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Development of Hot Mix Asphalt Pavement Performance Properties for Long-Life Pavement Design: Caltrans District 4, Interstate 80, Solano County, California

Version 1

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Work Conducted as Part of Partnered Pavement Research Center Strategic Plan Element No. 3.18.2: Long-Life Pavement Designs for District 2, Interstate 5 Red Bluff and Weed, and for District 4, Interstate 80 Dixon, Solano County

PREPARED FOR:

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Division of Research, Innovation and System Information

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Abstract: In the period 2012 to 2014 Caltrans designed and built three long-life asphalt pavement (LLAP) rehabilitation projects. Two projects were in District 2 on Interstate 5—one just north of the city of Red Bluff and the other on the interstate running through and north of the city of Weed—and one in District 4 on Interstate 80 in Solano County between the cities of Dixon and Vacaville. This technical memorandum describes the processes by which performance criteria were developed for a pavement section that is part of the LLAP project on Interstate 80. This pavement section, designed and constructed as an LLAP section, consisted of the following pavement components:

- A hot mix asphalt (HMA) surface course containing a polymer-modified asphalt (PG 64-28PM) with 15 percent reclaimed asphalt pavement (RAP) and a representative virgin aggregate from the local area treated with 1.2 percent lime (marinated)
- An HMA intermediate course containing a conventional asphalt binder (PG 64-10), and the same lime-treated aggregate as the surface course plus 25 percent RAP

Caltrans headquarters staff from the Office of Asphalt Pavement designed the structural pavement sections using material parameters developed from AASHTO T 320 shear testing and AASHTO T 321 fatigue and stiffness testing results. Pavement design for the Solano project made use of the same mix parameters as those used for the design of the Caltrans District 2 Interstate 5 Red Bluff project but with traffic and climate data specific to the Solano site. In addition to the AASHTO T 320 and T 321 results used for the design and performance-related specifications, results from AASHTO T 324 Hamburg Wheel-Track Testing (HWTT) were required in the performance-based specifications as a consideration for moisture sensitivity. The HWTT results were not used in the design process.

Keywords: Long-life asphalt pavement; reclaimed asphalt pavement (RAP); hot mix asphalt (HMA) shear, fatigue, stiffness and Hamburg Wheel-Track Testing; HMA performance-based specifications

Proposals for Implementation: Use HMA shear, fatigue, and stiffness data for structural pavement section design; use these test data and HWTT data to develop performance-based HMA specifications; following construction, provide systematic and periodic pavement performance evaluations for at least five years, and preferably longer.

Related Documents:

- Monismith, C.L., J.T. Harvey, B.-W. Tsai, F. Long, and J. Signore. 2009. The Phase 1 I-710 Freeway Rehabilitation Project: Initial Design (1999) to Performance after Five Years of Traffic (2008): Summary Report. (UCPRC-SR-2008-04).
- Tsai, B.W., J. M. Signore, C. L. Monismith. 2014. Development of Hot Mix Asphalt Pavement Performance Properties for Long-Life Pavement Design: Caltrans District 2, Interstate 5, Red Bluff, California. (UCPRC-TM-2014-03)
- Signore, J. M., B.W. Tsai, C. L. Monismith. 2014. Development of Hot Mix Asphalt Pavement Performance Properties for Long-Life Pavement Design: Caltrans District 2, Interstate 5, Weed, California. (UCPRC-TM-2014-04)

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DISCLAIMER STATEMENT

PROJECT OBJECTIVES

The objectives of Partnered Pavement Research Center Strategic Plan Element (PPRC SPE) 3.18.2 were to further develop methods for the Mechanistic-Empirical (M-E) design of pavements, to validate and improve the process of pavement design and rehabilitation, and to add new information to the State Standard Materials Library available in the design software *CalME*.

The long-life asphalt pavement (LLAP) design portion of this SPE had the following objectives:

1. Identification of pilot projects to be utilized for LLAP designs. Obtaining representative materials and establishing performance-related test specifications (criteria) for each of the mixes in the pavement design used on each project.
2. Create asphalt concrete (AC) long-life pavement designs, utilizing M-E concepts for each of the pilot projects selected.

To accomplish these objectives, three long-life pavements were designed and constructed: one on Interstate 5 near Red Bluff, California, one on Interstate 5 in Weed, California, and one on Interstate 80 in Solano County, California.

This technical memorandum describes the work conducted in Objective 2 for the third pilot project, an 8.1 mile stretch on Interstate 80 in Caltrans District 4 in Solano County (04-Sol-80-30.6/38.7) between the cities of Dixon and Vacaville. Because of time constraints, the HMA mix performance characteristics developed for the Red Bluff project were used by Caltrans for the design of an HMA overlay on cracked and seated jointed plain concrete pavement (JPCP) slabs. The UCPRC used the same data to develop the HMA performance specifications for the Solano project considering the temperature conditions and traffic estimates for the site.

To ensure that mixes used by the contractor met the specification requirements for the structural pavement section prior to HMA placement, and to expedite construction, Caltrans selected the UCPRC to be the laboratory of record for HMA performance testing (shear, stiffness, fatigue, and HWTT tests) of the contractor's materials.

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LIST OF ABBREVIATIONS

AASHTO	American Association of State Highway and Transportation Officials
AC	Asphalt concrete
ASTM	American Society for Testing and Materials
CDF	Cumulative distribution function
CT	Caltrans
HMA	Hot mix asphalt
HWTT	Hamburg Wheel-Track Testing
ICM	Integrated Climate Model
JPCP	Jointed plain concrete pavement
LLAP	Long-life asphalt pavement
LMLC	Laboratory-mixed, laboratory-compacted
ME	Mechanistic-Empirical
NCDC	National Climate Data Center
PCC	Portland cement concrete
PPRC	Partnered Pavement Research Center
RAP	Reclaimed Asphalt Pavement
RB	Rich bottom
RSCH	Repeated Simple Shear Test at Constant Height
RWC	Rolling wheel compaction
SF	Shift factor
SHRP	Strategic Highway Research Program
SPE	Strategic Plan Element
SSP	Standard Special Provisions
TCF	Temperature conversion factor
UCPRC	University of California Pavement Research Center
WIM	Weigh-in-motion

LIST OF TEST METHODS AND SPECIFICATIONS

AASHTO T 209	Standard Method of Test for Theoretical Maximum Specific Gravity (Gmm) and Density of Hot Mix Asphalt (HMA)
AASHTO T 320	Standard Method of Test for Determining the Permanent Shear Strain and Stiffness of Asphalt Mixtures Using the Superpave Shear Tester (SST)
AASHTO T 321	Standard Method of Test for Determining the Fatigue Life of Compacted Asphalt Mixtures Subjected to Repeated Flexural Bending
AASHTO T 324 (Modified)	Standard Method of Test for Hamburg Wheel-Track Testing of Compacted Hot-Mix Asphalt (HMA)
AASHTO PP3-94	Standard Practice for Quantifying Roughness of Pavements
ASTM D7312	Standard Test Method for Determining the Permanent Shear Strain and Complex Shear Modulus of Asphalt Mixtures Using the Superpave Shear Tester (SST)
ASTM D7460	Standard Test Method for Determining Fatigue Failure of Compacted Asphalt Concrete Subjected to Repeated Flexural Bending
LLP – AC2	Caltrans – Sample Preparation and Testing for Long-Life Hot Mix Asphalt Pavements

1 INTRODUCTION

1.1 Background

In early December 2009, a Long-Life Asphalt Pavement (LLAP) Technical Working Group for Northern California (consisting of Caltrans headquarters staff, Industry representatives, and researchers from the University of California Pavement Research Center [UCPRC]) was convened to develop long-life pavement projects on the state highway system in Northern California. In 2010, a number of meetings were held in which potential sites were discussed. In December of that year, Caltrans District 2—on the recommendation of Mr. A. Benipal, the State Pavement Engineer—agreed to the use of two pavement sections in that district on Interstate 5 (I-5) for design and construction as LLAP sections. One section is just north of the city of Red Bluff (Tehama County, Post Mile 37.0 – Post Mile 41.5 NB/SB) and the other is through and north of the city of Weed (Siskiyou County, Post Mile 19.0 – Post Mile 25.3 NB/SB). In 2012, a third LLAP project was initiated on Interstate 80 in District 4 (Solano County Post Mile 30.6 – Post Mile 38.70) between the cities of Dixon and Vacaville. *(Note:* In this memorandum, these are referred to as the Red Bluff, Weed, and Solano projects, respectively.) A decision was made to conduct these projects under Caltrans/UCPRC Partnered Pavement Research Center Strategic Plan (PPRC SPE) Number 3.15, which was changed soon after to PPRC SPE 3.18.2.

1.2 The Specification Development Process

Long-life pavement design in California is based on lessons learned from the construction of the state's first LLAP project—the multiphase rehabilitation of the Long Beach Freeway, Interstate 710 (I-710), in Los Angeles County—which began in 2001. Monismith et al. *(1)* summarized the lessons learned from the initial design through the performance of that project after five years of traffic.

The current process for developing a performance specification for long-life asphalt concrete (AC) mix designs requires a series of steps, including the selection of a location (including route and post mile range) and the development of a conceptual pavement design, which in this case were both accomplished by Caltrans (see Section 1.2.1).

1.2.1 Solano Long-Life Asphalt Pavement Design

The Solano LLAP section was selected by District 4 staff and then designed by Caltrans headquarters staff using the *California Mechanistic-Empirical Analysis and Design* software program (*CalME)* design methodology. The existing pavement consisted of jointed plain concrete pavement (JPCP) without dowels that had been built in the 1960s and the 1970s and had extensive transverse, longitudinal, and corner cracking, many slabs with third stage cracking, cracked replacement slabs, and extensive faulting after 35 to 45 years of traffic.

Based on the availability of reclaimed asphalt pavement (RAP) materials, a decision was made that consideration should be given to the use of more than 15 percent RAP (an option available to contractors in the current Caltrans hot mix asphalt [HMA] specifications) in the appropriate layers of the structural pavement sections. Further, based on the familiarity of District 2 staff with a number of aggregate sources in the district, a decision was also made that all the HMA used in the project should contain 1.2 percent lime (based on the weight of the virgin aggregate) applied using the process of *marination* rather than the alternatives, which are the application of dry lime on damp aggregate or the use of an additive in the asphalt.

After a review of as-built information and use of *CalME* mechanistic-empirical design program by staff from Caltrans headquarters and the UCPRC—and after consideration of the binder grades for the project area, the structural condition of the pavement, and other distress types—it was decided that the pavement layers for the structural section for the Solano project should consist of the following components:

- An HMA surface course containing a polymer-modified asphalt (design binder PG 64-28PM) containing 15 percent reclaimed asphalt pavement (RAP) and a representative virgin aggregate from the local area treated with 1.2 percent lime (marinated)
- An HMA intermediate course containing conventional asphalt binder (design binder PG 64-10 [PG 64-16] supplied by the refinery and allowed by Caltrans since the properties of the PG 64-16 meet all of the specifications for PG 64-10]), and the same lime-treated virgin aggregate as the surface course plus 25 percent RAP

This structural section was constructed on the existing jointed concrete pavement (JPCP) that was cracked and seated prior to placing the HMA components. In the I-710 and Red Bluff projects, pavements constructed under overcrossings were full-depth HMA structures that contained “rich bottom” HMA layers. For the two overcrossings on the Solano project, precast concrete slabs were used in place of HMA base layers for the freeway and also for the approach and leave slabs for culvert bridges.

1.2.2 Development of Performance-Based Specifications by UCPRC

As noted, the LLAP Technical Working Group agreed that UCPRC staff would: (1) conduct the necessary performance tests; (2) provide the required data for the structural pavement designs to Caltrans staff; and (3) provide the requisite data for the mix performance requirements based on laboratory testing and the traffic and environment (temperature) in the locations of the three long-life projects. UCPRC staff accomplished this and developed the specifications for all the asphalt concrete (AC) mixes proposed for each location by following these steps in Project SPE 3.18.2.

Design of the pavement sections for Red Bluff I-5 and Weed I-5 projects *(2, 3)* required mix performance test data. District 2 Materials staff supplied representative aggregates and available RAP used in the Red Bluff and Weed areas. Mix performance data included the results of UCPRC-performed repeated simple shear tests at constant height (RSCH) (AASHTO T 320)[1] flexural fatigue and stiffness tests (AASHTO T 321), and Hamburg Wheel-Track Testing (HWTT) (AASHTO T 324). Because of time constraints, no mix tests were performed by the UCPRC for the Solano I-80 project. Rather, Caltrans selected the Red Bluff mix performance specification requirements for the design of the pavement section for the Solano project, and adjusted them with traffic and climate data specific to the Solano project.

To ensure that mixes used by the contractor met the specifications requirements for the structural pavement section prior to HMA placement and to expedite construction, Caltrans selected the UCPRC to be the laboratory of record for HMA performance testing (shear, stiffness, fatigue, and HWT tests) of the contractor's materials.

This technical memorandum documents the collaboration between Caltrans and the UCPRC to perform any required laboratory mix testing, and establish performance criteria for construction of the District 4 Solano County section. Traffic and climatic effects are included because they are a critical part of the development of performance requirements. Separate technical memoranda have been produced for the Red Bluff and Weed projects.

Chapter 2 of this memorandum summarizes how and why materials selected for the Red Bluff test specimens were used for the Solano project. Chapter 3 discusses the traffic and temperature estimates used to design and to determine material testing parameters. Chapter 4 summarizes the processes used for HMA mix testing that were followed in the Red Bluff project since those materials were used for the Solano project. Chapter 5 presents the shear, fatigue, and flexural stiffness requirements developed for the mixes. Chapter 6 presents the suggested mix performance requirements developed for the Solano project. Chapter 7 presents an overview of the project and includes a recommendation for future work. Appendix A contains a shortened version of the lab testing data obtained by UCPRC for this project.

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[1] Modified according to the Lab Procedure, LLP-AC2, "Sample Preparation and Testing for Long-Life Hot Mix Asphalt Pavements," available at *www.dot.ca.gov/hq/esc/Translab/ormt/pdf/LLP-AC2_Sample_Preparation_for_LL_HMA-Pavement.pdf*.

2 MATERIALS

Because of the planned construction start date for the Solano project chosen by District 4, there was insufficient time for gathering representative aggregates and mix performance testing, structural pavement section design, development of plans and specifications, production of bid documents, and selection of a contractor. As noted in Chapter 1, these time constraints led to the decision to use the Red Bluff mix performance data instead of conducting a mix test program like those used for the Red Bluff and Weed projects. Eliminating the time required for the mix performance testing by using the Red Bluff mix data rather than developing mix performance data made it possible to meet the deadline for construction. It should also be noted that the asphalts used for the Red Bluff mixes were representative of those used for the Solano project. The specifications for mix performance testing, however, were based on the anticipated traffic and temperature conditions for the Solano segment of I-80.

Reference *(2)* contains both the aggregate and asphalt properties and specifications as well as gradations for the aggregates.

3 TRAFFIC AND PAVEMENT TEMPERATURE ESTIMATES

Traffic and pavement temperature are two key factors used in determining material test parameters and pavement performance. Since the test parameters for shear testing are directly related to pavement temperature, and mix design is related to traffic estimates, how these were selected is discussed below.

3.1 Traffic

Traffic data were obtained from recorded Caltrans weigh-in-motion (WIM) data within the area of the Solano project (WIM stations, WIM041 and WIM042) contained in the *CalME* software. Following the model of the I-710 Phase 1 LLAP project *(1)*, traffic estimates were based on the first five years after opening of the rehabilitated sections to traffic. This determination provided a total of 7.8×10^6 ESALs based on a 3 percent linear annual growth rate.

These estimates were used to determine the requirements for the shear test results, based on the premise (and experience) that as long as the mix is properly designed and constructed, the majority of rutting in the HMA layer will occur during the first five years *(1, 4, 5)*.

The total estimated traffic for a forty-year period was used by Caltrans staff to determine the final structural sections following the *CalME* design methodology, together with both the fatigue and shear test data provided.

3.2 Pavement Temperature for Shear Testing

Temperature data covering a period of years for the Solano project was obtained from the National Climate Data Center (NCDC) and the UCPRC Weather Database, using nearby Sacramento climate as a surrogate. This temperature information was then used to determine the temperature for shear testing of the HMA. Test temperature selection was based on that at a 2 in. depth in the HMA. Selection of this depth was based on analyses that suggest that the maximum shear stress from tires that leads to rutting occurs at the edge of the tire at about this depth *(1, 4)*. Moreover, the majority of rutting results when temperatures above about 40°C (104°F) last for an extended period of time (e.g., seven days). Accordingly, the test temperature was based on the daily maximum air temperature based on a 30 year (if available) period. This information permitted determination of the seven-day moving average of daily maximum temperature (ADMT_7). The ADMT_7 data were then plotted as a cumulative distribution function (CDF), as illustrated in Figure 3.1. Data used for Sacramento were based on a ten-year period (01/01/2001 to 12/31/2010) recorded by the NCDC. Data for Weed and Cottonwood (Red Bluff) are also shown as this temperature assessment for the three LLAP projects was conducted at the same time for both the Red Bluff and Weed projects.

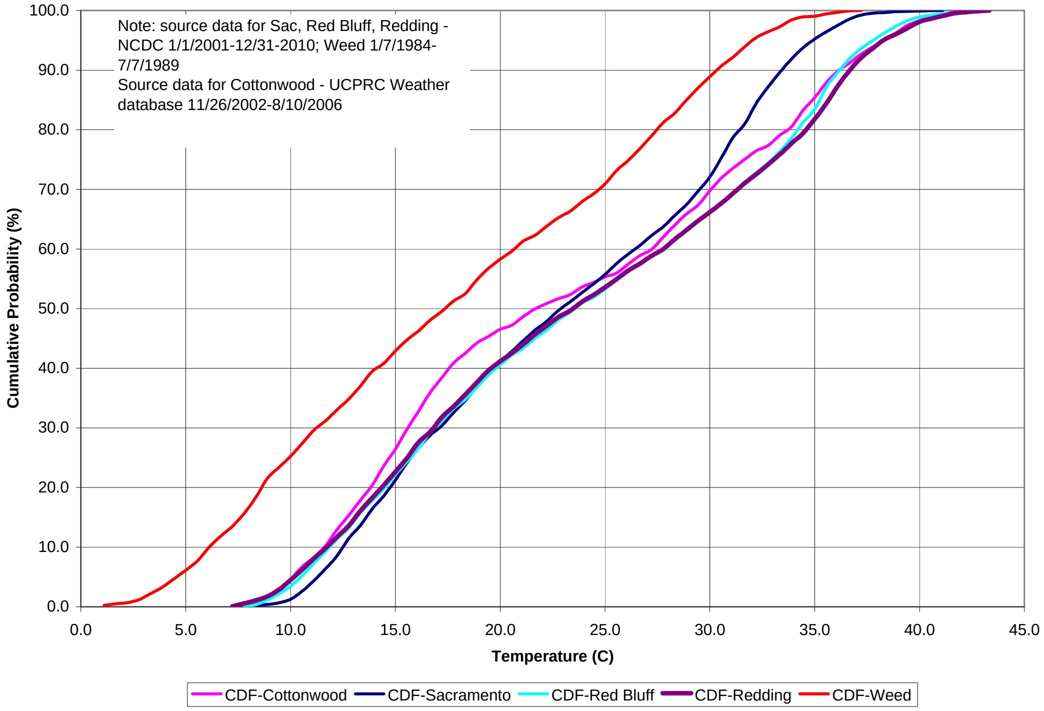

Figure 3.1: Seven-day moving average of maximum daily air temperatures for Cottonwood, Sacramento, Red Bluff, Redding, and Weed.

The pavement temperature distribution with depth came from use of the Integrated Climate Model (ICM) and is the same data used in the *CalME* program. For this computation, temperatures for Sacramento for a period of 30 years were used (01/01/1961 to 12/31/1990) since these were the only temperatures available in *CalME* that would be similar to those at the Solano I-80 site. Assumptions for this computation included an albedo of 0.95, 10 inch (254 mm) thick asphalt and constant temperature of 4°C (9°F) at depth of about160 inches (4 m).

Computations for the pavement surface temperature and temperature at the 2 in. depth are shown Figure 3.2.

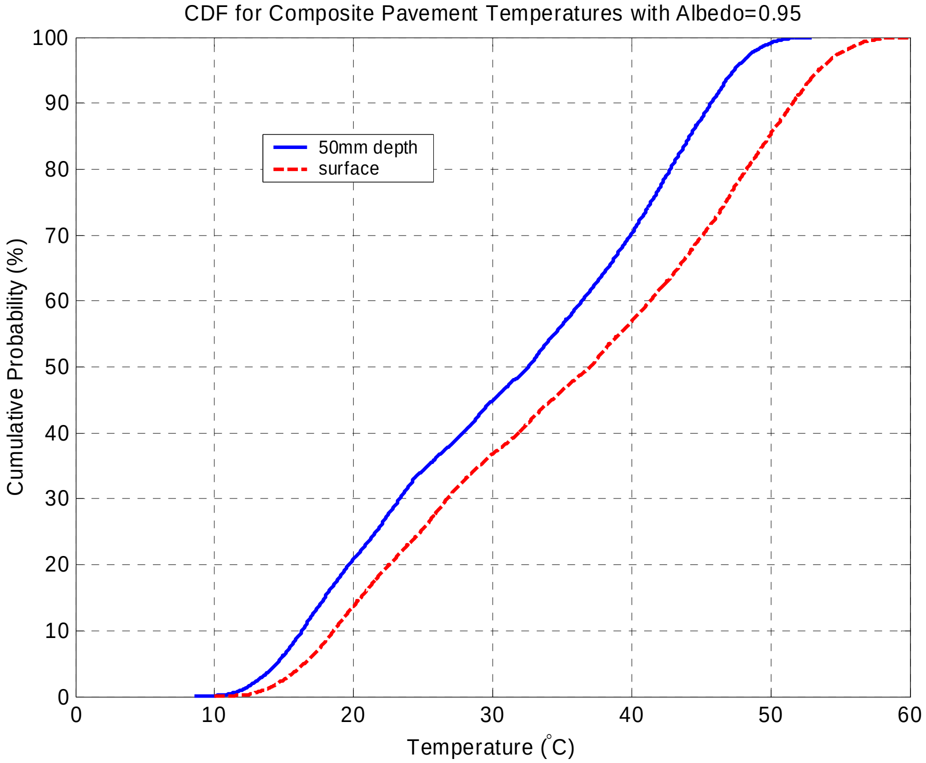

Figure 3.2: Seven-day moving average of maximum daily surface temperatures and temperatures at a 2 in. depth for Sacramento, based on analysis using the ICM.

Based on the information shown in Figure 3.1 and Figure 3.2 for Sacramento, a test temperature for shear testing was selected for Solano. At 2 inch depth, the temperature, corresponding to the 95th percentile for Sacramento, is about 48°C (118°F); this was increased to 50°C (122°F) to be conservative.

4 MIX TESTING

As noted earlier, the I-80 Solano project did not include the mix testing used to develop the mix test performance requirements that are typically contained in project bid document specifications. Shear testing specifications were developed from temperature and traffic data, as discussed in Chapter 3.The mix fatigue and stiffness data used for the specifications for this project were those for the Red Bluff I-5 project *(2)*.

For information purposes only, since no performance testing was conducted for this project, the HMA performance requirements for the Red Bluff and Weed projects were developed using the following AASHTO test procedures:

- AASHTO T 320 (ASTM D7312): the RSCH,used to select the design mix binder content for each of the mixes to be used in the Red Bluff Project.
- AASHTO T 321 (ASTM D7460): the flexural fatigue and frequency sweep test used to determine mix fatigue response at the selected design binder content.
- AASHTO T 324, Hamburg Wheel-Track Testing (HWTT) used to evaluate the moisture sensitivity response of each of the mixes.
- All of the specimens for the performance tests, except for the HWTT specimens, were prepared using rolling wheel compaction (RWC). This compaction method was used because the aggregate structure prepared by this method is similar to that obtained in mixes during pavement construction *(6)*. Rolling-wheel compaction, which was used for a number of years by organizations in Europe (e.g., Royal Dutch Shell and the French LCPC), was developed during the Strategic Highway Research Program (SHRP) and published as AASHTO PP3-94. The HWTT specimens were prepared by Superpave Gyratory Compaction because that is the current requirement in AASHTO T 324.

To define the performance requirements, the AASHTO procedures were subsequently modified and those modifications have been listed in the Caltrans Flexible Pavement Test Method LLP-AC2 *(7)*. The modifications are detailed in the footnotes to Table 6.1, which shows the HMA performance requirements for the Solano project.

As was noted in Chapter 3, a shear test temperature of 50°C was selected. Thus, as will be seen in Chapter 6, the shear test mix performance requirements are different than those used at Red Bluff because of a different temperature regime and level of traffic for the five-year design period for rutting. The mix performance characteristics for fatigue, stiffness, and the HWTT are the same as those for Red Bluff.

5 DEVELOPMENT OF FATIGUE AND STIFFNESS MIX PERFORMANCE SPECIFICATION CRITERIA

5.1 RSCH Specification Development

As with the I-710 Freeway long-life project, the criteria for the mix designs have been selected to accommodate the traffic estimated during the first five years of operation *(1)*. Based on the traffic data available, the design value for the five-year period is 7.8 x 10^6 ESALs, termed N_{demand}. The RSCH criteria listed in Table 6.1 were then developed according to the following equations:

$$(N_{supply}) \geq M \cdot (N_{demand}) \qquad \textbf{(6.1)}$$

N_{demand} was determined as follows:

$$N_{demand} = \text{Design ESALs} \cdot \text{TCF} \cdot \text{SF} \qquad \textbf{(6.2)}$$

where:

TCF = temperature conversion factor; estimated to be 0.12 for the I-80 Solano area
SF = shift factor, value of 0.04 was used (developed in Reference [4]).

The development of the parameters for $N_{demand,}$ TCF and SF is documented in the SHRP-A-415 research report *(4)*. The TCF developed for California and the SF values referred to above were taken from tables in Chapter 15 of the A-415 report.

To determine N_{supply}, a reliability multiplier, M, equal to 5 for a 95 percent reliability level was used. The reliability factor is based on the RSCH test variance and the variance in ln(ESALs). Reference *(4)* provides a range of reliability factors that are dependent on the number of shear tests performed (test variance) and the level of accuracy of traffic estimates (ln [ESALs]). For the I-80 Solano project, estimated traffic was determined to be equal to 7.8×10^6 ESALs—as noted earlier. Using Equations (6.1) and (6.2), N_{supply} required from shear tests was estimated to be 190,000 repetitions. This result is listed in Table 6.1 as the specification for shear test results for both the mix containing the PG 64-28PM binder and that with the PG 64-10 binder. Although the layer containing the PG 64-10 binder was located beneath the layer containing the PG 64-28PM binder, there was concern that the top layer might not be placed before the rainy season, with the result that winter traffic would travel over the layer containing the PG 64-10 binder.

5.2 Suggested Fatigue and Stiffness Performance Requirements

Fatigue and stiffness mix performance specification criteria for I-80 Solano project were those used for the Red Bluff I-5 project. Details of this process and the origins of these specification values are described in the Red Bluff technical memorandum *(2)*. The suggested fatigue specification requirements for the mixes in this project are shown in Table 5.1. Suggested stiffness requirements are shown in Table 5.2.

Table 5.1: Recommended Fatigue Performance Requirements (repetitions) at 200 and 400 Microstrain at 20ºC

Mix Type	Min. Requirements for Fatigue Life		Regression Line Requirement
	200 microstrain	400 microstrain	
PG 64-10 25% RAP w/1.2% lime	935,232	24,933	Regression line has to be above the lower bound
Suggested	950,000	25,000	
PG 64-28 PM 15% RAP w/ 1.2% lime	345.053,136	23,123,732	Regression line has to be above the lower bound
Suggested	345, 000,000	23,000,000	

Notes:

1. For each mix type, the fatigue test results have to comply with the following requirements:
    (a) The fatigue life has to comply with the minimum requirement.
    (b) The regression line constructed by three 200 microstrain fatigue tests and three 400 microstrain fatigue tests have to be above the lower bound.
2. The lower bound of PG 64-10 25% RAP with 1.2% lime was based on the use of all of the seven tests.
3. The lower bound of PG 64-28PM 15% RAP with 1.2% lime was based on the use of five of the six tests.

Table 5.2: Recommended Flexural Stiffness Requirements for Mix Performance

Mix Type	Flexural Stiffness at 20°C (10 Hz) 95% Confidence Interval		Flexural Stiffness at 30°C (10 Hz) 95% Confidence Interval	
	Lower Bound MPa (psi)	Upper Bound MPa (psi)	Lower Bound MPa (psi)	Upper Bound MPa (psi)
PG 64-10 25%RAP w /1.2% lime	5,997 (869,791)	6,965 (1,010,188)	801 (116,175)	4,760 (690,380)
Suggested (psi)	870,000	1,000,000	220,000	No limit recommended
PG64-28PM 15% RAP w/1.2%lime	2,822 (409,297)	3,354(486.452)	1,497 (217,122)	1,662 (241,053)
Suggested (psi)	415,000	486,000	No limit recommended	No limit recommended

Notes:

1. The flexural stiffnesses at 20°C (10 Hz) were based on the flexural fatigue test results.
2. The flexural stiffnesses at 30°C (10 Hz) were based on the flexural frequency sweep test results.

6 RECOMMENDED MIX PERFORMANCE SPECIFICATIONS FOR I-80 SOLANO PROJECT

The fatigue, stiffness, and shear test parameters are based on the analyses included in Chapter 5. In Table 6.1, the numbers have been rounded to what are considered to be significant figures for the test values.

HWTT requirements are those cited in the Caltrans standard specification.

Table 6.1: Recommended HMA Mix Performance Requirements for Solano I-80 Project

Design Parameters	Test Method	Requirement
Permanent deformation (minimum):	AASHTO T 320 Modified[1]	
PG 64-28PM (with RAP and lime)[2a]		190,000 stress repetitions[3,4]
PG 64-10 (with RAP and lime)[2b]		190,000 stress repetitions[3,4]
Fatigue (minimum):	AASHTO T 321 Modified[1]	
PG 64-28PM (with lime)[5a,6]		23,000,000[4,8] 345,000,000[4,9]
PG 64-10 (with RAP and lime)[5b,7]		25,000 repetitions[4,8] 950,000 repetitions[4,9]
Moisture sensitivity (minimum):	AASHTO T 324 Modified[1]	
PG 64-10 (with RAP and lime)		20,000 repetitions[10]

Notes:

1. Included in the testing procedure, LLP-AC2 (rolling wheel compaction), “Sample Preparation and Testing for I-710–Long-Life HMA,” available at *www.dot.ca.gov/hq/esc/Translab/ormt/pdf/LLP-AC2_Sample_ Preparation_for_LL_HMA-Pavement.pdf*.

2a. At proposed asphalt binder content (mix containing 1.2% lime) and with mix compacted to 3%+/-0.3% air voids.

2b. At proposed asphalt binder content (mix containing RAP and 1.2% lime) and with mix compacted to 3%+/-0.3% air voids.

3. In repeated simple shear test at constant height (RSCH) at a temperature of 50°C at 100kPa.

4. Minimum test value measured from tests on three specimens.

5a. At proposed asphalt binder content (mix containing 1.2% lime) and with mix compacted to 6%+/-0.3% air voids (determined using AASHTO T 209 [Method A]).

5b. At proposed asphalt binder content (mix containing RAP and 1.2% lime) and with mix compacted to 6%+/-0.3% air voids (determined using AASHTO T 209 [Method A])

6. At proposed asphalt binder content, the average mix stiffness at 20°C and a 10 Hz load frequency must be in the range 415,000 to 486,000 psi. At proposed asphalt binder content, the minimum stiffness at 30°C and a 10 Hz load frequency must be equal to or greater than 220,000 psi.

7. At proposed asphalt binder content (mix containing RAP and 1.2% lime), average stiffness at 20°C and a 10 Hz load frequency must be in the range 870,000 to 1,000,000 psi.

8. At 400×10^{-6} strain, results shall be reported for this strain level but may be obtained by extrapolation. Minimum number of repetitions required prior to extrapolation defined within test procedure.

9. At 200×10^{-6} strain, results shall be reported for this strain level but may be obtained by extrapolation. Minimum number of repetitions required prior to extrapolation defined within test procedure.

10. Minimum number of repetitions for rut depth of 0.5 in. at 50°C (average of two specimens).

7 SUMMARY AND RECOMMENDATION

7.1 Summary

This technical memorandum summarizes the process used to develop suggested HMA performance-related specifications for the I-80 Solano LLAP project. Because of time constraints described herein, Caltrans made use of the HMA performance-related tests data for the mix used on the Red Bluff I-5 project. Traffic and environmental conditions for this project in Solano County on I-80, however, were used in the development of the permanent deformation performance specifications. Caltrans HQ staff also used the mix data for the design of the pavement structure using *CalME* flexible pavement design methodology. The suggested performance specifications were ultimately included in the Standard Special Provisions (SSPs) of the bid document for the project.

After this project was awarded to the selected contractor, Caltrans selected UCPRC as the laboratory of record for evaluation of the proposed HMA mixes. When the contractor’s mixes were tested, results were reported directly to the contractor—and whether or not they met the required specifications. In addition to this, UCPRC staff regularly participated in moderator-led partner meetings with the contractor and Caltrans, as required for projects of this size. A summary of the results of the HMA tests for the contractor are included in Appendix A.

7.2 Recommendation

While not a part of this investigation, it is strongly recommended, following completion of construction, that systematic and periodic pavement performance evaluations be conducted for at least five years, and preferably longer, following a similar approach to that used on the I-710 Phase 1 Project *(1)* and the Red Bluff project. This is especially important since this is one of the first projects using the higher percentage of RAP in HMA mixes for LLAPs.

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APPENDIX A: SUMMARY OF LABORATORY TEST DATA OBTAINED BY THE UCPRC BERKELEY LABORATORY SERVING AS THE LABORATORY OF RECORD (AS DESIGNATED BY CALTRANS)

Summary of *Laboratory of Record* Test Program

To expedite the construction of the LLAP I-80 Solano project, as stated in the technical memorandum, Caltrans designated the UCPRC UC Berkeley Laboratory as the Laboratory of Record.

The contractor prepared the surface and base courses at two different HMA plants. The surface course HMA was produced at Plant No. 1111 (batch); and the base course was produced at Plant 1135 (continuous).

This appendix contains eight tables containing the test data, four for each mix from the two plants. Table A.1 through Table A.4 contain the test results for Plant 1111 and Table A.5 through Table A.8 test results for Plant 1135. Test specimens cut from slabs were prepared by the contractor using rolling-wheel compaction following Caltrans test procedure, LLP-AC2, "Sample Preparation and Testing for Long-Life Hot Mix Asphalt Pavements," available at: *www.dot.ca.gov/hq/esc/Translab/ormt/pdf/LLPAC2_Sample_Preparation_for_LL_HMA-Pavement.pdf*.

Test specimens included cylinders for the shear tests and beams for the fatigue and stiffness tests. In addition, the contractor provided gyratory-compacted specimens for the HWTT tests. Figure A.1 and Figure A.2 contain the shear test results versus the mix binder contents for the two mixes. Both mixes are critical mixes; design binder contents were selected considering this criticality.

Table A.1: RSST Test Results for Solano 80 ME Long-Life: 15%, 4.96% Binder Content, Plant 1111

	Specimen ID	Air-Void Content (%)	Height (mm)	Test Temp. (C)	Test Shear Stress Level (kPa)	Initial Res. Shear Mod. (MPa)	Perm. Shear Strain at 5,000 Cycles	Cycles to 5% Perm. Shear Strain	Int. or Ext.
4.96	L23-1	2.9	50.9	54.8	68.63	98	0.023548	611,246	Ext.
	L23-3	2.7	51.0	54.9	71.30	96	0.020920	2,330,646	Ext.
	L23-4	2.7	50.8	54.9	66.64	88	0.022893	406,524	Ext.

Table A.2: Flexural Fatigue Test Results for Solano 80 ME Long-Life: 15% RAP, 4.96% Binder Content, Plant 1111

Binder Content (%)	Specimen ID	Air-Void Content (%)	Test Temp. (°C)	Test Strain Level	Initial Phase Angle (Deg.)	Initial Stiffness (MPa)	Fatigue Life N_f	Int. or Ext.
4.96	R22-5	6.3	20.13	0.000203	29.38	4,578	400,219,400	Ext.
	R23-1	6.3	20.38	0.000206	28.88	4,960	66,127,523	Ext.
	R24-5	6.1	19.87	0.000197	25.77	6,447	198,819,524	Ext.
	R27-3	6.1	20.14	0.000203	28.26	4,576	195,413,792	Ext.
	R20-3	6.3	20.20	0.000403	29.95	4,627	776,520	Int.
	R20-2	6.1	20.14	0.000408	29.68	4,624	870,114	Int.
	R21-4	6.4	19.86	0.000381	23.80	5,136	1,162,874	Int.

Table A.3: Fatigue Stiffness Test Results for Solano 80 ME Long-Life: 15% RAP, 4.96% Binder Content, Plant 1111

Binder Content (%)	Specimen ID	Air-Void Content (%)	Test Temp. (°C)	Phase Angle (Deg.)	Initial Stiffness (MPa)	Initial Stiffness (psi)	Requirement	Pass or Fail
4.96	R22-6	6.3	10.1	17.64	9,145	1,326,420	-	
	R24-3	5.7	10.0	15.66	11,048	1,602,334	-	
	R24-1	5.7	19.7	24.20	6,057	878,493	415,000	Pass
	R24-6	5.8	19.8	22.89	6,487	940,813	415,000	Pass
	R20-4	6.3	29.9	36.72	1,907	276,563	220,000	Pass
	R21-3	6.4	29.5	37.99	2,166	314,224	220,000	Pass

Table A.4: Hamburg Wheel-Track Test Results for Solano 80 ME Long-Life: 15% RAP, 4.96% Binder Content, Plant 1111

Position	Specimen ID	Air-Void Content (%)	Average Rut Depth (mm)	
			15k Passes	20k Passes
Rt.	TS80-1135-15R-B5	7.3	-0.84	-0.92
	TS80-1135-15R-B6	7.1		
Lt.	TS80-1135-15R-B9	7.1	-1.41	-1.47
	TS80-1135-15R-B8	7.1		

Table A.5: RSST Test Results for Solano 80 ME Long-Life: 25% RAP, 4.8% Binder Content, Plant 1135

Binder Content (%)	Specimen ID	Air-Void Content (%)	Height (mm)	Test Temp. (C)	Test Shear Stress Level (kPa)	Initial Res. Shear Mod. (MPa)	Perm. Shear Strain at 5,000 Cycles	Cycles to 5% Perm. Shear Strain	Int. or Ext.
4.8	Z2-1	2.9	51.9	53.7	101.11	225	0.025933	94,805	Ext.
	X2-1	2.9	51.4	48.5	101.25	239	0.018155	741,678	Ext.
	Z2-5	2.9	51.6	48.4	103.74	278	0.029730	50,034	Ext.
	X2-2	2.8	52.0	48.4	98.47	243	0.020080	324,226	Ext.
	Z2-3	3.0	52.1	54.9	103.51	344	0.021581	170,162	Ext.
	X1-1	2.7	52.3	48.3	96.60	196	0.015363	5,230,364	Ext.

Table A.6: Flexural Fatigue Test Result for Solano 80 ME Long-Life: 25% RAP, 4.8% Binder Content, Plant 1135

Binder Content (%)	Specimen ID	Air-Void Content (%)	Test Temp. (°C)	Test Strain Level	Initial Phase Angle (Deg.)	Initial Stiffness (MPa)	Fatigue Life (Nf)	Int. or Ext.
4.8	x3-1	6.2	20.27	0.000199	19.70	9,004	6,101,453	Ext.
	z4-5	6.0	20.10	0.000199	20.83	8,002	1,685,598	Int.
	z4-4	6.3	19.85	0.000184	19.24	7,829	2,495,328	Int.
	z3-6	5.7	20.36	0.000402	20.55	8,988	34,540	Int.
	z5-6	6.0	19.90	0.000373	22.28	8,269	24,228	Int.
	z4-3	6.3	20.17	0.000402	22.22	7,390	57,400	Int.

Table A.7: Fatigue Stiffness Test Result for Solano 80 ME Long-Life: 25% RAP, 4.8% Binder Content, Plant 1135

Binder Content (%)	Specimen ID	Air-Void Content (%)	Test Temp (°C)	Phase Angle (Deg.)	Initial Stiffness (MPa)	Initial Stiffness (psi)	Requirement	Pass or Fail
4.8	z5-1	6.3	9.9	10.78	13,578	1,969,268	-	-
	z5-2	6.1	9.9	11.23	13,936	2,021,296	-	-
	z4-2	6.3	20.0	18.85	7,988	1,158,527	870,000	Pass
	z5-5	6.0	20.0	16.60	9,468	1,373,193	870,000	Pass
	z3-1	5.7	30.2	27.10	4,381	635,445		
	z4-6	6.1	30.5	32.22	3,901	565,735		

Table A.8: Hamburg Wheel-Tracking Test Result for Solano 80 ME Long-Life: 25% RAP, 4.8% Binder Content, Plant 1135

Position	Specimen ID	Air-Void Content (%)	Average Rut Depth (mm)	
			15k Passes	20k Passes
Rt.	TS80-1135-25R-E	6.7	-1.34	-1.45
	TS80-1135-25R-B	6.9		
Lt.	TS80-1135-25R-K	6.8	-2.17	-2.33
	TS80-1135-25R-C	6.9		

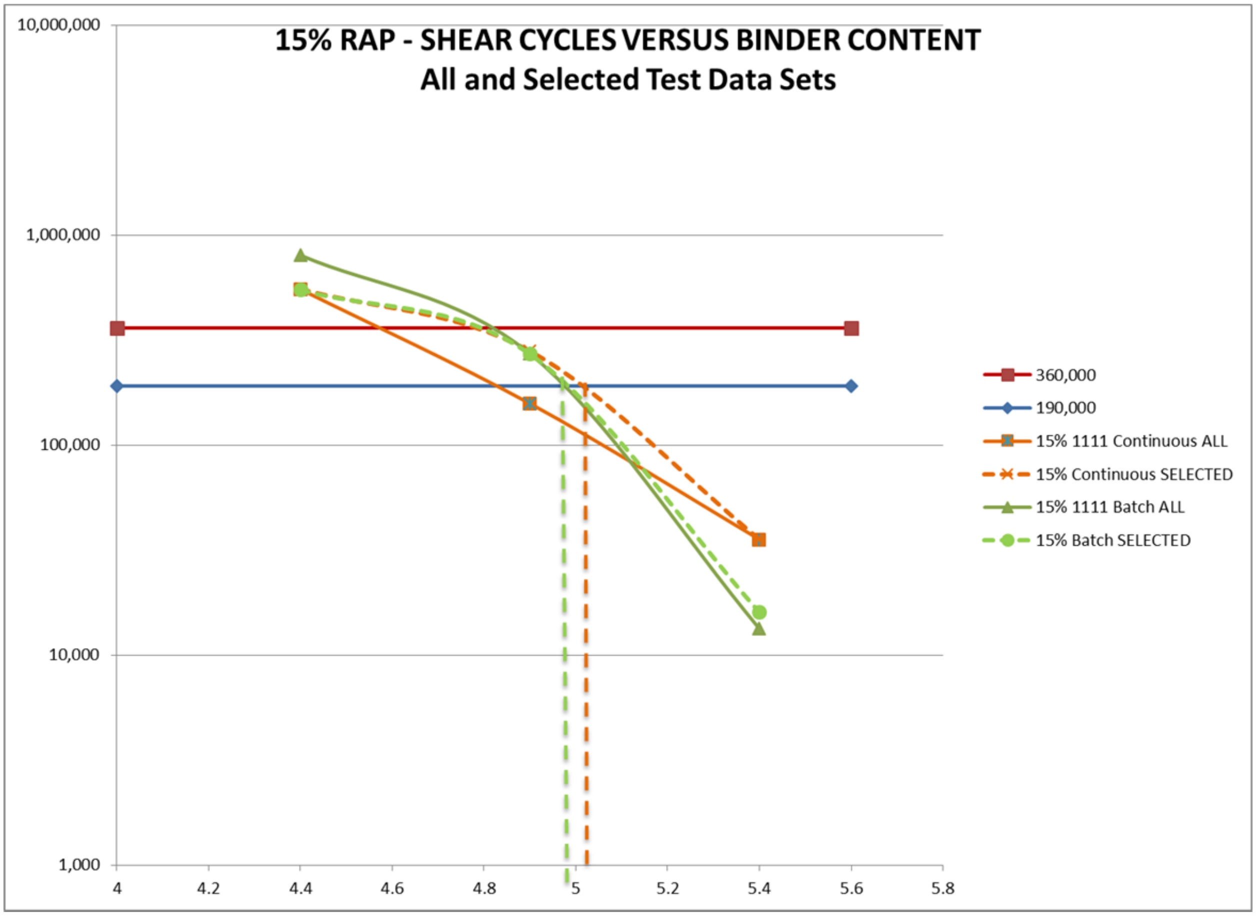

Figure A.1: Shear cycles versus asphalt content (mix basis), surface course.

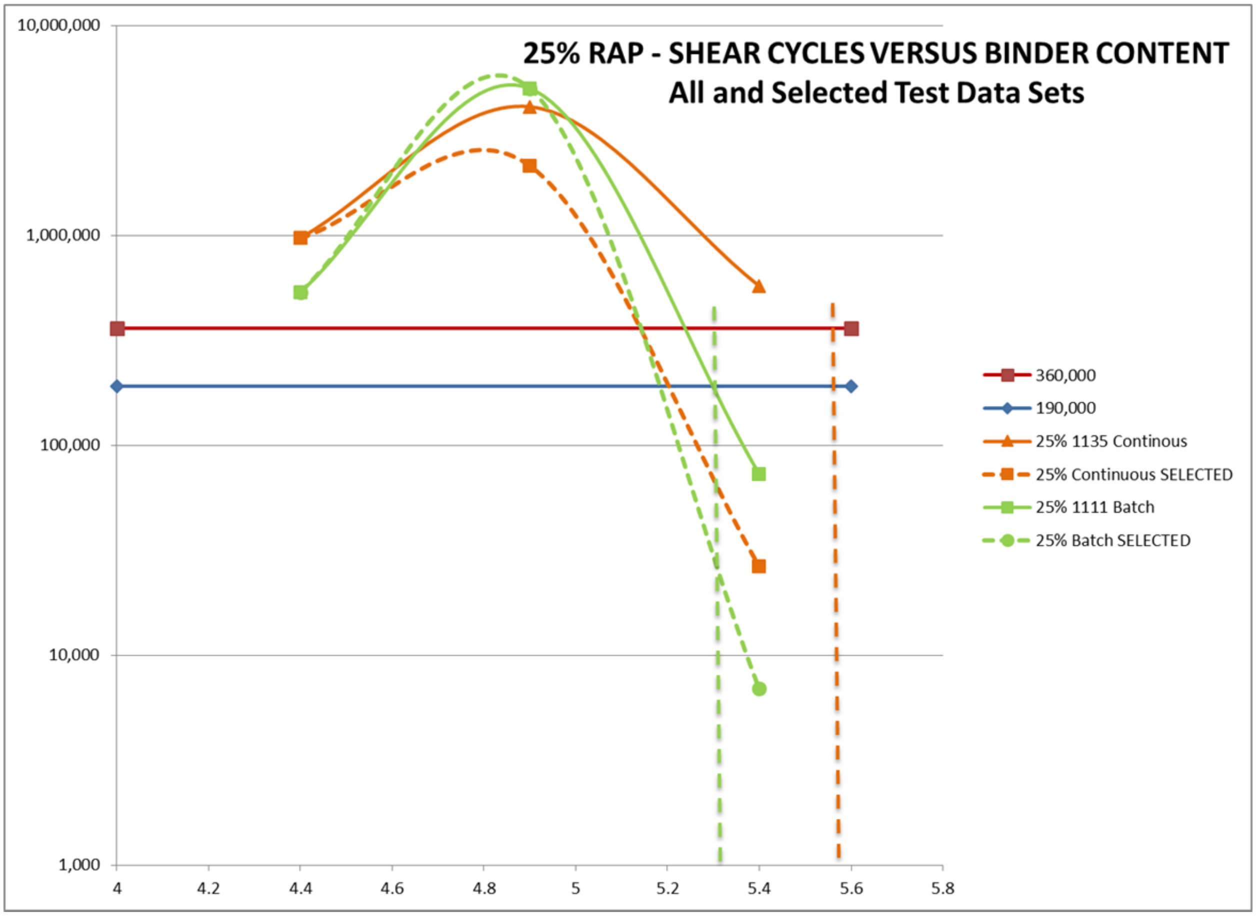

Figure A.2: Shear cycles versus asphalt content (mix basis), base course.