development of laboratory performance tests and subsequent performance models was one of the goals of the Strategic Highway Research Program (SHRP) that was initiated in 1987 (1). One of the major products of the SHRP asphalt program was the development of the Superpave volumetric mix design and analysis system (2). To address performance issues such as permanent deformation, fatigue, and low temperature cracking, the Superpave analysis system developed advanced testing equipment and methods that can be used at the mix design stage to predict the potential performance of mixture throughout its pavement service life. This report is Volume IV in the series of reports on the implementation of Superpave mix design method in Nevada (3,4,5).

An in depth evaluation of the Superpave system has been jointly undertaken by the Nevada Department of Transportation (NDOT) and the Western Regional Superpave Center (WRSC) at the University of Nevada Reno (UNR) to assess the performance of the Superpave system in both laboratory and field settings. The research has been ongoing for over 6 years. The goal of the evaluation is to allow NDOT to become familiar with the Superpave mixture design and analysis system, while at the same time gaining valuable knowledge about differences in performance among various types of HMA mixtures used within the State of Nevada.

The research activities conducted in this report covered both laboratory and field evaluation of HMA mixtures designed with the Superpave volumetric mix design and the NDOT

Hveem mix design methods. Several field projects have been constructed which included Superpave and Hveem test sections that are being evaluated side-by-side under the combined action of traffic and environment. The materials used in the field projects were sampled and tested at numerous stages during the design, construction, and throughout the service life of the field projects. Field performance observations were also made on at least a bi-annual basis. McNamara, et.al, reported on the initial laboratory evaluations associated with two of the projects in AAPT in 2001 (6). The findings of the effort described in this report have been used to formulate mixture design refinements and additional field performance tests by NDOT.

FIELD PROJECTS AND MIXTURE DESIGNS

This research effort evaluated mixtures and field performance from three NDOT projects consisting of a total of four Superpave and four Hveem mixtures. Two of the projects included one Hveem and one Superpave section and the third project included two Hveem and two Superpave sections. The Superpave mixtures were designed in accordance with the Superpave procedure as published at the completion of the SHRP research program and the Hveem mixtures were designed in accordance with the NDOT standard procedures (7,8). The exact same mineral aggregates and asphalt binders were used within each project. The only real difference between the Superpave and Hveem designed mixtures within a project was the gradations. The Superpave mixture gradations were all coarse (below the restricted zone), while the Hveem mixture gradations were all very dense plotting close to the maximum density line on a 0.45 power chart. The performance-graded asphalt binders used within each project met or exceeded the 98 percent reliability requirements for the projects environments. The SHRPBIND software was used to select the appropriate binders at the time of design (9).

Descriptions of the projects follow along with materials and mixture design summaries. A summary of field performance is presented which is followed by laboratory performance test properties measured on field-produced specimens over several years. The field performance and laboratory test results are then contrasted. A summary and conclusions section is then presented to conclude the report.

Contract 2751

The Contract 2751 project was constructed in 1996 on SR 278 in Eureka County, Nevada. The project included one Hveem section and one Superpave section. The Hveem mixture section covered the majority of the project 13 miles while the Superpave section was placed on 2 miles of the project. The constructed layer consisted of placing a 2in HMA overlay in a single lift with ¾" open graded friction course over the existing 2in old HMA layer and 8in crushed aggregate base. The Superpave design traffic category for the project was 0.3 to 1.0 million ESALs.

Figure 1 shows the gradations of the Hveem and Superpave mixtures employed on contract 2751. The same PG64-28 asphalt binder was used in both mixture types. Tables 1 and 2 summarize the materials properties and the mix designs for the Superpave and Hveem mixtures constructed on contract 2751, respectively. The design air temperature for the project location was 39°C and the initial, design, and maximum numbers of gyrations were 7, 76, and 119, respectively. The data in Tables 1 and 2 show that all materials and mixtures satisfy the corresponding specifications except for the gradation of the Superpave mix which slightly violated the lower control point at the 2.36mm sieve. The Superpave section was added to a standard NDOT project via change order. The project was being constructed with a limited number of stockpiles and with gradations that could not be blended any closer to the Superpave specifications than that shown in Figure 1.

Contract 2827

This project was constructed in 1997 on US 93 in White Pine County, Nevada. The project included one Hveem and one Superpave section. The Hveem section covered only 1mile of the project while the Superpave section covered the majority of the project's 13 miles. The constructed layer consisted of placing a 2in HMA overlay with ¾" open graded friction course over the existing 3in old HMA layer and 6in crushed aggregate base. The Superpave design traffic category for the project was 1 to 3 million ESALs.

Figure 2 shows the gradations of the Hveem and Superpave mixtures constructed on contract 2827. The same PG64-34 asphalt binder was used in both mixture types. Tables 3 and 4 summarize the materials properties and the mix designs for the Superpave and Hveem mixtures constructed on contract 2827, respectively. The design air temperature for the project location was 39°C and the initial, design, and maximum numbers of gyrations were 7, 86, and 134, respectively. It can be seen from Tables 3 and 4 that the materials and mixtures satisfied the corresponding specifications.

Contract 2880

The contract 2880 project was constructed in 1998 on IR 80 in Churchill County, Nevada. The project included two Hveem and two Superpave sections. Each section consists of a 500ft performance monitoring area and two sampling areas (one at the beginning and one at the end of the section). There were transition areas between consecutive sections. Construction activities included milling the top 2in of the existing 8in HMA layer and placing a 4in HMA overlay in two 2in lifts. The base course was a 9in crushed aggregate layer. The Superpave sections did not receive open grade friction courses while the Hveem sections received a ¾" open graded friction course one year after construction. The Superpave design traffic category for the project was 3 to 10 million ESALs. The design air temperature for the project location was 39°C and the initial, design, and maximum numbers of gyrations were 8, 96, and 152, respectively.

The following is a description of the sections nomenclature:

SPAC-20P: this section was designed using the Superpave mix design system with a binder grade of AC-20P
SPPG64-22: this section was designed using the Superpave mix design system with a binder grade of PG64-22
NVPG64-22: this section was designed using the NDOT Hveem mix design method with a binder grade of PG64-22
NVAC-20P: this section was designed using the NDOT Hveem mix design method with a binder grade of AC-20P

Figure 3 shows the gradations of the Hveem and Superpave mixtures constructed on contract 2880. Tables 5 through 8 summarize the materials properties and the mixture designs for the Superpave and Hveem mixtures constructed on the project.

FIELD PERFORMANCE

The overall condition of the existing pavements were determined by visual inspection prior to construction of each section and at least bi-annually thereafter. The field condition survey data are summarized in Table 9. Figures 5 through 8 are photographs of the Contract 2751 and 2827 project pavements taken at the time of the 2001 condition surveys. The year 0 data represents pre-construction survey results. There is no pre-construction survey data for the Contract 2880 project because the existing pavement was milled prior to the overlay.

On Contract 2751 five years of field performance data were collected. No significant rutting was observed during the five-year period for either of the mixtures. More transverse and block cracking was observed in the NVPG64-28 mixture than in the SPPG64-28 mixture. However the SPPG64-28 mixture showed more raveling than the NVPG64-28 mixture. There is a significant elevation change between the NV and SP mixture locations on this project that may also explain some of the additional cracking in the NVPG64-28 mixture. Some of the cracking observed in both mixtures was likely reflective cracking. The fatigue performance of the mixtures was essentially equal.

Four years of performance data were available for the Contract 2827 project. No significant rutting was observed during the four-year period for either of the mixtures. However, significantly more fatigue cracking (40 to 45 percent more) was observed in the SPPG64-34 mixture than in the NVPG64-34 mixture. The different is far too great to be due to random differences in reflective cracking. There was also more raveling observed in the SPPG64-34 mixture than in the NVPG64-34 mixture.

On the Contract 2880 project data was only collected for three years. The only form of distress identified during that period was rutting. Rut depths are plotted in Figure 4. An open graded friction course was placed on the NV mixtures in July of 1999 (1 year after construction) so measured rut depths for those mixtures decreased. Arrows were placed on Figure 4 to show that the total rut depths after that point in time would actually be greater than that indicated on the plot. After July 1999 the reported rut depths for the NVAC-20P and NVPG64-22 mixtures should actually be what is shown plus 3 and 4mm (the rut depths prior to placement of the open graded friction course), respectively. The SPPG64-22 mixture had to be milled out and replaced after two years because rut depths exceeded 0.5in. The rut depths appeared to have stabilized at that point in time in the other Contract 2880 mixtures. Rut depths in the SPAC-20P section were 0.30" when last surveyed. At the same time rut depths in the NVPG64-22 and NVAC-20P mixtures had reached only 0.20 and 0.16", respectively.

In summary, in the low traffic environments NV mixtures performed better in terms of durability as indicated by raveling and equally or better in terms of general cracking and fatigue. In the high traffic environment, the SP mixtures exhibited more rutting than the NV mixtures and the mixtures made with polymer modified asphalt binder (AC-20P) exhibited less rutting than the mixtures incorporating a neat PG64-22 binder regardless of mixture design method.

LABORATORY MATERIALS AND MIXTURE EVALUATIONS

Extensive materials and mixtures evaluations were cooperatively conducted by NDOT and UNR for each project. They included pre-construction, construction, and post-construction evaluations. The pre-construction evaluations were limited to Superpave and Hveem materials selection and mixture designs presented in the previous section. The construction evaluations included typical quality control (asphalt content, gradation, volumetrics and in-place density). The post-construction evaluations encompassed permanent deformation, stiffness, fatigue, thermal cracking, moisture sensitivity, and durability measures on lab mixed-lab compacted (LMLC), field mixed-lab compacted (FMLC), and field mixed-field compacted (FMFC) mixtures samples. FMFC samples were cores and/or slabs cut directly from the pavements immediately after construction and annually for up to five years thereafter. Binder was also extracted from field cores over time to assess the degree of time hardening. The test methods used in the post-construction evaluations along with the test specimen sample types are summarized in Table 10.

Pre-construction Mixture Designs and Construction Quality Control

The pre-construction mixture designs were presented in Tables 1 through 8 and Figures 1 through 3. There were significant differences (up to approximately 1 percent) in optimum asphalt contents within projects between mixture design methods as shown in Table 11. The differences are not consistently shifted one direct between mixture design methods. The design traffic and air temperatures resulted in different Superpave compactive efforts (N_{design}) among the projects while the Hveem procedure specifies a fixed effort regardless of design traffic. This coupled with the gradation differences between design methods within each project led to the significant differences in optimum asphalt contents observed.

Construction quality control data are summarized in Table 12. The data for Contracts 2751 and 2827 were collected by NDOT during construction and represent between 30 and 156 individual tests per asphalt content value reported (10). Asphalt content was measured using the ignition method. In-place air voids were measured on a limited number of cores. Significantly more nuclear density measurements were made (30 to 156) but only on the Hveem designed sections. The nuclear air void values are presented in Table 12 in parenthesis. The target asphalt content for the 2751 SPPG64-28 mixture was field adjusted to 5.7 percent producing on average 4.4 percent laboratory compacted air voids. No other asphalt content targets were field adjusted. The reported construction quality control data for the Contract 2880 sections are actually data determined by the Federal Highway Administration from 3 or 4 cores per lift per mixture type.

Acknowledging the target adjustment for the 2751 mixture, the data in Table 12 indicate good field control of asphalt content on all sections with the exception of the Contract 2880 Hveem sections in which asphalt content was high. In-place air voids among the Superpave and Hveem sections within a project were typically similar. The only exception was the bottom lift of the Superpave sections on the 2880 Contract. Note however that the top lift air voids are similar among the Superpave and Hveem sections for this contract.

The HMA plant used for the contract 2880 project did not incorporate a system to accurately meter the return of baghouse fines into the mix. Thus, all or none of the baghouse fines can be returned. When the bottom lifts of the mixtures were placed all of the baghouse fines were returned to the mixtures. Quality control tests indicated that the amount of material passing the #200 sieve was greater than the target values. Therefore when the top lifts were placed all baghouse fines were rejected. Then for the top lifts the observed and target p#200 levels were essentially equal. The high fines content in the bottom HMA lift of the mixtures played a significant role in compaction and resulted in low in-place air voids measured on field cores for the Superpave sections.

In-place air voids in both HMA lifts were measured on cores taken immediately after construction. These data showed the over-compaction of the lower lifts of both Superpave mixtures. Even though the p#200 were high (above target) in the Hveem mixtures also, low in-place air voids were not experienced. This suggests that the Hveem mixtures were less sensitive to p#200.

Laboratory Performance Testing

Available relevant laboratory performance test results are described in this section. The information in this section and the previous one are then used to try to explain the observed field performance. The focus of the laboratory data review is placed on rutting and durability/age hardening/cracking.

Repeated Shear at Constant Height Tests

Repeated Shear at Constant Height (RSCH) tests were performed in accordance with AASHTO TP-7 on FMLC and field core samples at 5°C to assess potential rutting behavior. The FMLC samples were prepared with target air voids of 3±0.5 percent as specified in AASHTO TP-7. The observed air voids and permanent strain after 5000 load cycles (γ_{max}) data are presented in Table 13 for the FMLC and core specimens. There are significant differences in γ_{max} between FMLC and core test specimens. The bulk of the differences are likely due to the difference in compaction method, and to some degree specimen air voids. In all cases the observed γ_{max} values are much larger for core specimens than FMLC specimens. This indicates sensitivity of the RSCH test to compaction method and air void level.

In general the observed trends in γ_{max} and air voids as a function of time are logical with

γ_{max} and air voids both decreasing with age. With the exception of Contract 2827, the data suggest that the NV mixtures would be more rut resistant than the SP mixtures. It also suggests that mixtures made with modified asphalt binders would be more rut resistant than mixtures made with neat asphalt binders. The limited anomalies in the data are more likely due to test method variability than actual material property differences. It should be noted that the difference in air voids between Tables 11 and 13 are primarily due to field sampling location. This is particularly true for Contracts 2751 and 2827, where sampling locations for quality control testing as well as annual coring for performance testing were never the same.

McNamara also conducted RSCH tests on FMLC specimens from the Contract 2880 project (10). Replicate tests were conducted at 50°C on specimens compacted to N_{design} gyrations in a Superpave gyratory compactor, rather than to a specified air void level. The RSCH test results are presented in Table 14 and show mixture rankings from best to worst. This data further support the suggested finding associated with the data presented in Table 13.

Resilient Modulus

Resilient modulus (M_R) tests were also performed on FMLC and field core samples over time at 25°C in accordance with ASTM D4123 to assess potential performance on the Contract 2880 project only. The data are presented in Table 15 and show that laboratory reheating for compaction induced some aging as noted by FMLC modulus values consistently being greater than the modulus values on cores at comparable air void levels taken immediately after construction. The air void level targeted for the FMLC specimens was equal to the year 0 air void level of the cores. The data in Table 15 shows that the NV mixtures have higher modulus than the Superpave mixtures, although both were constructed with the same asphalt binder. This is an interesting observation unexplained by air voids and likely due to the denser aggregate gradations employed for the NV mixtures. The observed trends in M_R are very similar to the observed trends in RSCH test results presented in Table 13. To assess time hardening and its potential influence on durability/cracking and rutting performance, the ratios of core modulus values at age 3 years to age 0 years were determined. Interestingly, the hardening ratios are shown in Table 15 do not rank consistently among binder type.

The data in Table 15 show reductions in air voids were observed for all four mixtures over time. The SPPG64-22 mixture that exhibited excessive rutting experienced the greatest reduction in air void, while at the same time the SPAC-20P mixture that also exhibited significant rutting showed only a nominal change in air voids.

Recovered Asphalt Binder Stiffness (Viscosity)

Asphalt binder was extracted and recovered from loose mixtures sampled behind the paver as well as cores on all of the projects as a function of time to determine if any relationship existed between binder stiffness or hardening and performance. The testing was performed in accordance with ASTM D2172, D5404, and D4402. The recovered binder viscosities are presented in Table 16. The PG64-28 binder used on Contract 2751 was about twice as stiff as the binders used on the other Contracts at 135 degrees Celsius. As expected, increases in viscosity were observed with time for the first couple of years. Then there is a consistent drop in observed viscosities. This is not surprising consider the large coefficient of variation reported for viscosity measurements on recovered asphalt binders in ASTM D1856 (ASTM D5404 does not incorporate a precision statement) (11). Similar to the resilient modulus data, hardening ratios (or aging indices) were determined from the data. The ratios were calculated from the first year core data that was available and the unaged original asphalt viscosities(Table 16).

FIELD PERFORMANCE AND LABORATORY TEST RESULTS

The laboratory test results described above were used to try to explain the observed field performance. To assist with this effort Tables 17 and 18 were developed. Anticipated performance were grouped into two general categories: 1) durability, cracking and fatigue, and 2) rutting. The laboratory test results were then used to rank anticipated performance from best to worst with a ranking of 1 representing the best performance and diminishing performance represented by an increasing rank greater than 1. The parameters considered included optimum asphalt content from mixture designs, γ_{max} from RSCH tests, mixture stiffness (M_R) and hardening ratio, and recovered binder stiffness and hardening ratio. Table 17 shows relative anticipated field performance among the mixtures within each contract based on laboratory tests. Quality control data were not considered in this effort as quality control data would not be available in the mixture design process.

Table 18 shows the actual effectiveness of the laboratory tests in ranking actual relative field performance. The effectiveness of the test methods was determined by comparing the rankings in Table 17 to the actual durability/cracking/fatigue and rutting performance rankings observed in the field. The information in Table 18 suggests that relative optimum asphalt contents may be an indicator of durability/cracking/fatigue and are likely a reasonable indicator of rutting potential. RSCH, M_R, and recovered asphalt binder stiffness all led to appropriate field performance rankings for the projects. Somewhat surprisingly, neither recovered asphalt binder stiffness nor hardening ratio was effective in ranking observed durability/cracking/fatigue performance. Question marks are shown in Table 18 for situations where the effectiveness of a given test could not be assessed because either rutting or durability/cracking/fatigue were not observed on field projects.

FUTURE IMPLEMENTATION/RESEARCH

Based on the knowledge gained to date through the field and laboratory evaluations described in this report, NDOT has initiated additional research to further refine mix design methods and specifications and field test them in Nevada. During the 2002 construction season two Superpave field test sections were constructed and two more will be constructed during the 2003 construction season. The Superpave volumetric design procedure is being followed with the following supplemental changes:

1. The NDOT "PG Plus" binder specification which dictates polymer modification will be employed;
2. The Restricted Zone will be encroached upon;
3. At the optimum asphalt content identified using the Superpave volumetric criteria, specimens will be compacted in a Kneading compactor and Hveem Stability will be measured (37 minimum criteria); and
4. The Asphalt Pavement Analyzer will be used as a rutting performance indicator in lieu of the SST for simplicity.

CONCLUSIONS AND RECOMMENDATIONS

To assess implementation and applicability of the Superpave mixture design method specifically for conditions in Nevada a cooperative research effort was undertaken by NDOT. A series of mixtures were designed for a range of traffic and environmental conditions typically encountered in Nevada using both the Superpave and Hveem mix design methods. The mixtures were then placed in the field to allow for direct performance comparisons under actual field conditions. Extensive laboratory evaluations were also conducted on the materials pre-, during-, and post-construction. A suite of laboratory performance tests were performed on the project materials to evaluate rutting, fatigue, and durability performance over time. Field performance was also monitored for up to five years after construction. Contrasting laboratory test results and field performance led to the refinement of materials selection and mixture design procedures that will be implemented by NDOT on a trial basis during the 2002 and 2003 construction seasons.

Specific findings observed in this effort and recommendations were:

- The application of Superpave and Hveem mix design methods to the same materials resulted in optimum asphalt contents ranging from very similar to significantly different (≈1% difference).
- Construction quality control and field performance data suggest that the fine graded mixtures are less sensitive to deviations in asphalt content and passing #200 from the target values than coarse graded mixtures.
- Mixtures incorporating polymer modified asphalt binder performed better than mixtures employing neat PG binders.
- Mixtures with gradations passing through the restricted zone performed better than coarse graded mixtures.
- The stiffness of mixtures with gradations passing through the restricted zone were greater than the stiffness of coarse graded mixtures made from the same materials (binder and aggregate sources).
- The field performance of Hveem designed mixtures was equal to or better than the performance of Superpave designed mixtures on low and high traffic volume projects.

Hveem designed mixtures exhibited less durability/cracking/fatigue in low traffic environments and less rutting in high traffic environments.

- The RSCH test appropriately ranked rutting performance observed in this study. However the test appears to be very sensitive to sample preparation method (SGC vs. field compaction) and air void level.
- The resilient modulus test also appropriately ranked rutting performance observed in this study.
- Neither recovered asphalt binder stiffness nor aging index appropriately ranked durability/cracking/fatigue performance.
- The Superpave field and laboratory evaluations conducted to date in Nevada have proven to be valuable and will shape the next generation of materials specifications and mixture design test methods.
- Continued support should be provided at the national level for refinement of the Superpave system, development of a PG binder specification that recognizes the benefits of polymer modification, laboratory performance test developments, and performance modeling.

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TABLES

Table 1. Superpave Mix Design for Contract 2751.

Binder Properties (64-28)		
Property	Measured	Specification
Flash Point, (°C)	240	> 230
Mass Loss, (%)	0.33	< 1.0
Brookfield Viscoisty, (Pa*S), @ 135°C	0.91	< 3.0
Original G*/(sinδ), (kPa), @ 64 °C	1.4	> 1.0
RTFOT G*/(sinδ), (kPa), @ 64 °C	2.6	> 2.2
PAV G*(sinδ), (kPa), @ 19°C	1700	< 5000
Creep Stiffness, (Mpa), @ -18°C	213	< 300
Slope (m), @ -18°C	0.31	> 0.30
Direct Tension, Fail Strain % @ -18°C	N/a	> 1.0
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
Mixtures Properties		
Property	Measured	Specification
% Gmm at N_{design}	96.0	96.0
% AC (by twm)	6.3	n/a
% VMA at N_{design}	17.1	>13.0
% VFA at N_{design}	77	65 – 78
Filler to Effective AC Ratio at N_{design}	0.8	0.6 -1.2
% Gmm at $N_{initial}$	86	< 89.0
%Gmm at N_{max}	98	< 98.0
Retained Strength Ratio, (%)	N/a	> 80

Table 2. Hveem Mixture Design Properties for Contract 2751.

Binder Content % by dwa	Hveem Stability	Air Voids (%)
5.0	46	8.0
5.5	44	5.6
6.0	40	4.3
6.5	31	3.3
7.0	0	1.4

Table 3. Superpave Mix Design for Contract 2827.

Binder Properties (PG64-34)		
Property	Measured	Specification
Flash Point, (°C)	266	> 230
Mass Loss, (%)	0.27	< 1.0
Brookfield Viscoisty, (Pa*S), @ 135°C	0.41	< 3.0
Original $G^*/(\sin\delta)$, (kPa), @ 64°C	1.3	> 1.0
RTFOT $G^*/(\sin\delta)$, (kPa), @ 64°C	2.7	> 2.2
PAV $G^*(\sin\delta)$, (kPa), @ 22°C	1600	< 5000
Creep Stiffness, (Mpa), @ -24°C	213	< 300
Slope (m), @ -24°C	0.31	> 0.30
Direct Tension, Fail Strain % @ -24°C	na	> 1.0
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
Mixtures Properties		
Property	Measured	Specification
% Gmm at N_{design}	96	96.0
% AC (by twm)	5.6	n/a
% VMA at N_{design}	14.3	13.0
% VFA at N_{design}	72	65 - 75
Filler to Effective AC Ratio at N_{design}	1.03	0.6 -1.2
% Gmm at $N_{initial}$	86	< 89.0
%Gmm at N_{max}	98	< 98.0
Retained Strength Ratio, (%)	na	> 80

Table 4. Hveem Mixture Design Properties for Contract 2827.

Binder Content % by dwa	Hveem Stability	Air Voids (%)
6.0	44	8.2
6.5	44	7.3
7.0	46	5.4
7.5	44	4.1
8.0	41	2.5

Table 5. Superpave Mix Design for Contract 2880, section SPAC-20P.

Binder Properties (AC-20P)		
Property	Measured	Specification
Flash Point, (^{o}C)	284	> 230
Mass Loss, (%)	0.38	< 1.0
Brookfield Viscoisty, (Pa*S), @ 135^{o}C	0.41	< 3.0
Original $G^*/(\sin\delta)$, (kPa), @ 58^{o}C	1.8	> 1.0
RTFOT $G^*/(\sin\delta)$, (kPa), @ 58^{o}C	2.5	> 2.2
PAV $G^*(\sin\delta)$, (kPa), @ 22^{o}C	2920	< 5000
Creep Stiffness, (Mpa), @ -12^{o}C	199	< 300
Slope (m), @ -12^{o}C	0.40	> 0.30
Direct Tension, Fail Strain % @ -12^{o}C	1.8	> 1.0
Aggregate Properties		
Property	Measured	Specification
Coarse Aggregate Angularity, (%)	100/100	> 85/80
Fine Aggregate Angularity, (%)	46	> 40
Flat and Elongated Particles, (%)	0	< 10
Sand Equivalent, (%)	72	> 45
Mixtures Properties		
Property	Measured	Specification
% Gmm at N_{design}	96	96.0
% AC (by twm)	5.8	n/a
% VMA at N_{design}	14.7	13.0
% VFA at N_{design}	73	65 - 75
Filler to Effective AC Ratio at N_{design}	1.32	0.6 -1.2
% Gmm at $N_{initial}$	87	< 89.0
%Gmm at N_{max}	97	< 98.0
Retained Strength Ratio, (%)	96	> 80

Table 6. Hveem Mixture Design Properties for Contract 2880, section NVAC-20P.

Binder Content % by dwa	Hveem Stability	Air Voids (%)	VMA (%)
3.5	48	7.2	15.6
4.0	47	5.7	15.3
4.5	46	4.0	14.8
5.0	38	2.1	14.1
5.5	33	0.9	14.0

Table 7. Superpave Mix Design for Contract 2880, section SPPG64-22.

Binder Properties (PG64-22)		
Property	Measured	Specification
Flash Point, (°C)	340+	> 230
Mass Loss, (%)	0.14	< 1.0
Brookfield Viscoisty, (Pa*S), @ 135°C	0.38	< 3.0
Original G*/(sinδ), (kPa), @ 64°C	1.23	> 1.0
RTFOT G*/(sinδ), (kPa), @ 64°C	2.7	> 2.2
PAV G*(sinδ), (kPa), @ 25°C	3070	< 5000
Creep Stiffness, (Mpa), @ -12°C	167	< 300
Slope (m), @ -12°C	0.34	> 0.30
Direct Tension, Fail Strain % @ -12°C	1.7	> 1.0
Aggregate Properties		
Property	Measured	Specification
Coarse Aggregate Angularity, (%)	100/100	> 85/80
Fine Aggregate Angularity, (%)	46	> 40
Flat and Elongated Particles, (%)	0	< 10
Sand Equivalent, (%)	72	> 45
Mixtures Properties		
Property	Measured	Specification
% Gmm at N_{design}	96	96.0
% AC (by twm)	5.8	n/a
% VMA at N_{design}	13.9	13.0
% VFA at N_{design}	72	65 - 75
Filler to Effective AC Ratio at N_{design}	1.35	0.6 -1.2
% Gmm at $N_{initial}$	87	< 89.0
%Gmm at N_{max}	98	< 98.0
Retained Strength Ratio, (%)	87	> 80

Table 8. Hveem Mixtures Design Properties for Contract 2880, section NVPG64-22.

Binder Content % by dwa	Hveem Stability	Air Voids (%)	VMA (%)
4.0	41	7.8	16.1
4.5	41	5.7	15.1
5.0	43	3.4	14.0
5.5	31	2.1	13.9

Table 9. Field Condition Surveys Summary.

Contract	Project	Age (years)																							
		Rut Depth (mm)						% Transverse and Block Cracking						% Fatigue Cracking						Raveling					
		0	1	2	3	4	5	0	1	2	3	4	5	0	1	2	3	4	5	0	1	2	3	4	5
2751	SPPG64-28	None reported						5	0	0	1	1	2	5	0	0	0	30	35	Na			S	Na	H
	NVPG64-28							5	0	0	1	10	16	5	0	0	3	35	23	Na			S	Na	M
2827	SPPG64-34							30	0	0	0	0		5	0	1	51	45		Na				M	
	NVPG64-34							30	0	0	0	0		5	0	0	5	7		Na				S	
2880	SPAC-20P		6	7	7			None reported						None reported						None reported					
	SPPG64-22		8	13	R & R																				
	NVPG64-22		4	5	5																				
	NVAC-20P		3	4	4																				

* L=low, M=moderate, and H=high severity and extent

Table 10. Post-Construction Evaluation Methods.

Performance Parameter	Test Method	Test Specimen Types and Projects		
		LMLC	FMLC	FMFC
Rutting	AASHTO TP-7 (RSCH)	2751 2827 2880	2751 2827 2880	2751 2827 2880
Stiffness	ASTM D4125 (Resilient Modulus)			2880
Fatigue	AASHTO TP-8 (Flexural Beam Fatigue)	2751 2827 2880	2751 2827 2880	2751 2827 2880
Thermal Cracking	AASHTO TP-10 (TSRST)	2751 2827 2880	2751 2827 2880	2751 2827 2880
Moisture Sensitivity	AASHTO T283 (Modified Lottman)	2751 2827 2880	2751 2827 2880	2751 2827 2880
Durability (Age Hardening)	ASTM D4402 (Rotational Viscosity)		2751 2827 2880	2751 2827 2880

Table 11. Optimum or Design Asphalt Contents.

Contract	Section	N_{design}	Gradation Type	Optimum Asphalt Contents (%)	
				Total weight of mix	Dry weight of agg.
2751	Superpave	76	Coarse	6.3	6.7
	Hveem	N/a	Fine	5.7	6.0
2827	Superpave	86	Coarse	5.6	5.9
	Hveem	N/a	Fine	7.0	7.5
2880	Superpave	96	Coarse	5.8	6.2
	Hveem	N/a	Fine	4.3	4.5

Table 12. Construction Quality Control Data.

Contract	Section	Asphalt Contents (%)				In-Place Air Voids (%)		
		Target	Top Lift	Bottom Lift	Average	Top Lift	Bottom Lift	Average
2751	SPPG64-28	6.3	5.7	N/a	5.7	5.1	N/a	5.1
	NVPG64-28	6.0	6.2	N/a	6.2	5.3 (7.5)	N/a	5.3 (7.5)
2827	SPPG64-34	5.6	5.6	N/a	5.6	9.0	N/a	9.0
	NVPG64-34	7.5	7.3	N/a	7.3	7.7 (8.3)	N/a	7.7 (8.3)
2880	SPAC-20P	5.8	6.0	5.7	5.9	5.7	2.0	3.8
	SPPG64-22	5.8	6.0	6.4	6.2	5.8	2.0	3.9
	NVPG64-22	4.5	5.3	4.9	5.1	6.2	6.0	6.1
	NVAC-20P	4.5	5.4	5.2	5.3	6.3	6.5	6.4

Table 13. Permanent Deformation Characteristics of Contracts 2751, 2827, and 2880 Mixtures.

Contract	Mixture	Property	Core Ages (years)					
			0 (FMLC)	0	1	2	3	4
2751	SPPG64-28	γ_{max} @50°C, %	0.8	N/a	5.9	2.1	3.5	3.7
		Air Voids, %	2.5	N/a	5.1	4.4	4.4	4.3
	NVPG64-28	γ_{max} @50°C, %	0.5	N/a	0.3	0.2	0.2	0.1
		Air Voids, %	2.9	N/a	5.3	6.1	8.4	7.8
2827	SPPG64-34	γ_{max} @50°C, %	0.5	N/a	3.0	2.9	0.50	
		Air Voids, %	3.5	N/a	9.1	5.8	4.1	
	NVPG64-34	γ_{max} @50°C, %	0.7	N/a	5.2	N/a	5.0	
		Air Voids, %	3.0	N/a	7.7	N/a	3.6	
2880	SPAC-20P	γ_{max} @50°C, %	1.4	2.5	1.5	1.7	2.1	
		Air Voids, %	3.0	4.4	4.4	3.7	3.8	
	SPPG64-22	γ_{max} @50°C, %	1.5	failed prior to test	3.1	2.6	2.0	
		Air Voids, %	2.8		5.2	4.4	2.7	
	NVPG64-22	γ_{max} @50°C, %	0.6	1.5	N/a	1.2	1.9	
		Air Voids, %	3.0	5.1	N/a	5.4	3.7	
	NVAC-20P	γ_{max} @50°C, %	1.1	2.7	N/a	0.8	0.8	
		Air Voids, %	3.4	4.8	N/a	5.1	3.9	

Table 14. RSCH Results on FMLC Specimens at N_{des} Gyrations.

Contract	Mixture	Average Permanent Strain at 5000 Load Cycles (%)	Standard Deviations	Rank (Best to Worst)
2880	SP PG64-22	2.5	0.36	4
	SP AC-20P	1.5	0.18	3
	NV PG64-22	0.8	0.20	2
	NV AC-20P	0.7	0.17	1

Table 15. Resilient Modulus of Mixtures Used on Contract 2880.

Mixture	Property	Core Ages (years)				Hardening Ratio
		0 (FMLC)	0	1	3	
SPAC-20P	M_R @ 25°C, ksi	394	334	362	632	1.9
	Air Voids, %	4.1	4.7	4.6	4.5	
SPPG64-22	M_R @ 25°C, ksi	348	213	374	449	2.1
	Air Voids, %	4.3	N/a	5.1	2.0	
NVPG64-22	M_R @ 25°C, ksi	581	508	N/a	795	1.6
	Air Voids, %	5.2	5.3	N/a	3.7	
NVAC-20P	M_R @ 25°C, ksi	605	534	N/a	1188	2.2
	Air Voids, %	5.1	4.9	N/a	3.9	

Table16. Recovered Asphalt Binder Stiffness.

Contract	Mixture	Rotational Viscosity at 135°C						Hardening Index
		Core Age (years)						
		0 (Unaged Original Asphalt Binder)	0 (Loose Field Mix)	1	2	3	4	
2751	SPPG64-28	0.910					1.346	1.48
	NVPG64-28	0.910					3.546	3.90
2827	SPPG64-34	0.412				1.100		2.67
	NVPG64-34	0.412				1.912		4.64
2880	SPAC-20P	0.416	0.754	0.812	0.815	0.750		1.81
	SPPG64-22	0.375	0.675	0.705	0.788	0.821		1.80
	NVPG64-22	0.416	0.856	0.900	0.937	1.113		2.06
	NVAC-20P	0.375	0.685	0.800	0.905	0.825		1.83

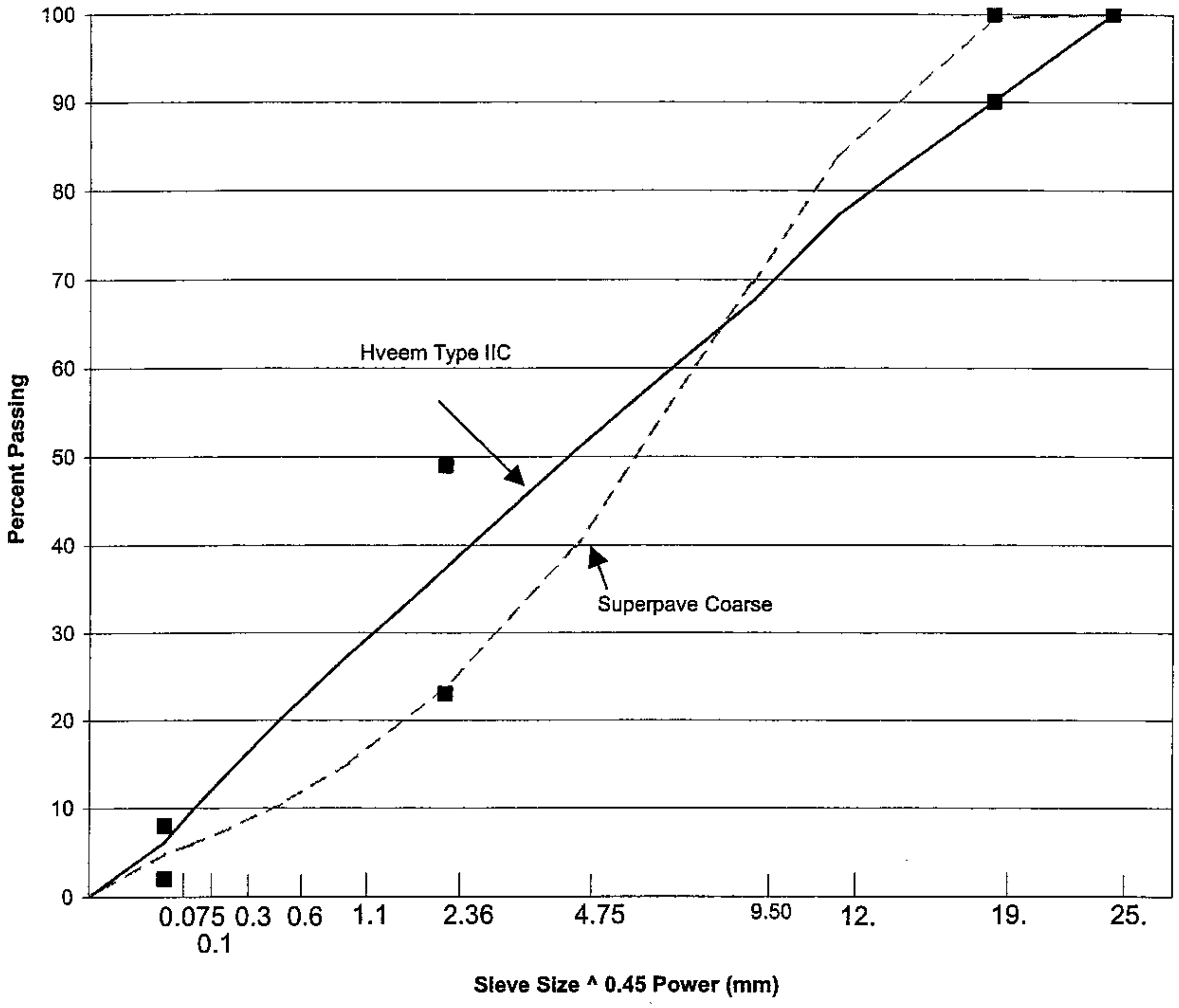

Figure 3. Gradations of Mixtures used on Contract 2880.

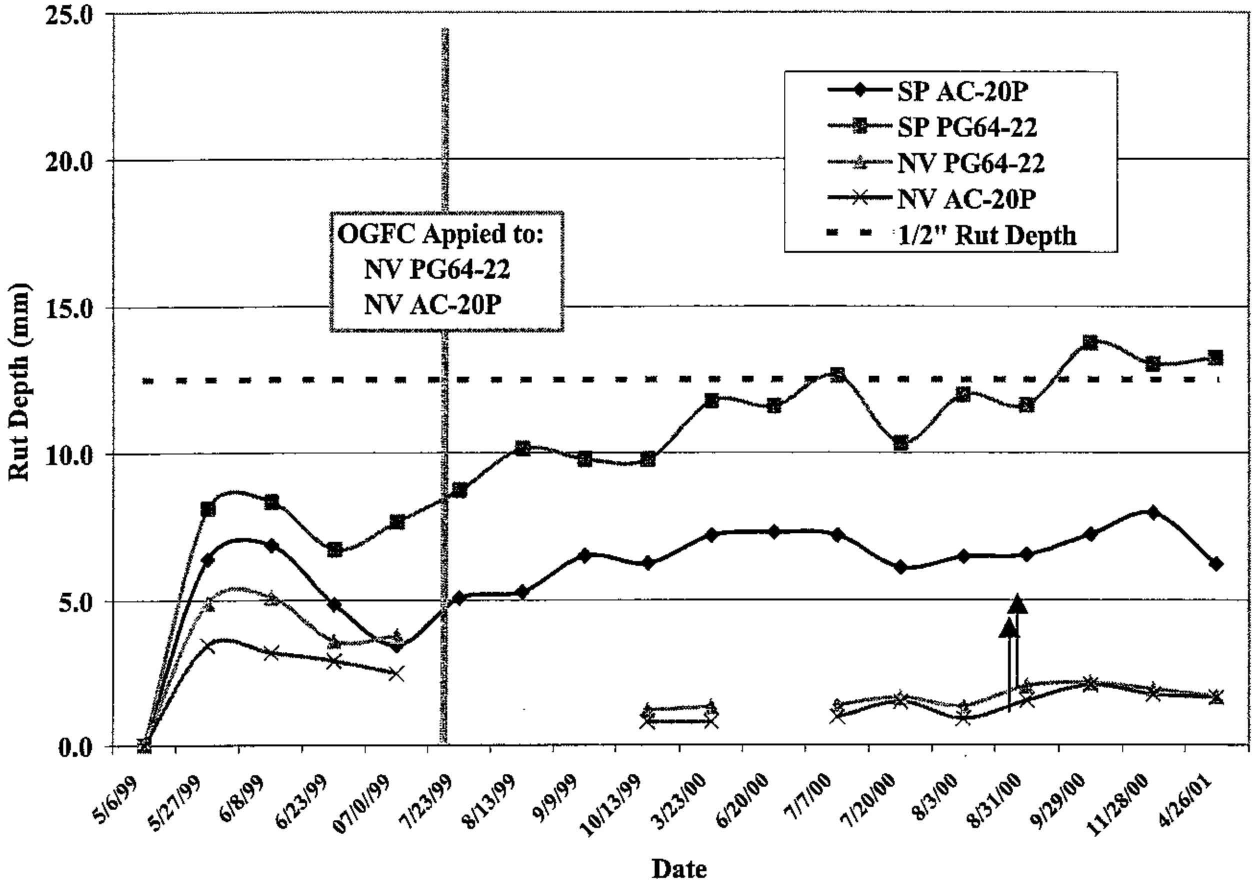

Figure 4. Observed Rutting on Contract 2880.

Figure 5. Contract 2751 NVPG64-22.

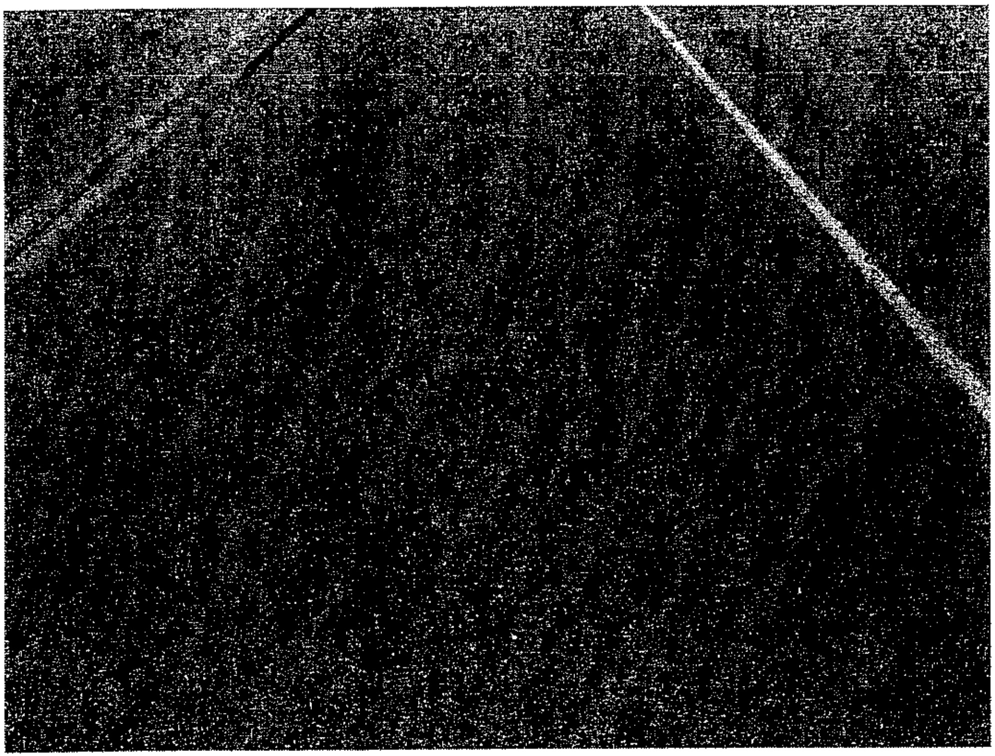

Figure 7. Contract 2827 NVPG64-34.

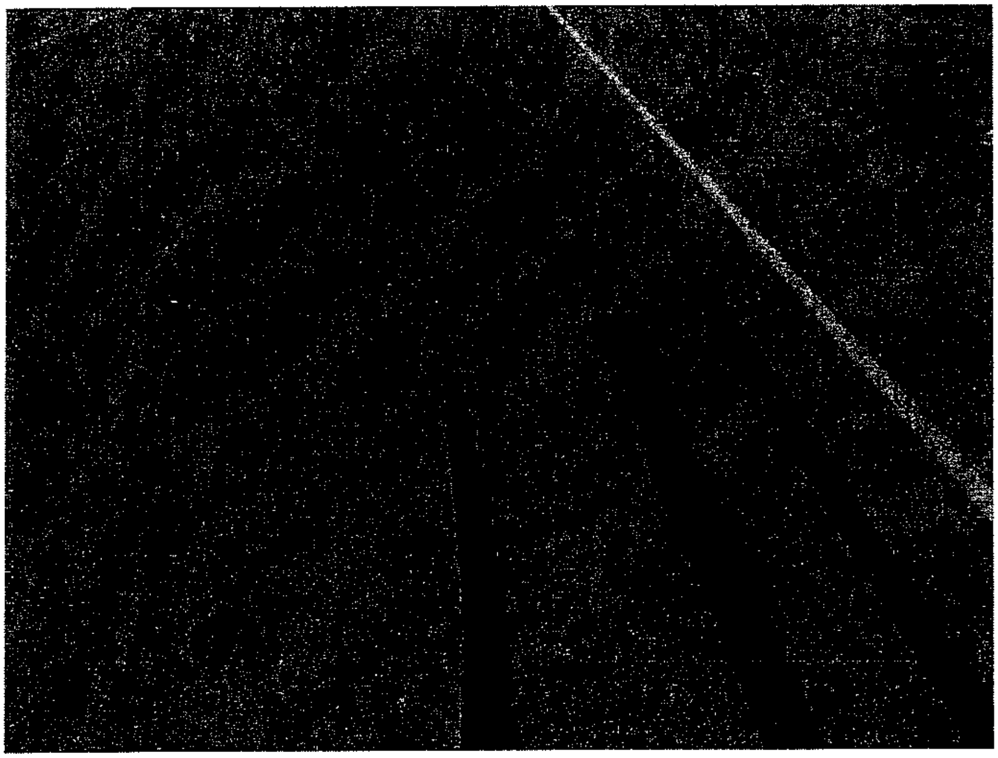

Figure 8. Contract 2827 SPPG64-34.

Kenny C. Guinn, Governor

Nevada Department of Transportation
Tom Stephens, P.E. Director
Prepared by Research Division
Alan Hilton, Research Manager
(775) 888-7803
ahilton@dot.state.nv.us
1263 South Stewart Street
Carson City, Nevada 89712