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EVALUATION OF RUTTING RESISTANCE OF SUPERPAVE AND HVEEM MIXTURES
VOLUME I – INTRODUCTION AND BACKGROUND

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16. Abstract

An in-depth evaluation of the Superpave system has been jointly undertaken by the Nevada Department of Transportation (NDOT) and the University of Nevada Pavements/Materials Program to assess the performance of the Superpave system in both laboratory and field settings. 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.

The research activities conducted under this effort 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 were constructed which included Superpave and Hveem test sections to be 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 and construction of the field projects.

This report is the first in a series of four reports which document the permanent deformation evaluation studies that were conducted on mixtures used on various field projects. The field projects included sections of Hveem and Superpave designed mixtures with polymer modified and unmodified asphalt binders.

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INTRODUCTION

With the recent dramatic changes in asphalt binder properties, traffic volumes, traffic weights, and tire pressures, a significant increase in rutting of asphalt concrete pavements has been observed across the United States and Canada. In 1987, the Strategic Highway Research Program (SHRP) began a five-year $150 million dollar study with $50 million earmarked to address and provide solutions to performance problems observed in hot mix asphalt (HMA) pavements (1). One of the major products from the SHRP asphalt program was the development of the Superpave volumetric mix design and analysis system. To address performance issues such as permanent deformation, fatigue, and low temperature cracking, the Superpave analysis system developed advanced testing equipment along with corresponding performance models.

An in-depth evaluation of the Superpave system has been jointly undertaken by the Nevada Department of Transportation (NDOT) and the University of Nevada Pavements/Materials Program to assess the performance of the Superpave system in both laboratory and field settings. 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.

The research activities conducted under this effort 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 were constructed which included Superpave and Hveem test sections to be 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 and construction of the field projects.

This report is the first in a series of four reports which document the permanent deformation evaluation studies that were conducted on mixtures used on various field projects. The field projects included sections of Hveem and Superpave designed mixtures with polymer modified and unmodified asphalt binders. The following represents the titles of the reports series. Since the major effort was to evaluate the permanent deformation characteristics of the mixtures, the individual reports are identified by the specific task that is documented in each one.

Volume I: Evaluation of Rutting Resistance of Hveem and Superpave Mixtures - Introduction and Background

Volume II: Evaluation of Rutting Resistance of Hveem and Superpave Mixtures - Impact of Aggregate Gradations

Volume III: Evaluation of Rutting Resistance of Hveem and Superpave Mixtures - Impact of Gyratory Compaction

Volume IV: Evaluation of Rutting Resistance of Hveem and Superpave Mixtures - Impact of Mixtures Source and Moisture Sensitivity

BACKGROUND

The road building industry has undergone considerable changes within the last decade with regards to 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 the produced mixtures under field-loading conditions. The development of laboratory performance tests and subsequent performance models was one of the major goals of the Strategic Highway Research Program (SHRP) which was initiated in 1987 (1). This section provides an overview of permanent deformation of asphalt concrete mixtures and reviews the current methodologies regarding causes, laboratory test procedures, and performance prediction models associated with this failure mechanism.

Permanent Deformation

One of the major forms of distress present in HMA pavements is rutting or permanent deformation. This distress is characterized by longitudinal depressions in the wheel paths of a roadway with small upheavals to the sides as shown in Figure1 (2,3). This figure clearly indicates that there appears to be two distinct phases associated with the rutting phenomena. In the first phase, traffic loading causes significantly larger amounts of irreversible deformation directly below the tires, with very little occurring in the upheaval zones. The second phase occurs a number of years (load cycles) into the pavements life after initial densification of the HMA mixture has taken place. At this point, deformation directly below the tire and in the upheaval zone increases at approximately the same rate (4).

Once ruts reach depths greater than 0.2 inch, hydroplaning and steering problems can be expected which directly result in a reduction in the overall level of service of the section and are a major safety concern to motorists (3).

Causes of Permanent Deformation

Permanent deformation or rutting of asphalt concrete pavements can result from consolidation, mechanical deformation, or plastic flow (3). Consolidation is defined as the compaction a pavement incurs from traffic loading immediately after its initial construction. During construction, it is imperative that control of in place density be strictly monitored to ensure that air voids in the HMA layer are within the 4%-8% range. From construction experience, it is well documented that air-void contents greater than 10% will produce mixtures with poor stability under initial traffic loading which can lead to premature rutting (4). Mechanical deformation can also arise from traffic compaction and bearing compaction type of failure of the base, subbase, or subgrade after a number of years of traffic loading. The compaction of the supporting layers results in the development of ruts in the pavement surface. The final mode of failure is plastic flow, which occurs in HMA mixtures containing excessive amounts of asphalt binder and insufficient air voids. In mixtures with these properties, the asphalt binder behaves as a lubricant and reduces the internal friction or stability of the mixture promoting the development of ruts under areas of high load concentrations.

For properly constructed pavements, it is generally speculated that plastic flow caused by the application of large shear stresses in the upper portion of the HMA layers is the governing failure mechanism (5). In addition, severity of permanent deformation is directly correlated to the temperature of the HMA mixture. Moreover, it has been well documented that high temperature regions of the United States such as Nevada, Arizona, Texas and Florida are highly susceptible to this form of pavement distress (4).

The development of permanent deformations in HMA mixtures has been shown to be correlated to the following properties (6):

- Increased traffic loads,
- Increased tire pressures,
- Selection of excessively high asphalt contents,
- Excessive minus 200 material (fines),
- Use of rounded aggregates,
- Rate of traffic loading,
- High in service pavement temperatures,
- Air void contents,
- Soft asphalts,
- Age (function of stiffness).

As can be concluded from Table 1, aggregate, binder, and mixture properties greatly influence the permanent deformation characteristics of HMA pavements (7).

Aggregates Properties

Aggregate properties such as surface texture, angularity, and nominal maximum size have been shown to greatly affect a mixture's resistance to permanent deformation (1,6). Cross et al. examined the effect of gradation on permanent deformation properties of HMA mixtures using the APA rut tester and four mixtures with gradings ranging from coarse to fine (8). The results of this study indicated that finer gradations had significantly more resistance to shear deformation than the coarser gradation as measured by the rut tester. Furthermore, it appeared that the fine-graded mixtures were less sensitive to performance loss, due to coarsening of the gradation (segregation), than observed with the coarse mixtures.

Research performed by El-Basyouny et al. fabricated gradations passing above, through, and below the Superpave restriction zone in an attempt to examine gradation effects on permanent deformation resistance of HMA mixtures (9). Creep tests were performed on each gradation and predicted rut depths were calculated using the VESYS-3AM software package. It was concluded that the mixture passing below the restriction zone exhibited the least amount of predicted rut depth compared to the other two gradations. This conclusion contradicts results obtained by both Cross et al. and the findings from WesTrack that indicated coarse gradations passing below the restriction zone had significantly less shear resistance as compared to fine gradations reviewed in both experiments (6,8). One must remember that El-Basyouny et al. used creep parameters and VESYS-3AM software to predict long-term performance, which is only an estimation of the expected performance.

Roque et al. examined eighteen different gradations fabricated with various amounts of material retained on the 12.5mm, 9.5mm, 4.75mm, and 2.00mm sieves (10). The goal of this study was to investigate the impact of changes in gradations on the shear resistance of HMA mixtures. From the data reviewed, it was concluded that the shear resistance of HMA mixtures appears to be strongly correlated to the coarse-aggregate fraction (material above the 2.00mm size) of the gradation. The final conclusion from this study was that coarse-graded mixtures similar to SMA and Superpave coarse-type aggregate gradations, appear to posses superior shear resistance to that observed in all other gradation types.

Binder Properties

The consistency or stiffness of the asphalt binder plays a significant role in the overall resistance of HMA mixtures to permanent deformation (4). During the development of the Superpave performance-grade binder system, a significant effort was exerted to characterize the rutting potential of the asphalt binder. Methodology indicates that for rutting resistance, asphalt binders with both high complex modulus (G*) and low phase angles (δ) are desirable (11). The larger the G*, the stiffer the binder will be, and similarly the lower the phase angle, the more the binder will perform as an elastic material thus incurring minimal plastic strain. Developed directly from the SHRP research, the energy equation for sinusoidal loads is expressed as follows (11):

$$W_c = \pi \times \sigma_o^2 \frac{1}{G^*/\sin\delta} \qquad (11)$$

where

W_c = work dissipated per load cycle,

σ_o = Stress applied during the load cycle,

G^* = complex modulus,

δ = phase angle.

This relationship indicates that in order to minimize permanent deformation in the asphalt binder, the work dissipated after each load cycle should be minimized.

In recent years, there has been an increase in the use of modified asphalt binders throughout the pavement industry. Modifiers such as polymers and microfillers have been shown to increase a mixture's resistance to permanent deformation (12). Marccarrone et al. performed a study in which a direct comparison was made between modified and unmodified asphalt binders and their resistance to permanent deformations using the accelerated loading facility (ALF) (13). Results from this study indicated that the use of modified binders significantly increases the resistance of HMA mixtures to permanent deformations. The resistance of modified mixtures was upwards of 5 to 8 times that obtained with unmodified mixtures using the same aggregate gradations. Also, a significant reduction in the rate of rutting with increase in temperature was observed in mixes using the modified asphalt binders.

Mixture Properties

Mixture properties such as asphalt binder content and air-void content also play a significant role in the permanent deformation characteristics of HMA mixtures. Research performed by Mahboub et al. indicated that excessive asphalt contents and subsequent lower air-void levels had a tendency to result in mixtures with increased rutting potential (14). Furthermore, it was concluded that when specimens are tested at excessively high asphalt binder contents, the binder appears to "lubricate" the mixture thus reducing the internal friction between the aggregates and the overall stability of the mix.

An extensive field study was performed in 1987 by the National Center for Asphalt Technology (NCAT) to review construction practices and their influence on rutting potential of HMA pavements (15). From this study, which reviewed forty-two different pavement sections, it was concluded that mixtures with in-place air voids below 3% were susceptible to premature rutting. In addition, it was concluded that the use of angular aggregates significantly improved the strength of the aggregate skeleton, resulting in an increase in the resistance to permanent deformation.

Laboratory Test Procedures

At the present time, a number of laboratory tests exist that are used to evaluate the resistance of HMA mixtures to permanent deformation. With the advent of modern-day, closed-loop electro-hydraulic test systems and computers, the ability to accurately quantify permanent deformation properties of asphalt concrete mixtures has greatly improved. However, simulating the actual state of stress a pavement encounters in the field with a single laboratory test procedure is still a difficult, if not an impossible task. The following subsections outline tests currently used to measure permanent deformation properties of HMA mixtures. While reviewing these sections, the reader is reminded that the objective of any laboratory test procedure is to be:

1. Able to simulate the state of stress a sample will be subjected to in the field.
2. Simple in design and operation.
3. Very repeatable.
4. Fast, as to minimize testing times as much as possible.
5. Test used for mix design and structural design.

Repeated Load Triaxial Test

One of the most popular and fundamental laboratory test procedures to measure permanent deformation resistance of HMA mixtures is the repeated load triaxial test (RLTT). Although this test can be performed using either a static or dynamic load application, the dynamic-load test is favored due to its ability to vary stress conditions applied to the test specimen. Research conducted by Fwa et al. showed that the repeated load test is a very effective tool in modeling pavement response under moving traffic loads (16).

The triaxial test applies a repeated vertical stress to a sample while simultaneously applying a confining pressure that simulates the confining pressure observed by a typical pavement section in the field. The duration of load pulse cycles, magnitude of the deviator and confining stresses, and all other test parameters are selected in an attempt to replicate in situ conditions. These test parameters are a function of traffic speed, layer thickness and a number of other site-specific factors. The permanent deformation throughout the test duration is measured in both the vertical and horizontal directions using linear variable differential transducers (LVDTs). Typical specimen dimensions are 102 mm x 104 mm and a schematic of the test apparatus is shown in Figure 2 (17).

Based on the literature reviewed, the repeatability of this test is comparable to other performance tests of this nature. However, as outlined by Krutz et al., coarser gradations tend to produce increased variation in the results (18). This variation can be explained by either segregation in the samples thus causing non-uniformity in the aggregate skeleton, or by the fact that as samples approach their shear failure point their behavior can become highly unpredictable.

The uniaxial version of this test can performed using the same general test apparatus by eliminating the confining pressure from the procedure and only a vertical stress is applied to the specimen.

Wheel-Tracking Devices

At the present time, the following wheel-tracking test apparatus are used to evaluate permanent deformation characteristics of HMA (3,4):

a. French Pavement Rutting Tester,

b. Georgia Loaded-Wheel Tester (Asphalt Pavement Analyzer, APA), and

c. Hamburg Rut Tester.

Although each of the above listed testing apparatus has different schematic layouts, their general operation and data obtained regarding permanent deformation characteristics of HMA mixtures are very similar.

Wheel-tracking tests in general apply a repeated load to a HMA sample by means of rubber tire, steel wheel, or a variation of these two loading techniques. From the literature reviewed, all of the laboratory wheel-tracking devices have the ability to control test temperatures with only a limited few possessing the ability to perform a moisture sensitivity evaluation (4).

Historically many researchers have encountered problems with the repeatability of wheel-tracking devices (19). An extensive study performed by Tayebali et al. evaluated three pavement sections using both the French Pavement Rutting Tester (PRT) and the Georgia Loaded-Wheel rut tester (20). Both testing devices indicated that severe rutting should take place based on specimens tested, however, no rutting was observed in actual field sections. This illustrates one of the major problems associated with laboratory tests in general, that being the limited amount of correlation or transfer functions that exist to correlate laboratory to field performance.

As concluded in SHRP report A/IR 91-104, all wheel-tracking devices need further evaluation in both laboratory and field settings (7). These evaluations should examine loading techniques and the corresponding state of stress the specimens are subjected to during the test.

Superpave Shear Tester (SST)

As previously stated, this test apparatus was developed as part of the Strategic Highway Research Program to quantify HMA mixture’s properties for pavement performance modeling purposes (1). The SST is a closed-loop servo-hydraulic system that has been widely adopted in the pavement research industry due to its ability to accurately reproduce stress conditions that HMA mixtures are subjected to under typical field loading (19). The SST in its original configuration and as outlined in AASHTO TP7-94, has the ability to execute the following tests (21):

1. Volumetric test
2. Uniaxial strain test
3. Repeated shear at constant stress ratio
4. Repeated shear test at constant height (RSCH)
5. Simple shear test at constant height (SSCH)

6. Frequency sweep at constant height (FSCH)

Although six tests were outlined in the original AASHTO procedure, the majority of research performed to date has used only the RSCH, SSCH, and FSCH test procedures. A schematic of the SST testing apparatus is shown in Figure 3.

Current Research Using the SST

In a recent study performed by Romero et al., a single aggregate source was mixed with five different asphalt binders and tested using the SSCH and FSCH tests (22). Results indicated that both tests had the ability to differentiate and rank the performance of the five HMA mixtures evaluated in the analysis. Furthermore, it was observed that identical rankings between the various mixtures were attained using either the binder's complex modulus divided by the sine of the phase angle or just using the complex shear modulus alone.

In a continuation of the previous study, Romero et al. examined the ability of the SST to discern between two HMA mixtures fabricated with a single asphalt binder and two different nominal maximum-sized gradations (23). The experiment consisted of mixing an AC-20P asphalt binder with two gradations using nominal maximum size aggregates of 19 mm and 37.5 mm. This study concluded that the SST was unable to discern between the two types of mixtures. Furthermore, it was observed that when the same mixtures were tested under the accelerated loading facility (ALF), trends observed in the SST did not appear to correlate to those observed under ALF testing.

It appears that the SSCH and FSCH test procedures have had varying degrees of success in differentiating among performance characteristics of a variety of mixtures types. However, as with other permanent deformation tests outlined in this literature review, limited amounts of correlations or transfer functions have been developed which relate laboratory to field performance. From recent studies performed using the SSCH and FSCH tests, coefficients of variation were in the range of 5 to 15 and 5 to 10% respectively, which would indicate that acceptable repeatability exists for both test procedures (3,22,23).

The RSCH test has been utilized in a number of research studies with varying degrees of success. From testing performed to date, the overall consensus is that at test temperatures greater than 40°C, the variability in the test results becomes excessive. This increased variability with increased test temperature was observed by Romero et al. where coefficients of variation of the response of three identical test specimens were in the order of 30% to 45% (22,23).

From the initial SHRP research outlined in report SHRP A-003A, it was concluded that the RSCH test was sensitive to changes in mixtures variables such as asphalt content and air voids (2). Furthermore, it was concluded that trends regarding the relationship between optimal performance in the RSCH test and optimum asphalt contents appeared to agree with the Hveem method.

In 1993, a study by Harvey et al. was performed to examine the effects of aggregate and asphalt binder on the permanent deformation resistance of HMA mixes as measured by the RSCH test (24). A total of three binders and two aggregate sources were combined and tested using the RSCH test to 2% strain or 5,000 load cycles. Results indicated that in general, specimens with higher air voids had a reduced resistance to shear failure. Furthermore, it was concluded that partially crushed aggregate sources exhibited less permanent strain than that observed in mixture using fully crushed aggregates.

In a recent study performed by Tayebali et al., three test sections were examined using the RSCH test to evaluate performance in the lab and its correlation to actual field performance (20). For each section, cores were taken and tested to 5000 cycles or 5% plastic strain in the RSCH test. From this analysis, it was concluded that the RSCH test could clearly identify the rutting potential of mixes analyzed in the study. This study recommended that RSCH test be performed on samples compacted to approximately 4% air voids. This recommendation agrees with results obtained by Harvey which indicated that critical air-void levels at which shear deformation of HMA mixtures should be evaluated was between 2.5% and 4.5% (24).

TEST TEMPERATURE SELECTION

Currently a number of different philosophies exist regarding the appropriate test temperature for laboratory permanent deformation testing. AASHTO TP7-94 in its present form requires the

RSCH test temperature to be selected using the maximum 7-day average high pavement temperature at a specified depth in the HMA layer (21). The maximum 7-day average high pavement temperature is obtained using the SHRPbind Version 2.0 binder selection program (25). The SHRPbind software package is a data base of over 6800 weather stations throughout the United States and Canada and uses the following equation to estimate the change in temperature as a function of depth from the pavement surface:

$$T(depth) = T(surface)*(1-0.063*depth + 0.007*depth^2 - 0.0004*depth^3)$$

Where: T(depth) and T(surface) are in °F, and depth is in inches.

For the purposes of RSCH testing, the 50% reliability temperature has been found to accurately simulate actual in situ temperatures observed in the pavement.

A second method as outlined in SHRP report SHRP-A-415, utilizes the concepts of effective, critical and maximum test temperatures for different climatic regions of the United States (3). The critical temperature is defined as the temperature at which the most permanent deformation will occur over an average year of the pavement's life. This critical temperature is considered optimal because it minimizes errors associated with variations in mix temperature sensitivity and also results in an accelerated rate of damage accumulation, which will reduce testing times.

Although different methods currently exist to specify a single test temperature for permanent deformation testing, the overall ideology in selecting this temperature should consider (3,4):

1. Test times will be minimized if test temperatures are selected as to promote early failure.
2. Temperatures must be selected close to in situ conditions to enable direct comparison between laboratory and field performance.
3. Temperatures must not be too high as to promote excessive variability in the data.

PERFORMANCE MODELS

At the present time, prediction of permanent deformation in flexible pavements is performed using either layer-strain or viscoelastic methods (3). The layer-strain procedure uses laboratory tests to predict rut depths and analyzes the pavement structure using linear or non-linear elastic theory (16). Viscoelastic methods incorporate moving wheel loads with time-dependant material properties to determine the state of stress throughout the pavement structure.

One of the major objectives of the SHRP research in addition to developing performance testing equipment, was to establish performance models. In short, these performance models were simply prediction algorithms, which would utilize responses obtained from the performance testing equipment to predict actual field performance of the asphalt concrete mixture (1,26). As outlined in the initial SHRP research, the following models would be used in performance prediction (26):

- material property,
- pavement response,
- environmental effects, and
- pavement distress.

Figure 4 illustrates the performance prediction approach proposed by the Superpave system (27). Results obtained to this point indicate that the model does not always provide accurate prediction with regards to rutting observed in laboratory controlled experiments to that observed in actual pavement test sections (27). Based on these findings, it was concluded by researchers that in their current form, models were not ready for widespread distribution to the public.

At the present time, ongoing research is being performed in an attempt to finalize these models. FHWA researchers have established a work plan for future Superpave models development. Their schedule indicates that performance models should be completed by 2005, however field validation will take additional two years and thus the anticipated release of such models to the pavement industry will be in the year 2007.

REPEATED SHEAR AT CONSTANT HEIGHT

The Superpave Shear Tester repeated shear at constant height (RSCH) test was used to evaluate the resistance of HMA mixtures to permanent deformation throughout the entire evaluation program. The following sections outline the methodology and test specifications behind the RSCH test procedure.

Sample Preparation

All laboratory mixtures were compacted using the Superpave Gyratory compactor as per AASHTO TP4-93[1] specifications (28). Following AASHTO TP7-94 requirements, all specimens tested in the RSCH test were cut to a test height of 50 ± 2.5 mm by means of a circular diamond blade wet saw (21). Air-void measurements were performed in accordance with AASHTO test method T 269-94 (29).

Test Procedure

As outlined in the AASHTO TP7-94 test procedure F, the RSCH test consists of applying a repeated haversine shear stress of 68 kPa (0.1 sec load, 0.6 rest) to a compacted HMA specimen while supplying enough vertical stress to maintain a constant height (21). The test is performed either to 5000 load cycles or until 5% plastic shear strain is incurred by the sample. Plastic shear strain is measured as the response variable at periodic cycles throughout the test and recorded using LVDTs and a computerized data acquisition system. A schematic of the SST testing apparatus is shown in Figure 3.

For all the specimens tested in this research, a preconditioning time of four hours at the specified test temperature was used prior to the start of the test to ensure that a uniform temperature would be attained throughout the sample.

It should be stated that the constant height specification could not be attained in some of the tests performed. The lack of conformance to AASHTO test specifications was a direct result of equipment limitations related to the SST testing apparatus itself and also a function of air-void levels in the specimens. It was observed that at air-void levels greater than approximately 5%, it was extremely difficult for the SST to maintain the constant height without becoming unstable.

Although the constant-height specification was not satisfied in all testing, the actual amount of variance from the specification was minimal in most cases.

Calibration

As with any advanced testing apparatus, periodic calibration is required to ensure the system is performing properly. Since 1996, the Superpave Shear Tester has been calibrated on a periodic basis using a urethane calibration specimen. Results from this calibration procedure for complex shear modulus (G*) and phase angle (δ) obtained in 1996, 1998, and 1999 are shown in Tables 2 and 3. These results indicate that from 1996 through 1999, the SST has shown excellent repeatability as measured by the calibration sample in the Frequency Sweep at Constant (FSCH) test. Although this indicates good repeatability, one must keep in mind that the FSCH test had minimal variability to begin with (CV of 5% to 10%) when testing HMA samples as was shown by Romero et al. (22). Due to the fact that variations observed between both urethane calibration and HMA specimens are similar, one could conclude that the material differences are not causing the variability. This would indicate that most of the 5% to 10% variation noted in the testing is directly related to machine error.

The argument could be made that a calibration procedure is required for RSCH because of the large variability associated with this test (COVs of 20% to 45%) as was outlined earlier. At the present time, it is premature to conclude if the variation observed in the RSCH test is caused by the mechanical errors in the SST or variations in the material being tested.

Along with in-house calibration of the system, the original manufacturer has performed a yearly calibration of the entire testing apparatus. Other critical calibrations such as test-chamber temperature and LVDT’s were performed on a weekly basis.

STATISTICAL ANALYSIS TECHNIQUES

A number of statistical analysis techniques were used to analyze the data obtained from the various studies presented in this report series. A discussion of each technique is reviewed below.

Analysis of Variance

For all data obtained in this research, the goal was to statistically rank and differentiate the performance of the HMA mixtures. To accomplish this, mean comparisons were performed between single factors using SAS macro FIXANOVA2 and the Mac-call file Fixoneql.sas in an attempt to statistically comment on mixture comparisons in this study (30). As with any analysis of variance (ANOVA), the first step is to ensure that the ANOVA assumptions that random experimental errors are independent, are normally distributed with a mean of zero and a common variance for all treatments are not violated (31). To ensure adherence to these assumptions, the following statistical data exploratory techniques were used:

- Independent Error - all samples were randomly made and tested, thus satisfying this assumption.
- Normal Distribution of Error - this assumption was confirmed using the normal probability plot of student residuals. Also the D'Agostino-Pearson Omnibus normality test was used at a significant level of 0.05 as a secondary statistical tool to ensure the data did not have skewness or kurtosis problems.
- Equal Variance - Box–plots and residual plots were used to check for the equal variance assumption in the data.
- Outlier Detection - studentized residual plots were used to check for outliers and influential observations in the data. Due to the fact that the study was a designed experiment, no correction was applicable for outliers in the data.

Individual comparisons were performed using the LSMEAMS option and Tukey-Kramer adjustment at a significance level of 0.05.

Linear/Nonlinear Regression Analysis

A linear regression technique was used to normalize both plastic strain and slope data obtained in the gyration study analysis to an equal air-void level. To perform this normalization, a SAS macro developed by Dr. G. Fernandez of the University of Nevada was used to fit a linear regression line to strain or slope vs. air-void relationships (32). Along with fitting a simple regression line, this macro also had the ability to estimate the response variable (plastic shear strain) at various levels of air voids.

To estimate slopes for each specimen tested in the gyration study (Volume III), a non-linear regression power function was fit to the strain vs. load cycle curve using a SAS macro developed by Dr. G. Fernandez (32).

FIELD PROJECTS

This research effort evaluated mixtures and field performance from three NDOT projects. Two of the projects included one Hveem and one Superpave section and the third project included two Hveem and two Superpave sections. The following sections describe the locations and layouts of the three projects.

Contract 2751

This project was constructed in 1996 on SR 278 in Eureka County, Nevada. The project included one Hveem section and one Superpave section. The Hveem section covered the majority of the project (13 miles) while the Superpave section was placed on just two miles. The Superpave section included a tenth-of-a-mile stretch, which did not have an open-graded course. Figure 5 shows a typical cross section of this project.

Figure 6 shows the gradation of the Hveem and Superpave mixtures constructed on contract 2751. Table 4, 5 and 6 summarize the material properties and the mix design for the Superpave and Hveem mixtures constructed on contract 2751. It can be seen 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 2.36 mm sieve.

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 one mile of the project while the Superpave section covered the majority of the project (13 miles). Figure 7 shows a typical cross section of this project.

Figure 8 shows the gradation of the Hveem and Superpave mixtures constructed on contract 2827. Tables 7, 8 and 9 summarize the material properties and the mix design for the Superpave and Hveem mixtures constructed on contract 2827. It can be seen that all materials and mixtures satisfy the corresponding specifications.

Contract 2880

This 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 500-foot performance monitoring area and two sampling areas (one at the beginning and one at the end of the section). There are transition areas between consecutive sections. Figures 9 and 10 shows the layout of the four sections and a typical cross section, respectively. The following is a description of the sections nomenclature:

SPAC-20P: this section is designed using the Superpave system with a binder grade of AC-20P

SPPG64-22: this section is designed using the Superpave system with a binder grade of PG64-22

NVPG64-22: this section is designed using the NDOT Hveem method with a binder grade of PG64-22

NVAC-20P: this section is designed using the NDOT Hveem method with a binder grade of AC-20P

Figure 11 shows the gradation of the Hveem and Superpave mixtures constructed on contract 2880. Tables 10 through 14 summarize the material properties and the mix design for the Superpave and Hveem mixtures constructed on contract 2880. It can be seen that all materials and mixtures satisfy the corresponding specifications.

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Table 1 Parameters Affecting Rutting Resistance of Asphalt Concrete Mixtures.

	Factor	**Change in Factor**	**Effect of Change in Factor on Rutting Resistance**
Aggregate	Surface texture	Smooth to rough	Increase
	Gradation	Gap to continuous	Increase
	Shape	round to angular	Increase
	Size	Increase in max size	Increase
Binder	Stiffness	Increase	Increase
Mixture	Binder content	Increase	Decrease
	Air void content	Increase	Decrease
	VMA	Increase	Decrease
Test conditions	Temperature	Increase	Decrease
	State of stress/strain	Increase in contact pressure	Decrease
	Load repetitions	Increase	Decrease
	Water	Dry to wet	Decrease if mix is water sensitive

Table 2 Calibration of the Supperpave Shear Device on Urethane Samples Measuring the Complex Modulus (G*) in the Frequency Sweep Constant Height Test.

Frequency (Hz)	**G* (1196) (kPa)**	**G* (1998) (kPa)**	**G* (1999) (kPa)**
10	142608	146796	141215
5	136837	135841	134434
2	127991	125298	125915
1	123317	120762	121358
0.5	117225	117211	116046
0.2	111254	110537	110016
0.1	106883	105214	105524
0.05	103139	101677	102460
0.02	98578	96747	97154
0.01	95665	94369	93789

Table 3 Calibration of the Supperpave Shear Device on Urethane Samples Measuring the Phase Angle (δ) in the Frequency Sweep Constant Height Test.

Frequency (Hz)	**Phase Angle (1996) (degrees0**	**Phase Angle (1998) (degrees)**	**Phase Angle (1999) (degrees)**
10	13.47	15.96	14.23
5	11.29	12.6	12.60
2	8.62	10.48	11.15
1	7.61	9.08	9.15
0.5	6.68	6.97	8.03
0.2	6.52	6.24	7.14
0.1	5.73	6.94	7.35
0.05	5.37	5.54	6.23
0.02	5.78	5.51	5.96
0.01	5.40	5.43	6.34

Table 4 Recommended Superpave Mix Design for Contract 2751.

<table>
<tr><th colspan="3">Binder Properties (64-28)</th></tr>
<tr><th>Property</th><th>Measured</th><th>Specification</th></tr>
<tr><td>Flash Point, (^{o}C)</td><td>240</td><td>> 230</td></tr>
<tr><td>Mass Loss, (%)</td><td>0.33</td><td>< 1.0</td></tr>
<tr><td>Brookfield Viscoisty, (Pa*S), @ 135^{o}C</td><td>0.91</td><td>< 3.0</td></tr>
<tr><td>Original $G^*/(\sin\delta)$, (kPa), @ 64 ^{o}C</td><td>1.4</td><td>> 1.0</td></tr>
<tr><td>RTFOT $G^*/(\sin\delta)$, (kPa), @ 64 ^{o}C</td><td>2.6</td><td>> 2.2</td></tr>
<tr><td>PAV $G^*(\sin\delta)$, (kPa), @ 19^{o}C</td><td>1700</td><td>< 5000</td></tr>
<tr><td>Creep Stiffness, (Mpa), @ -18^{o}C</td><td>213</td><td>< 300</td></tr>
<tr><td>Slope (m), @ -18^{o}C</td><td>0.31</td><td>> 0.30</td></tr>
<tr><td>Direct Tension, Fail Strain % @ -18^{o}C</td><td>na</td><td>> 1.0</td></tr>
<tr><th colspan="3">Aggregate Properties</th></tr>
<tr><th>Property</th><th>Measured</th><th>Specification</th></tr>
<tr><td>Coarse Aggregate Angularity, (%)</td><td>87/83</td><td>> 65/-</td></tr>
<tr><td>Fine Aggregate Angularity, (%)</td><td>54</td><td>> 40</td></tr>
<tr><td>Flat and Elongated Particles, (%)</td><td>0.6</td><td>< 10</td></tr>
<tr><td>Sand Equivalent, (%)</td><td>43</td><td>> 40</td></tr>
<tr><th colspan="3">Mixtures Properties</th></tr>
<tr><th>Property</th><th>Measured</th><th>Specification</th></tr>
<tr><td>% Gmm at N_{design}</td><td>96.0</td><td>96.0</td></tr>
<tr><td>% AC (by twm)</td><td>6.3</td><td>n/a</td></tr>
<tr><td>% VMA at N_{design}</td><td>17.1</td><td>>13.0</td></tr>
<tr><td>% VFA at N_{design}</td><td>77</td><td>65 - 75</td></tr>
<tr><td>Filler to Effective AC Ratio at N_{design}</td><td>0.8</td><td>0.6 -1.2</td></tr>
<tr><td>% Gmm at $N_{initial}$</td><td>86</td><td>< 89.0</td></tr>
<tr><td>%Gmm at N_{max}</td><td>98</td><td>< 98.0</td></tr>
<tr><td>Retained Strength Ratio, (%)</td><td>na</td><td>> 80</td></tr>
</table>

Table 5 Properties of the Hveem Mixtures 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 6 NDOT Hveem Mix Design for the Hveem Section on Contract 2751.

STATE OF NEVADA
DEPARTMENT OF TRANSPORTATION
MATERIALS DIVISION
1263 S. STEWART ST. CARSON CITY, NV 89712
BITUMINOUS MIX DESIGN

LAB NUMBER:	BF97-3B	*BITUMEN RATIO:*	6.0 PG 64-28
CONTRACT NUMBER:	2751		
PROJECT NUMBER:	SP-050-4(14) & SPSR-278(9)		
COUNTY:	LANDER & EUREKA		
PRIMARY CONTRACTOR:	FREHNER CONSTRUCTION		
DATE AGG. SAMPLED:	06/28/96		
DATE AGG. RECEIVED:	08/12/96		
DATE ASPHALT RECEIVED:	07/30/96		
REPORT DATE:	08/20/96		
SAMPLED BY:	WAS NOT STATED ON TRANSMITTALS		
CHECKED BY:	MSB		
TYPE MATERIAL:	TYPE 2 PLANTMIX AGGREGATE		
SOURCE OF SAMPLE(S):	COARSE AGG. & CRUSHER FINES: EU 02-09; NATURAL FINES: LA 06-023		
MINERAL FILLER:	2.5% HYDRATED LIME WET-CURED (MARINATED) 48 HOURS		
TYPE ASPHALT:	PG 64-28		
ASPHALT PRODUCER:	PETRO SOURCE		

JOB DESCRIPTION:

ON US 50 FROM SR 376 TO 1 KILOMETER WEST OF HICKISON SUMMIT
& ON SR 278 FROM MOUNT HOPE ZINC MINE RD TO 24 KILOMETERS NORTH

SPECIFIC GRAVITY:	2.60	
SURFACE AREA m²/kg (ft²/lb):	5.857 (28.6)	
SAND EQUIVALENT:	65	*SPECIFICATIONS:*
+#4 WATER ABSORPTION:	1.5	*4% MAX*
SS SOUNDNESS COARSE:	4.7	*12% MAX*
SS SOUNDNESS FINES:	7.1	*15% MAX*
LIQUID LIMIT (BEFORE MARINATION):	COARSE: 21; CRUSHER FINES: 19; NATURAL FINES: 18	*35 MAX*
PLASTICITY INDEX (BEFORE MARINATION):	COARSE: 3; CRUSHER FINES: NP; NATURAL FINES: NP	*10 MAX*
LA ABRASION:	27.5	*45% MAX*
FRACTURE FACE COUNT:	100.0	*60% MIN*
VMA (BASED UPON CALIF. SP. GR.):	17.3	*12 - 22*
ORIGINAL TENSILE STRENGTH (kPa):	530.9 (77.0)	*450 kPa (65 PSI) MIN*
% RETAINED STRENGTH:	100.9	*70% MIN*

REMARKS:

FOR THE MATERIAL REPRESENTED BY THE SUBMITTED SAMPLES WITH THE ATTACHED GRADINGS,
LABORATORY TESTS INDICATE A BITUMEN RATIO OF AC- FOR TYPE PLANTMIX AGGREGATE
TREATED WITH 1.5% HYDRATED LIME AND WET CURED (MARINATED) 48 HOURS.

DISTRIBUTION:

1	*DISTRICT ENGINEER*
1	*RESIDENT ENGINEER*
1	*CONSTRUCTION ENG.*
1	*LAB FILES*
3	*BITUMINOUS LAB*
1	*ASPHALT LAB*
1	*DEAN WEITZEL*
1	*LAS VEGAS*

BIN PERCENTAGES:	48%	COARSE AGG.
	42%	CRUSHER FINES.
	10%	NATURAL FINES.

NOTE: CHANGES FROM THE RECOMMENDED BITUMEN RATIO WILL BE DISCUSSED WITH THE MATERIALS DIVISION.

Table 7 Recommended Superpave Mix Design for Contract 2827.

Binder Properties (PG64-34)		
Property	**Measured**	**Specification**
Flash Point, (^{o}C)	266	> 230
Mass Loss, (%)	0.27	< 1.0
Brookfield Viscoisty, (Pa*S), @ 135^{o}C	0.41	< 3.0
Original G*/(sinδ), (kPa), @ 64^{o}C	1.3	> 1.0
RTFOT G*/(sinδ), (kPa), @ 64^{o}C	2.7	> 2.2
PAV G*(sinδ), (kPa), @ 22^{o}C	1600	< 5000
Creep Stiffness, (Mpa), @ -24^{o}C	213	< 300
Slope (m), @ -24^{o}C	0.31	> 0.30
Direct Tension, Fail Strain % @ -24^{o}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 8   Properties of the Hveem Mixtures 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 9 NDOT Hveem Mix Design for the Hveem Section on Contract 2827.

STATE OF NEVADA
DEPARTMENT OF TRANSPORTATION
MATERIALS DIVISION
1263 S. STEWART ST. CARSON CITY, NV 89712
BITUMINOUS MIX DESIGN

LAB NUMBER:	SP98-2 (T-2)	*BITUMEN RATIO:*	7.5 PG 64-34
CONTRACT NUMBER:	2827		
PROJECT NUMBER:	SPF-093-4(14)		
COUNTY:	WHITE PINE		
PRIMARY CONTRACTOR:	FREHNER CONSTRUCTION		
DATE SAMPLED:	08/01/97 & 08/19/97		
DATE RECEIVED:	08/07/97 & 08/27/97		
REPORT DATE:	10/16/97		
SAMPLED BY:	JOHN FERGUSON		
CHECKED BY:	SJH		
TYPE MATERIAL:	TYPE 2 PLANTMIX AGGREGATE		
SOURCE OF SAMPLE(S):	WP 06-03		
MINERAL FILLER:	1.5% HYDRATED LIME WET-CURED (MARINATED) 48 HOURS		
TYPE ASPHALT:	PG 64-34		
ASPHALT PRODUCER:	PETRO SOURCE		
JOB DESCRIPTION:	ON US 93 FROM CHERRY CREEK ROAD TO US 93A		
SPECIFIC GRAVITY:	2.47		
SURFACE AREA m²/kg (ft²/lb):	26		
SAND EQUIVALENT:	59		*SPECIFICATIONS:*
+#4 WATER ABSORPTION:	2.0		*4% MAX*
SS SOUNDNESS COARSE:	8.9		*12% MAX*
SS SOUNDNESS FINES:	9.6		*15% MAX*
LIQUID LIMIT (BEFORE MARINATION):	COARSE: 23; 3/8" CHIPS: 21; CRUSHER FINES: 18		*35 MAX*
PLASTICITY INDEX (BEFORE MARINATION):	COARSE: 2; 3/8" CHIPS: 21; CRUSHER FINES: NP		*10 MAX*
LA ABRASION:	30.3		*45% MAX*
FRACTURE FACE COUNT:	100.0		*60% MIN*
VMA (BASED UPON CALIF. SP. GR.):	14.7		*12 - 22*
ORIGINAL TENSILE STRENGTH (kPa):			*450 kPa (65 PSI) MIN*
% RETAINED STRENGTH:			*70% MIN*

REMARKS:

FOR THE MATERIAL REPRESENTED BY THE SUBMITTED SAMPLES WITH THE ATTACHED GRADINGS, LABORATORY TESTS INDICATE A BITUMEN RATIO OF AC- FOR TYPE PLANTMIX AGGREGATE TREATED WITH 1.5% HYDRATED LIME AND WET CURED (MARINATED) 48 HOURS.

DISTRIBUTION:
1 DISTRICT ENGINEER
1 RESIDENT ENGINEER
1 CONSTRUCTION ENG.
1 LAB FILES
3 BITUMINOUS LAB
1 ASPHALT LAB
1 DEAN WEITZEL

BIN PERCENTAGES:
31% COARSE AGG.
5% 3/8" CHIPS.
64% CRUSHER FINES.

NOTE: CHANGES FROM THE RECOMMENDED BITUMEN RATIO SHALL BE DISCUSSED WITH THE MATERIALS DIVISION. THE RECOMMENDED BITUMEN RATIO IS BASED UPON DRY WEIGHT OF AGGREGATE.

Table 10 Recommended 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*/(sinδ), (kPa), @ 58^{o}C	1.8	> 1.0
RTFOT G*/(sinδ), (kPa), @ 58^{o}C	2.5	> 2.2
PAV G*(sinδ), (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 11   Recommended Superpave Mix Design for Contract 2880, Section SPPG64-22.

Binder Properties (PG64-22)		
Property	**Measured**	**Specification**
Flash Point, (^{o}C)	340+	> 230
Mass Loss, (%)	0.14	< 1.0
Brookfield Viscoisty, (Pa*S), @ 135^{o}C	0.38	< 3.0
Original G*/(sinδ), (kPa), @ 64^{o}C	1.23	> 1.0
RTFOT G*/(sinδ), (kPa), @ 64^{o}C	2.7	> 2.2
PAV G*(sinδ), (kPa), @ 25^{o}C	3070	< 5000
Creep Stiffness, (Mpa), @ -12^{o}C	167	< 300
Slope (m), @ -12^{o}C	0.34	> 0.30
Direct Tension, Fail Strain % @ -12^{o}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 12 Properties of the Hveem Mixtures 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 13 NDOT Hveem Mix Design for the NV AC-20P Section on Contract 2880.

STATE OF NEVADA
DEPARTMENT OF TRANSPORTATION
MATERIALS DIVISION
1263 S. STEWART ST. CARSON CITY, NV 89712
BITUMINOUS MIX DESIGN

LAB NUMBER:	BF99-15	*BITUMEN RATIO:* 4.25 AC-20P
CONTRACT NUMBER:	2880	
PROJECT NUMBER:	IM-080-1(131)50	
COUNTY:	LYON & CHURCHILL	
PRIMARY CONTRACTOR:	GRANITE CONSTRUCTION	
DATE AGG. SAMPLED:	07/10/98	
DATE AGG. RECEIVED:	07/24/98	
REPORT DATE:	08/02/98	
SAMPLED BY:	OLSON & SOMMERS	
CHECKED BY:	MSB & SJH	
TYPE MATERIAL:	TYPE 2C PLANTMIX AGGREGATE	
SOURCE OF SAMPLE(S):	LOCKWOOD PIT (BANK SAND FROM PATRICK PIT)	
MINERAL FILLER:	1.5% HYDRATED LIME WET-CURED (MARINATED) 48 HOURS	
TYPE ASPHALT:	AC-20P (CCAC99-173)	
ASPHALT PRODUCER:	TELFER SHELDON	
JOB DESCRIPTION:	ON 1-80 FROM 3.51 Km EAST OF EAST FERNLEY INTERCHANGE TO 2.90 Km WEST OF NIGHTINGALE INTERCHANGE	
SPECIFIC GRAVITY:	2.65	
SURFACE AREA m²/kg (ft²/lb):	4.81 (23.5)	
SAND EQUIVALENT:	63	*SPECIFICATIONS:*
+#4 WATER ABSORPTION:	1.7	*4% MAX*
SS SOUNDNESS COARSE:	6.3	*12% MAX*
SS SOUNDNESS FINES:	ROCK DUST: 11.6; BANK SAND: 2.4	*15% MAX*
LIQUID LIMIT (BEFORE MARINATION):	25X12.5mm, 19mm & 9.5mm: INSUFF., ROCK DUST: 23, BANK SAND: 22	*35 MAX*
PLASTICITY INDEX (BEFORE MARINATION):	25X12.5mm, 19mm & 9.5mm: INSUFF., ROCK DUST: 3, BANK SAND: NP	*10 MAX*
LA ABRASION:	13.9	*45% MAX*
FRACTURE FACE COUNT:	100	*60% MIN*
VMA (BASED UPON CALIF. SP. GR.):	15.0	*12 - 22*
ORIGINAL TENSILE STRENGTH (kPa):	687	*450 kPa MIN*
% RETAINED STRENGTH:	105	*70% MIN*

REMARKS:

FOR THE MATERIAL REPRESENTED BY THE SUBMITTED SAMPLES WITH THE ATTACHED GRADINGS, LABORATORY TESTS INDICATE A BITUMEN RATIO OF AC- FOR TYPE PLANTMIX AGGREGATE TREATED WITH 1.5% HYDRATED LIME AND WET CURED (MARINATED) 48 HOURS.

DISTRIBUTION:

1	*DISTRICT ENGINEER*
1	*RESIDENT ENGINEER*
1	*CONSTRUCTION ENG.*
1	*LAB FILES*
3	*BITUMINOUS LAB*
1	*ASPHALT LAB*
1	*DEAN WEITZEL*

BIN PERCENTAGES:

28%	25mm ROCK.
20%	19mm ROCK.
9%	9.5mm ROCK.
33%	CRUSHER FINES
10%	NATURAL FINES

NOTE: CHANGES FROM THE RECOMMENDED BITUMEN RATIO SHALL BE DISCUSSED WITH THE MATERIALS DIVISION. THE RECOMMENDED BITUMEN RATIO IS BASED UPON DRY WEIGHT OF AGGREGATE.

Table 14 Properties of the Hveem Mixtures 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

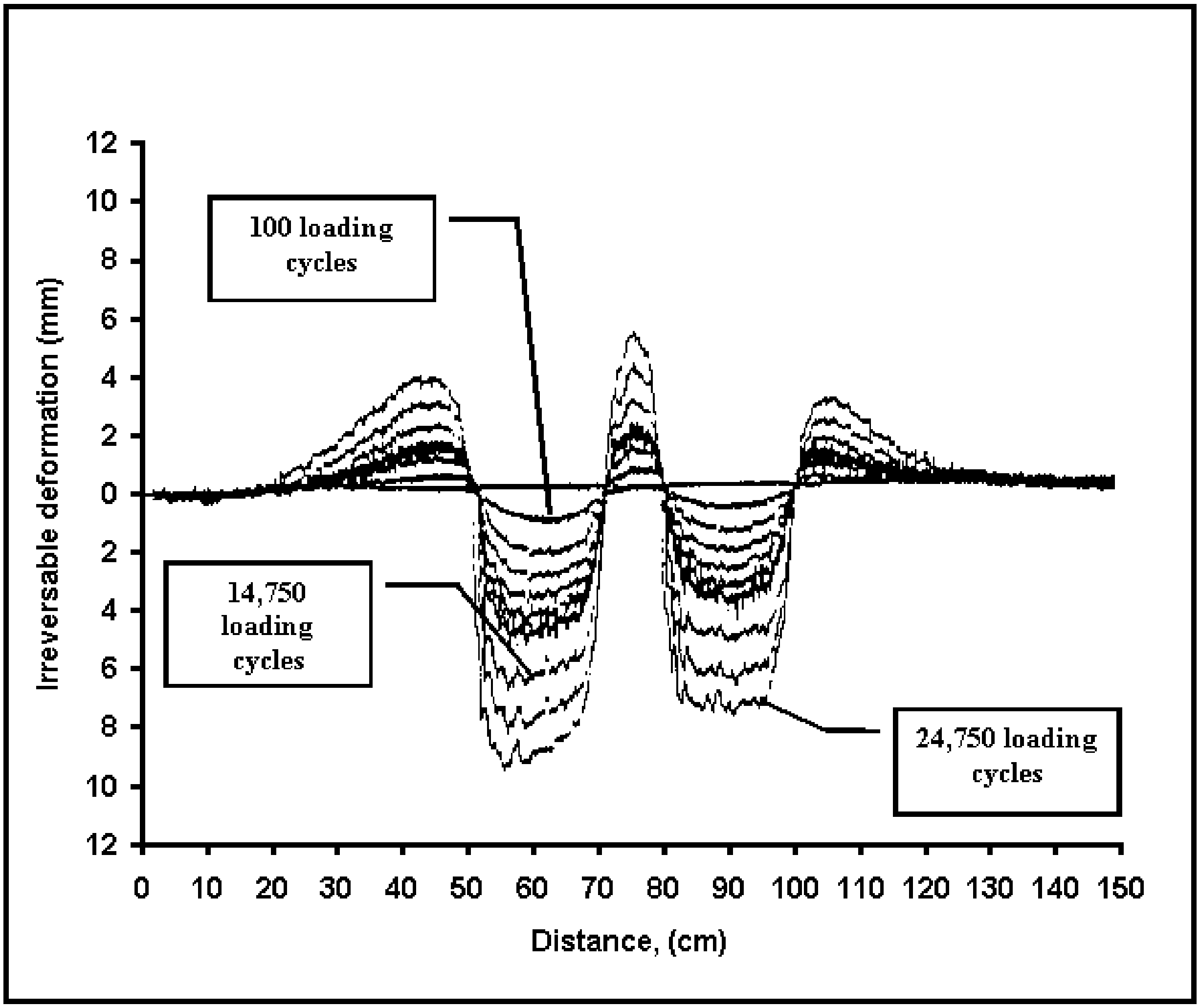

Figure 1 Progression of rutting as a function of load cycles.

Figure 2 Repeated load triaxial test machine.

Figure 3   Superpave Shear Tester machine.

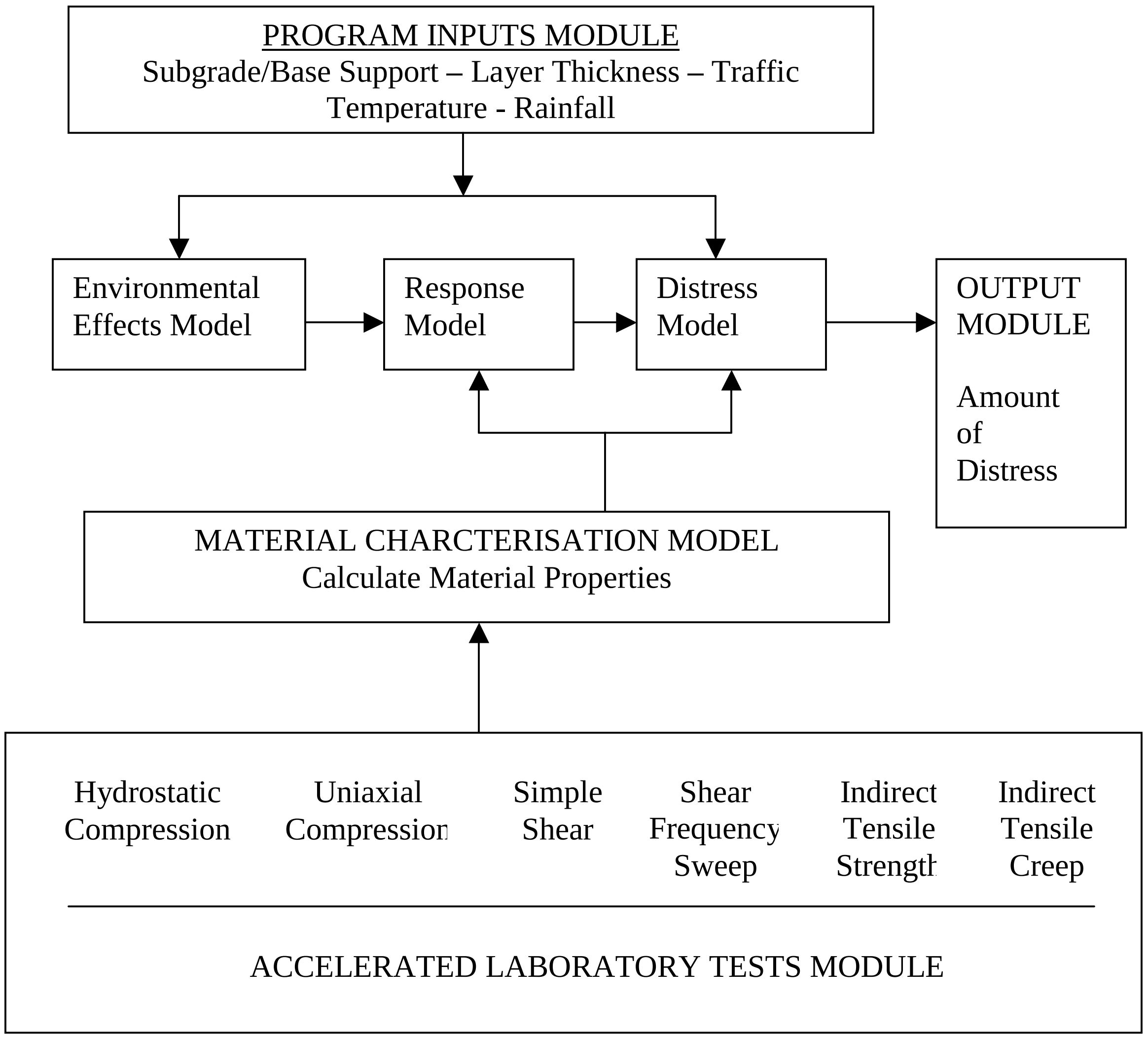

Figure 4 Performance prediction approach recommended by the Superpave system.

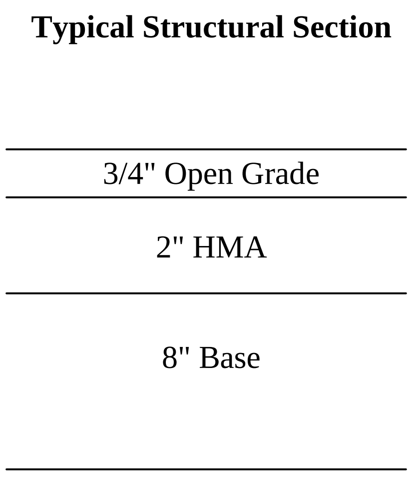

Figure 5 Typical cross section of contract 2751.

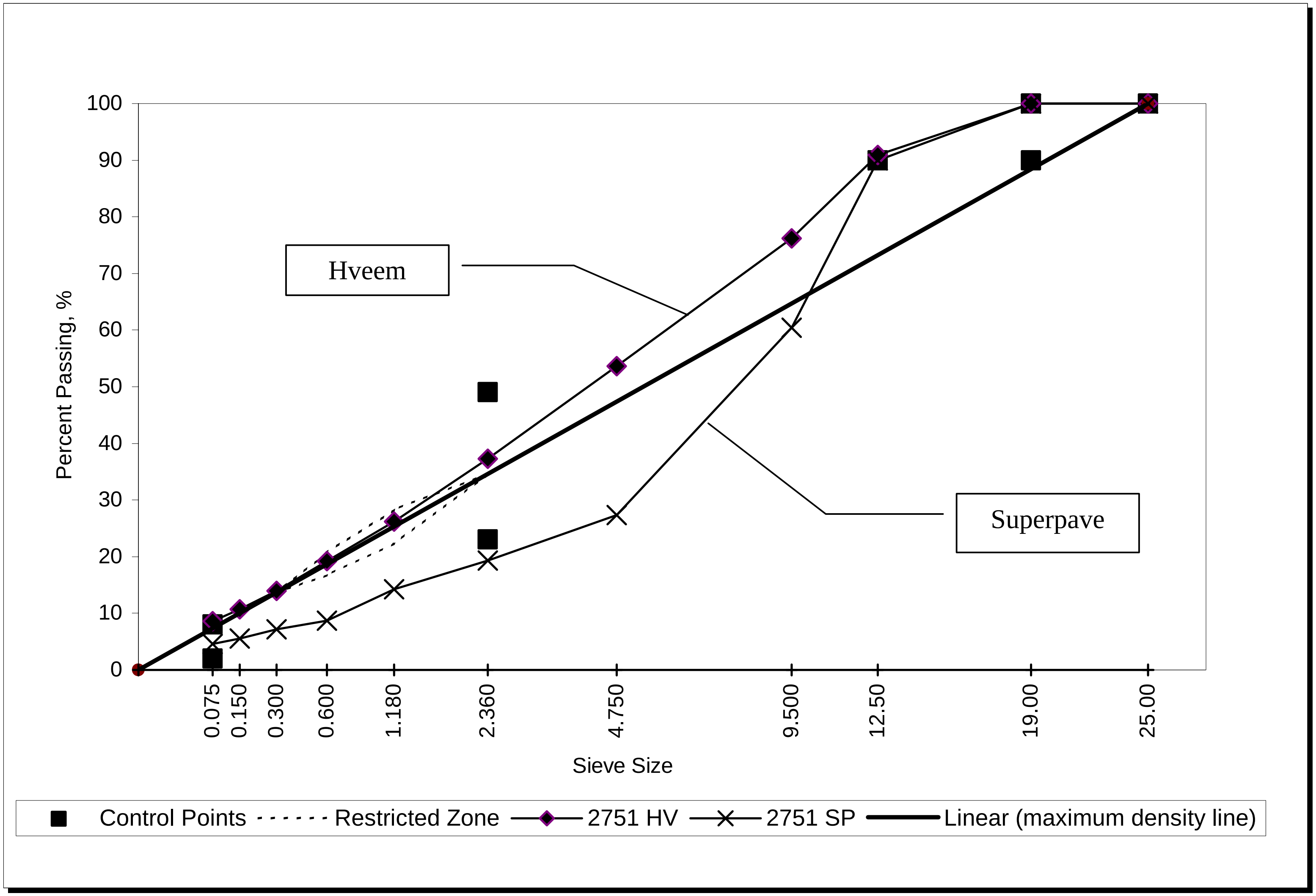

Figure 6 Aggregate gradations for the Hveem and Superpave mixtures used on contract 2751.

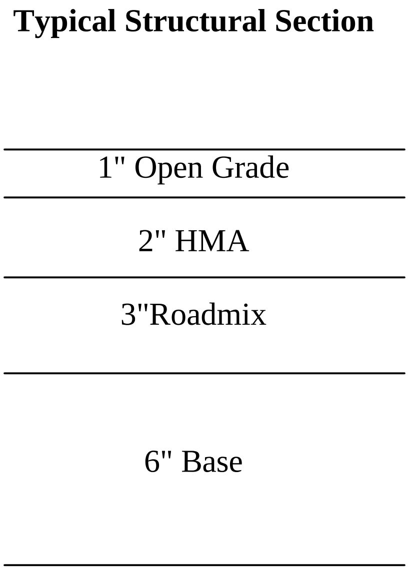

Figure 7   Typical cross section of contract 2827.

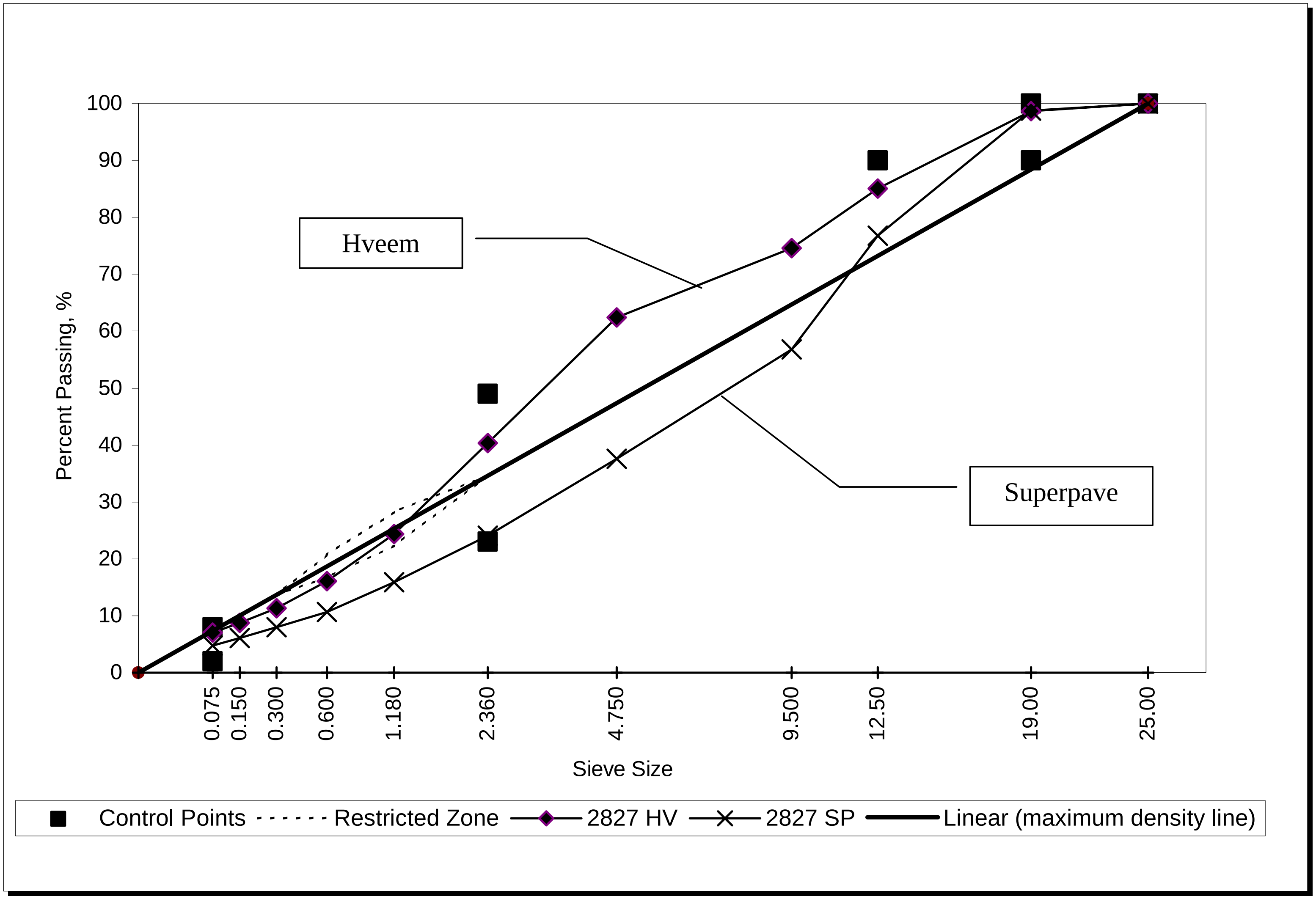

Figure 8 Aggregate gradations for the Hveem and Superpave mixtures used on contract 2827.

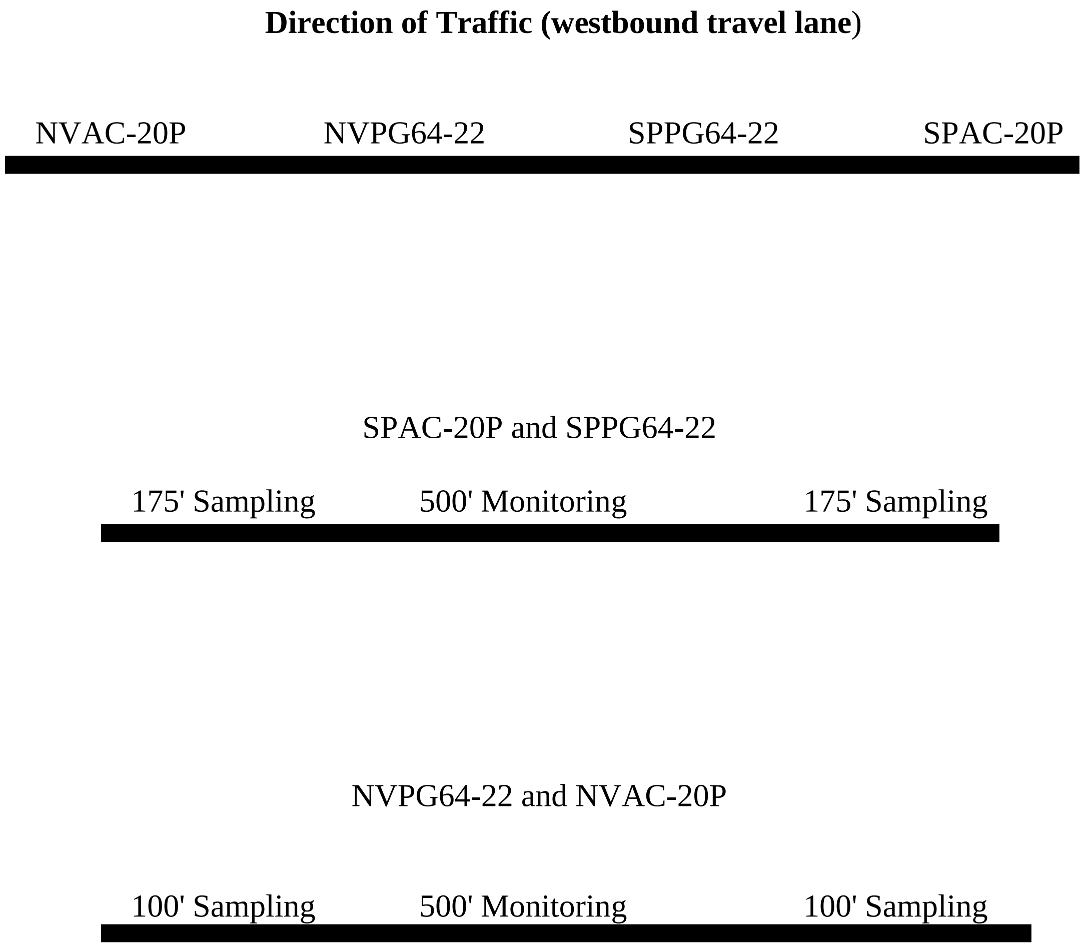

Figure 9 Layout of the test sections on I-80 westbound travel lane.

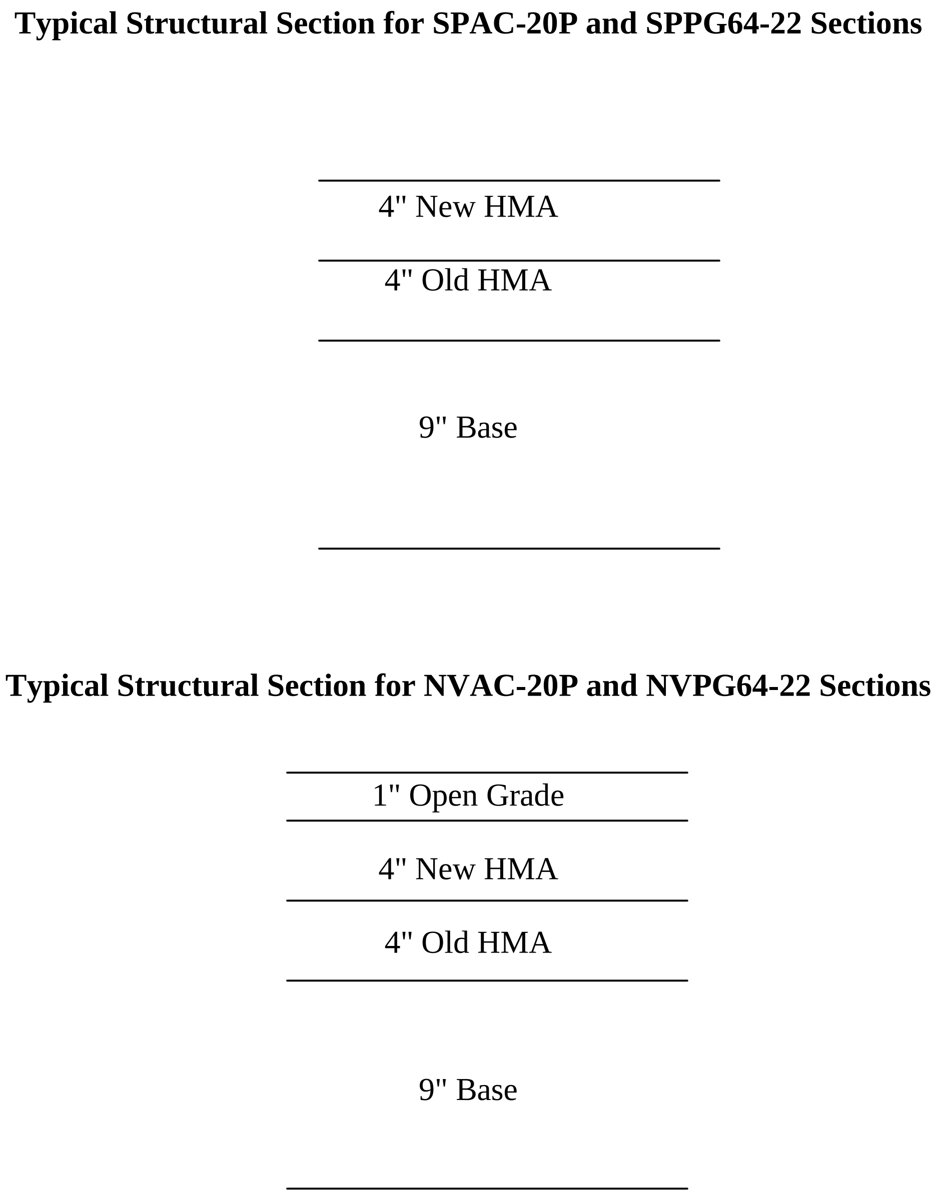

Figure 10   Typical cross sections of contract 2880.

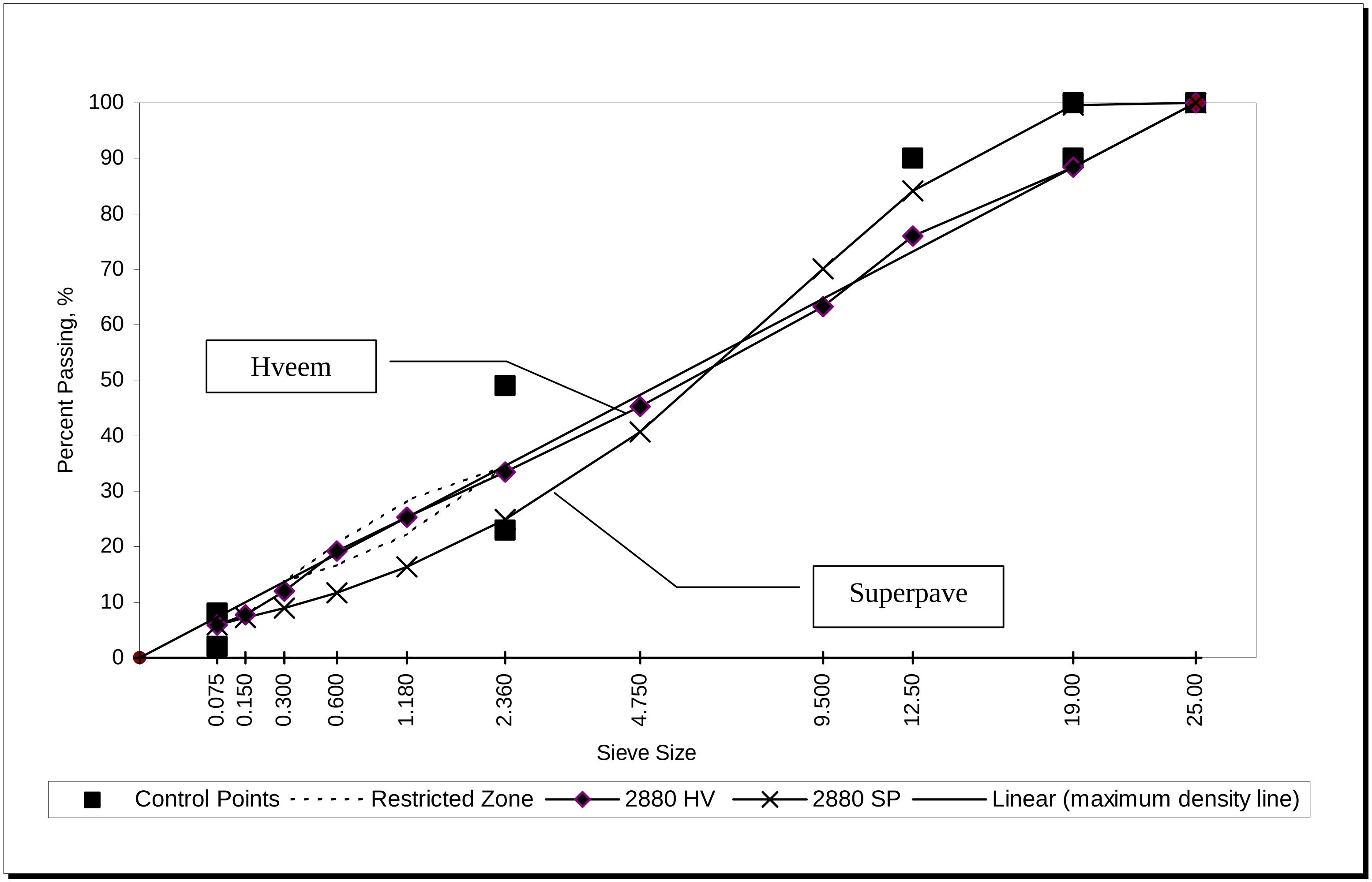

Figure 11 Aggregate gradations for the Hveem and Superpave mixtures used on contract 2880.

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