

WESTRACK FULL-SCALE TEST TRACK: INTERIM FINDINGS

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Abstract. A federally-funded multi-million dollar hot-mix asphalt (HMA) pavement research project is currently underway to further the development of performance related specifications (PRS) technology and to provide early field verification for the latest Superpave asphalt mixture design procedure. WesTrack refers to a full-scale road test experiment in which various asphalt mixes are being loaded in an accelerated fashion to determine the effect on field performance of “off-target” mix properties. The track is located near Reno, Nevada and the experiment is being carried out by a team made up of consulting firms, universities and road contractors.

This paper provides background for the project including the nature of the experiment, the experimental factors, structural and mix design, track construction, vehicle loading, driverless vehicle technology, performance monitoring and laboratory testing. It also presents information on the interim performance of the test sections, summarizes the planned approach to developing the pavement performance prediction models and describes the anticipated performance related specification system.

Keywords. Hot-mix asphalt, Superpave, performance related specifications, accelerated pavement test, autonomous vehicles.

INTRODUCTION

WesTrack is a \$14 million accelerated pavement test facility located in the state of Nevada approximately 100 km (60 mi) southeast of Reno. The pavement test facility was design and constructed and is presently being operated by a team of private companies and universities (WesTrack Team) under contract to the U.S. Department of Transportation’s Federal Highway Administration. The project was awarded to the WesTrack Team by the Federal Highway Administration in September of 1994. The test track was designed and constructed during the period between October 1994 to October 1995 and has been subjected to traffic since March 1996. Approximately 3 million equivalent single axle loads 80-kN (18,000 lb) ESALs have been applied to the pavement as of August 1, 1997. The experimental HMA sections are starting to deteriorate and useful information for performance assessment is being gathered.

OBJECTIVES

The project has two primary objectives as given below:

- Continue the development of performance related specifications (PRS) for hot-mix asphalt

pavements by evaluating the impact on performance of deviations in materials and construction properties (asphalt content, aggregate gradation, in-place air void content, etc.) from design target values.

- Provide early field verification of the SHRP Superpave HMA mixture design method.

The objectives are being addressed at WesTrack by designing, constructing, operating, monitoring performance, and developing performance prediction models from 34 different HMA test sections placed on a 3 km (1.8 mile) oval track. (Twenty-six test sections were placed and loaded originally and, one year after, eight “failed” sections were replaced with new experimental sections).

WESTRACK OVERVIEW

The WesTrack Team consists of the sponsoring agency (Federal Highway Administration) and seven private and university groups. Each of the groups has specific responsibilities within the framework of the project. Team members and primary responsibilities are given below:

- Nevada Automotive Test Center (prime contractor, driverless vehicle development, track loading).
- Nichols Consulting Engineers (experiment design, performance monitoring, PRS development).
- University of Nevada, Reno (pavement research, conventional HMA testing, construction coordination).
- University of California at Berkeley (SHRP-related HMA accelerated performance testing and performance modeling).
- Oregon State University (SHRP-related HMA testing, data analysis).
- Granite Construction Co. (track construction, rehabilitation, and maintenance).
- Harding Lawson Associates (track geometric design, construction inspection, quality control/quality assurance testing).

Principal Investigators for the WesTrack Team are Jon Epps (University of Nevada, Reno) and Stephen Seeds (Nichols Consulting Engineers). The Co-Program Managers are Henry C. Hodges Jr. and Colin Ashmore (Nevada Automotive Test Center). Principal participants are as follows: at Nichols Consulting Engineers, Sirous Alavi; at Granite Construction, Mike Robinson and Kevin Robertson; at Harding Lawson Associates, Stuart Dykins; at the University of Nevada, Adam Hand; at Oregon State

University, Rita Leahy; and at the University of California at Berkeley, Carl Monismith. Technical oversight on the project has been provided by Terry Mitchell, Ray Bonaquist, and Chris Williams of FHWA’s Turner-Fairbank Highway Research Center in McLean, Virginia.

BACKGROUND

Location and Climate. WesTrack is located in the Carson River valley in the high desert of northwest Nevada approximately 100 km (60 miles) from Reno and 60 km (35 miles) from Carson City, Nevada. The track is located on the proving grounds of the Nevada Automotive Test Center. The climate at the test site is typical of high desert climates in the intermountain western portion of the United States. A few summer days approach 40°C (104°F) and some winter days will fall to -25°C (-13°F). Annual precipitation, in the form of both rain and snow, is approximately 100 mm (4 in). Frost penetration into fill and subgrade materials is unlikely at this site.

Track Configuration. The track consists of two tangent sections connected by two spiral curves. All test sections are constructed on the tangents between the turnarounds. The tangent sections are 10.4 m (34 ft) wide consisting of two 3.7 m (12 ft) lanes with a 1.2 m (4 ft) HMA shoulder outside and a 1.8 m (6ft) gravel shoulder inside. The outside lane serves as the actual “test” lane while the inside lane serves as both a paved shoulder and a “trial” HMA placement lane. Each of the 26 experimental section sites is 70 m (230 ft) in length-25 meters (82 ft) for transition, 40 meters (131 ft) for performance monitoring, and 5 meters (16 ft) for destructive sampling (Figure 1).

Vehicle Loading. Pavement loading is being accomplished using four (driverless) tractor/triple-trailer combinations. A typical 3-axle tractor/single-axle semi-trailer (3S1) is followed by two trailers, each with two single axles. Weights on each load axle are 89 kN (20,000 lb), contributing to a total of 10.3 ESALs per truck pass. To aid in the electronic control of the trucks through the driverless vehicle system, each is equipped with a turbo-charged, electronically controlled engine. Automatic transmissions in each truck allow electronic control of the transmission function. The trucks and trailers are equipped with an anti-lock brake system (ABS) and electronic brake valve for electronic control of the brake system. The trucks are equipped with 700 kPa (100 psi), 295/75R22.5 radial tires. The test speed around the track is 64 km/h (40 mi/h).⁽²⁾

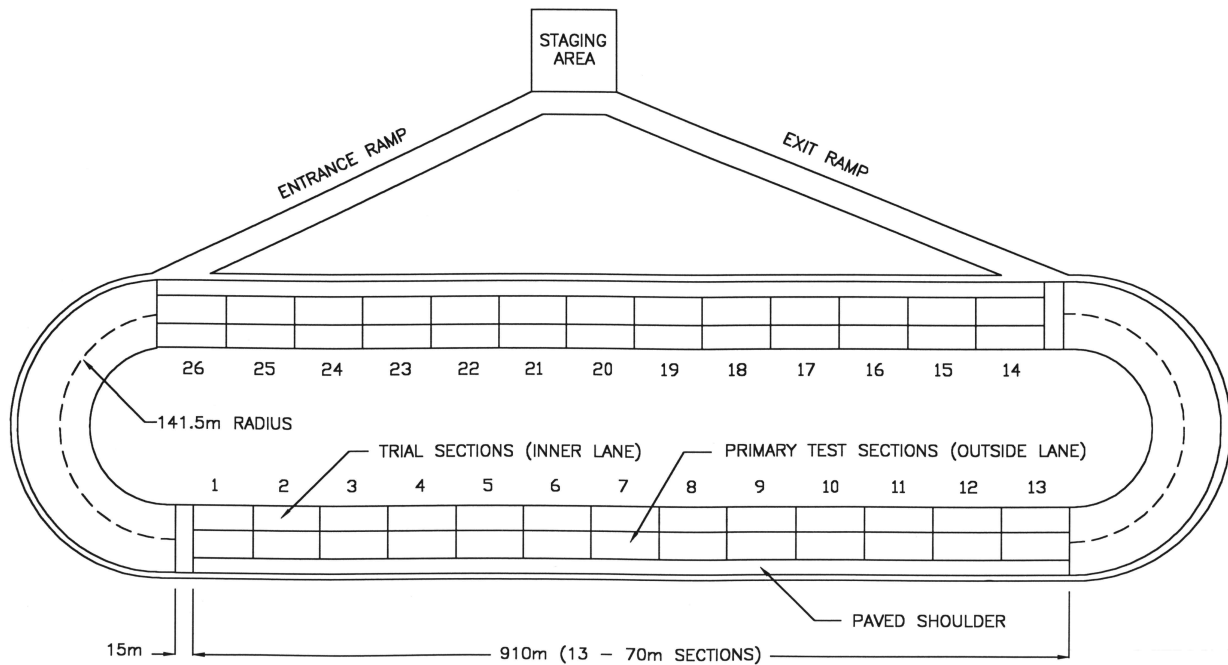


Figure 1. Layout of Test Track (not to scale)

Performance Monitoring. The methods and frequency of performance monitoring are shown in Table 1. Visual distress surveys and 35 mm pictures are taken to record the type, severity, and extent of distress on the test sections. Transverse profiles at the surface of the pavement are measured by the “Dipstick” (a commercially available profile device), an Arizona DOT transverse profile device and a newly developed laser device. Transverse profile at the interface of the hot-mix asphalt and the base course are measured using the U.S. Forest Service liquid level gauge.

Deflection measurements are made with a falling weight deflectometer (FWD), while longitudinal profile and surface friction are measured, respectively, using the K.J. Law Profilometer and modified ASTM Skid Trailer.

An accelerometer and load cells are mounted on one of the trucks to monitor vehicle dynamics. Strain gages have been installed at the bottom of the hot-mix asphalt in each section.

A Long-Term Pavement Performance (LTPP) weather station is located at the track, along with two LTPP seasonal monitoring devices for measuring temperature variations with depth, and for measuring moisture contents in the base, fill, and subgrade soil.

Table 1

WesTrack Pavement Performance Monitoring Procedures and Frequencies

Performance Data Type	Method or Protocol	Device	Collection Interval
Visual Distress Survey	SHRP P-338	Manual	2-week
Transverse Profile-Surface	SHRP P-338	FACE Technologies Dipstick*	2-week
Transverse Profile-Subsurface	—	USFS Liquid Level Gauge	2-week
Deflection Measurements	LTPP Manual	Dynatest FWD	4-week
Longitudinal Profile	SHRP P-378	K.J. Law Profilometer	2-week
Surface Friction	ASTM Skid (E274)	DFMV Traction Truck	4-week

*Note: An Arizona DOT manual and project built laser transverse profile devices were also used.

Additional hot-mix asphalt thermocouples were installed at a single location to provide five temperature readings with depth in the pavement layer.

EXPERIMENTAL DESIGN

Seven experimental factors were considered in developing the experimental plan: asphalt binder type, asphalt binder content, aggregate type, aggregate gradation, aggregate shape and surface texture, in-place air void content, and thickness of the hot-mix asphalt layer. A complete factorial was not feasible because of economic constraints. Three experimental factors were ultimately chosen, based on their potential impact on performance and/or the perception of how thoroughly they had been investigated in the past. All factors are discussed below.

Asphalt Binder. A single performance-graded asphalt binder was chosen, PG 64-22. This asphalt binder meets the high temperature requirement at the 98 percentile level for the Superpave specification. The asphalt binder meets the low temperature Superpave requirement at the 50 percentile level. Since the life of the test track is expected to be about 3 years, the use of a somewhat lower than desired low temperature grade for this climate was considered adequate. In addition, it was not possible to obtain a non-modified PG 64-28 from domestic crude at reasonable cost for use in the experiment.

Aggregate Type, Surface Texture, Shape and Gradation. A single primary aggregate source was selected for study. Three gradations were utilized. A gradation on the fine side of the Superpave 19 mm nominal maximum size gradation curve was one of the selections. This gradation was designated as the “fine” gradation, because a relatively large portion of the aggregate passes the No. 4 sieve. To meet this gradation, a natural sand was blended with the primary aggregate in approximately a 1 to 3 ratio by weight. The primary aggregate was a partially crushed fluvial deposited aggregate from a quarry near Dayton, Nevada.

A second gradation was obtained by adding approximately 2 percent “bag house” fines to the first selection, the fine graded aggregate. This gradation was designated “fine plus” as it is the “fine” gradation “plus” extra bag house fines. A third gradation was developed on the coarse side of the Superpave 19 mm nominal maximum size gradation band. This gradation was designated “coarse” because a relatively large portion of the aggregate is retained on the No. 4 sieve. This

aggregate blend was prepared with the primary aggregate. Figure 2 shows the gradations selected.

Asphalt Binder Content. An optimum asphalt binder content was determined by the SHRP volumetric mix design procedure for the “fine” and “coarse” gradations. (The target for the “fine plus” gradation was set at the target value for the “fine” gradation). The asphalt content was then varied plus and minus 0.7 percent from the optimum asphalt binder content for each of the gradations selected for evaluation. The target asphalt binder content for each mixture was designated at the optimum, target or “medium” level while the asphalt binder contents 0.7 below and 0.7 above the target were designated “low” and “high,” respectively.

In-Place Air Voids. Three levels of in-place air voids were selected for study in the project. Eight percent air voids were considered to be typical for hot-mix asphalt construction in the United States. This level of in-place air voids was designated as the “medium” level. The other target air voids selected were 4 and 12 percent and have been designated as “low” and “high.”

Thickness of Hot-Mix Asphalt. A single thickness of hot-mix asphalt was selected. The structural section for the track was designed to provide fatigue failure for a typical hot-mix asphalt at about 3.3 million ESALs. The structural section consists of 150 mm (6 in) of scarified and mixed subgrade soil, 300 mm (12 in) of engineered fill which was obtained from the natural subgrade materials, 300 mm (12 in) of dense-graded crushed aggregate base course and 150 mm (6 in) of hot-mix asphalt, constructed in two 75 mm (3 in) lifts.

Selected Experimental Design. The experimental design is shown in Table 2. Three aggregate gradations, three asphalt binder contents and three in-place air void contents were selected. Since it is unlikely that hot-mix asphalt pavements will be placed at low asphalt binder contents and low air voids or at high asphalt binder contents and high air voids, these cells in the factorial were not filled. Five replicate sections were included in the experimental design. (These are reflected by the cells which have two numbers).

MATERIALS AND MIXTURE DESIGNS

Asphalt Binder. A non-modified asphalt binder was selected for use at WesTrack. The PG 64-22 was refined at a West Coast refinery from a blend of U.S. domestic crudes. Table 3 contains Superpave binder

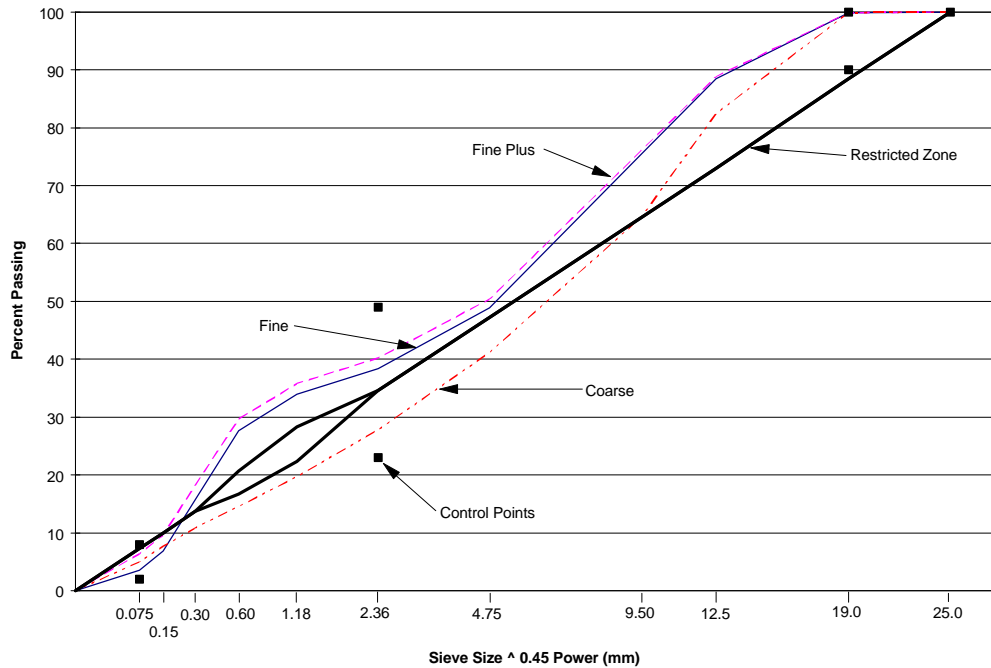


Figure 2. Mixture Gradations

**Table 2
Experiment Design for Original 26 WesTrack Sections**

Design Air Void Content (%)	Aggregate Gradation Designation								
	Fine			Fine Plus			Coarse		
	Design Asphalt Contents (%)								
	Low	Opt.	High	Low	Opt.	High	Low	Opt.	High
Low		04	18		12	09/12		23	25
Medium	02	01/15	14	22	11/19	13	08	05/24	07
High	03/16	17		10	20		26	06	

* Numbers shown in each cell represent WesTrack section numbers.

tests performed on samples of the binder obtained during construction. Table 4 shows binder test results obtained from the more traditional viscosity and penetration tests. The asphalt binder is classified as a PG 64-22 except for a few samples where the fatigue requirement indicated that the binder should be graded as a PG 64-16 (Table 3). The asphalt binder can also be classified as an AC-20 binder (Table 4).

Aggregate. Table 5 contains the aggregate test results available to date. The Dayton partially

crushed gravel and the Wadsworth natural sand meet the Superpave requirements. Additional aggregate testing is in progress, basically to verify angularity test results obtained previously.

Mixture Design. Mixture design for the “fine” and “coarse” graded aggregate systems were performed according to Superpave volumetric design methods. Optimum or target asphalt binder contents were established for these two mixtures. The asphalt binder contents for the “fine plus” gradation were identical to those used for the “fine” gradation.

Table 3
Superpave Quality Assurance Binder Test Results

Sample Date	Sample Time	DSR-Original			DSR-RTFOT			DSR-PAV			BBR		Perf. Grade (PG)
		G* (KPa)	δ	G*/sin δ	G* (KPa)	δ	G*/sin δ	G* (KPa)	δ	G*/sin δ	S (t)	m	
9/14	07:36	1.003	87.2	1.004	2.439	84.3	2.451	5.374	45.8	3.853	214.0	0.300	64-22
	11:59	1.041	87.0	1.042	2.389	84.2	2.401	6.346	45.3	4.511	200.5	0.310	64-22
9/18	10:03	1.148	87.2	1.149	2.454	84.5	2.465	6.045	47.9	4.483	205.0	0.330	64-22
	07:20	1.089	87.3	1.090	2.518	84.3	2.531	6.115	47.1	4.479	206.0	0.320	64-22
9/19	11:40	1.081	87.2	1.082	2.443	84.7	2.453	5.941	47.5	4.381	215.0	0.310	64-22
	8:58	1.244	84.7	1.249	2.395	84.5	2.406	4.454	48.0	3.308	215.5	0.335	64-22
9/20	8:58	1.127	87.2	1.128	2.577	84.4	2.589	5.751	48.6	4.313	215.0	0.335	64-22
	8:58	1.129	87.1	1.130	2.455	84.5	2.466	5.450	48.3	4.01	222.0	0.330	64-22
9/28	13:36	1.245	87.0	1.246	2.735	84.3	2.748	6.660	47.1	4.874	224.0	0.310	64-22
	07:30	1.151	87.4	1.152	2.469	84.6	2.480	5.533	47.5	4.080	212.0	0.315	64-22
9/29	10:38	1.176	87.3	1.177	2.951	84.4	2.965	5.411	47.3	3.978	229.0	0.320	64-22
	08:40	1.199	86.9	1.201	2.687	84.1	2.692	4.526	50.8	3.505	203.5	0.330	64-22
10/1	09:50	1.136	87.2	1.137	2.604	84.2	2.617	5.879	47.8	4.353	229.0	0.310	64-22
	8:13	1.227	87.3	1.228	2.754	84.3	2.768	5.524	51.6	4.332	228.0	0.310	64-16
10/2	8:13	1.236	87.3	1.237	2.763	84.4	2.776	5.092	50.8	3.948	230.5	0.315	64-16
	8:13	1.195	87.0	1.196	2.613	84.2	2.626	6.076	49.9	4.649	216.0	0.320	64-22
10/4	A.M.	1.232	87.5	1.233	2.324	84.9	2.333	6.562	47.7	4.855	233.0	0.305	64-22
	A.M.	1.240	86.8	1.242	2.800	82.9	2.822	5.061	51.5	3.960	246.0	0.310	64-16
	A.M.	1.117	86.9	1.119	2.710	84.1	2.724	4.859	47.2	3.564	224.5	0.310	64-22
	A.M.	1.189	86.4	1.191	3.224	83.6	3.244	6.360	46.4	4.607	230.0	0.305	64-22
Mean		1.160	87.0	1.162	2.615	84.3	2.628	5.651	48.2	4.205	219.9	0.317	-
Std. Dev.		0.071	0.6	0.071	0.220	0.4	0.222	0.638	1.8	0.435	11.7	0.011	-
Cost of Var.		6.1	0.7	6.1	8.4	0.5	8.4	11.3	3.8	10.3	5.3	3.3	-

Table 4
Conventional Quality Assurance Binder Test Results

Sample Identification		ASTM 3381 (Table 2) Specifications for Asphalt Cement Viscosity Graded at 60°C							
		Original				RTFOT			
Sample Date	Sample Time	Vis@60°C in Poises	Vis@135°C In C.St.	Pen@25°C in 1/10 mm	Pen@4°C in 1/10 mm	Flash-Point in °C	Solubility %	Vis@60°C in Poises	Duct.@25
		2000 ± 400	min. 300	min. 60	-	min. 232	min. 99.0	max. 10000	min. 50
9/14	07:36	1619.2	337.4	61	25	285		4377.8	>50
	11:59	1659.2	346.2	62	25	279		4837.6	>50
9/18	10:03	1928.7	364.7	50	18	282		4514.7	>50
	07:20	1903.7	364.7	49	19	271		4611.2	>50
9/19	11:40	1834.5	360.7	51	19	368		4508.6	>50
	8:58	1876.8	363.8	54	18	268		4583.5	>50
9/20	8:58	1934.5	363.9	56	17	279		4731.4	>50
	8:58	1905.6	365.0	56	18	277	99.9	4708.4	>50
9/28	13:36	1969.0	371.5	58	20	274		4489.5	>50
9/29	07:30	1904.8	362.9	58	20	279		4587.3	>50
	10:38	1999.0	372.4	56	19	279		5474.1	>50
10/1	08:40	2001.7	373.2	53	17	274		4349.5	>50
	09:50	1988.2	373.8	57	17	263		4134.9	>50
10/2	8:13	1979.0	372.4	56	26	282	99.9	5000.8	>50
	8:13	2039.0	54.9	56	21	279		5067.0	>50
	8:13	2075.1	378.7	46	18	277		5138.7	>50
	A.M.	1029.0	352.0	59	21	274		4145.4	>50
10/4	A.M.	1959.0	346.2	57	23	279	99.9	5000.8	>50
	A.M.	1999.0	343.3	57	20	271		4869.2	>50
	A.M.	197.0	363.6	58	21	273		5790.4	>50
Mean		1928.7	361.6	55.5	20.1	275.8	-	4746.0	-
Std. Dev.		114.7	11.4	4.0	2.8	5.6	-	417.1	-
Coef. of Var.		5.9	3.2	7.2	13.7	2.0	-	8.8	-

**Table 5
Preconstruction Aggregate Properties – 1994 Production**

Stockpile/ Mixture Designation	Coarse Aggr. Angularity*		Fine Aggr. Angularity*	Flat or Elong.*, %	Sand Equi.*, %	LA Abrab.**	Deleterious Materials**
	1 Face	2 Face					
Dayton ¾ inch	98.9	95.4		0.2		18.9	0.46
Dayton ½ inch	99.7	98.9		2.0		20.2	0.42
Dayton 3/8 inch	98.2	96.4				21.3	0.30
Dayton Rock Dust			47.6		49.0		0.46
Dayton Sand			44.5		31.0		
Wadsworth Sand			44.0		74.0		0.15
Fine	98.1	96.5	44.9***	0.6	65.0	20.3	0.21
Fine Plus	98.1	96.5	44.9***	0.6	65.0	20.3	0.21
Coarse	98.8	96.7	45.0	1.3	70.0	20.8	0.34

* Performed by FHWA

** Performed by University of Nevada

*** Based on Fine Aggregate Bulk Specific Gravity of 2.595 from field blend of July 8, 1995

Mixture design details can be found in reference 3.

PERFORMANCE

Performance of the hot-mix asphalt mixtures placed in the first 26 sections is available after 2.8 million ESALs (May 16, 1997). Five of the test sections (“fine plus” and “coarse” gradations at high asphalt contents) were removed from test and rehabilitated after 1.5 million ESALs (November 1996). Data from these sections are reported in this paper on the same graphs used for sections that have experienced 2.8 million ESALs.

The test track was designed to evaluate the rutting and fatigue performance of hot-mix asphalt. Low temperature or thermal cracking and water sensitivity problems were eliminated or minimized in the design process by binder selection and the use of hydrated lime. Performance information with respect to rutting and fatigue or alligator cracking is reported below. The track has not experienced any thermal or transverse cracking and water sensitivity does not appear to be a factor in performance to date.

Rutting. Table 6 contains rut depth information for the 26 test sections. Rutting data is reported as the maximum rut depth (peak to valley). This information is discussed below.

“Fine” Gradation Mixtures. Figure 3 shows the relationship between rut depth and initial in-place air void content at the target or optimum or medium

asphalt binder content. In general, an increase in rut depth is noted with an increase in initial in-place air voids regardless of the asphalt binder content. At the target asphalt binder content, the effects of initial air void content were significant after 2.8 million ESALs. The depths were all in the range of 9 to 12 mm. The two bars shown on Figure 3 at the medium air void level indicate that replicate test sections exist for this gradation, asphalt binder content, and air void content.

The relationship between rut depth and asphalt binder content for the “fine” graded mixture at the medium initial air void content (8 percent) is shown in Figure 4. A slight increase in rut depth is noted with increase in asphalt content. The rutting behavior of the “fine” graded mixture is not very sensitive to changes in asphalt binder content.

“Fine Plus” Gradation Mixtures. Figure 5 shows the relationship between rut depth and initial in-place air void content at the optimum asphalt binder content. A slight increase in rut depth is evident as the initial in-place air voids are increased.

The relationship between the rut depth and asphalt binder content for the “fine plus” graded mixture at the medium initial air void content is shown in Figure 6. A large increase in rut depth is noted at the high binder content. The high binder content mixtures at both the medium and low air void contents were removed after 1.5 million ESALs. The rutting behavior of the “fine plus” graded mixture is sensitive to changes in asphalt binder content at levels above the optimum asphalt binder content.

**Table 6
Rut Depth Summary**

Section Number	Designation		Rut Depth, mm	ESALs, $\times 10^6$ **	Status (after 2.8 million ESALs)
	Gradation	AC/AV Content *			
01	Fine	MM1	9	2.8	In Service
02	Fine	LM	6	2.8	In Service
03	Fine	LH1	10	2.8	In Service
04	Fine	ML	9	2.8	In Service
05	Coarse	MM1	22	2.8	Out of Test
06	Coarse	MH	30	2.8	Out of Test
07	Coarse	HM	36	1.5	Out of Test
08	Coarse	LM	23	2.8	Out of Test
09	Fine Plus	HL2	30	1.5	Out of Test
10	Fine Plus	LH	12	2.8	In Service
11	Fine Plus	MM2	11	2.8	In Service
12	Fine Plus	ML	10	2.8	In Service
13	Fine Plus	HM	20	1.5	Out of Test
14	Fine	HM	10	2.8	In Service
15	Fine	MM2	10	2.8	In Service
16	Fine	LH2	9	2.8	In Service
17	Fine	MH	10	2.8	In Service
18	Fine	HL	7	2.8	In Service
19	Fine Plus	MM1	10	2.8	In Service
20	Fine Plus	MH	11	2.8	In Service
21	Fine Plus	HL1	35	1.5	Out of Test
22	Fine Plus	LM	10	2.8	In Service
23	Coarse	ML	12	2.8	In Service
24	Coarse	MM2	26	2.8	Out of Test
25	Coarse	HL	27	1.5	Out of Test
26	Coarse	LH	19	2.8	Out of Test

* Where L stands for Low, M stands for Medium (Optimum), and H stands for High.

** For out-of-test sections, this is the cumulative ESALs at the time the section was removed from test.

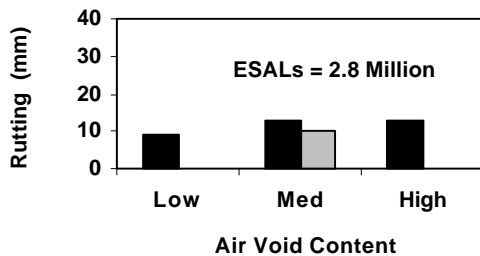


Figure 3. Fine Gradation at Optimum Asphalt Binder Content

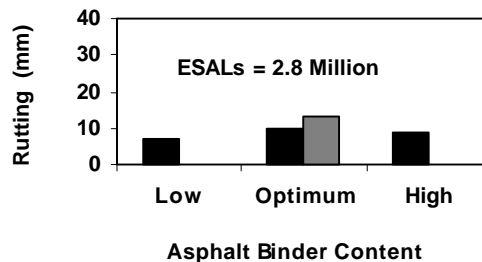


Figure 4. Fine Gradation at 8% Air Void Content

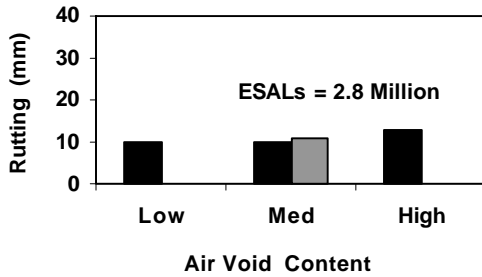


Figure 5. Fine Plus Gradation at Optimum Asphalt Binder Content

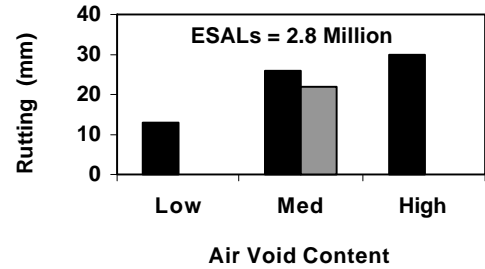


Figure 7. Coarse Gradation at Optimum Asphalt Binder Content

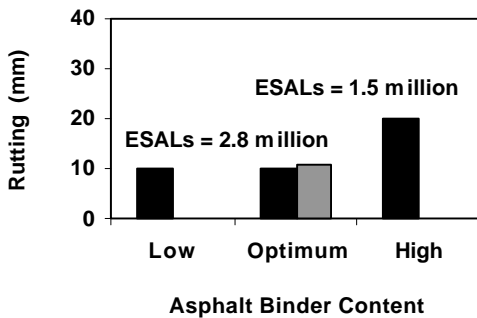


Figure 6. Fine Plus Gradation at 8% Air Void Content

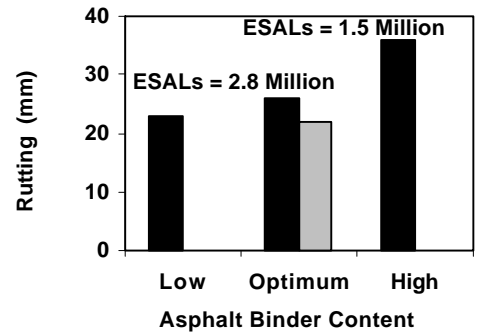


Figure 8. Coarse Gradation at 8% Air Void Content

“Coarse” Gradation Mixtures. Figure 7 shows the relationship between rut depth and initial in-place air void content at the optimum asphalt binder content. An increase in rut depth is evident as the initial in-place air voids are increased.

The relationship between the rut depth and asphalt binder content for the “coarse” graded mixture at the medium, initial air void content is shown in Figure 8. An increase in rut depth with asphalt binder content is noted. The rut depths of this mixture at all asphalt binder contents are large. The high binder content mixtures at both the medium and low air void contents were removed after 1.5 million ESALs.

Comparison of Gradations. Figure 9 shows the relationship between rut depth and gradation at the optimum asphalt binder contents and medium air void content. The “coarse” graded mixtures have the largest rut depth under these conditions. As the initial air voids are decreased, the differences among rut depth for the “fine plus” and the “coarse” graded mixtures decrease. In general, larger rut depths were observed for the “coarse” graded mixtures as compared to the “fine” graded mixtures under all

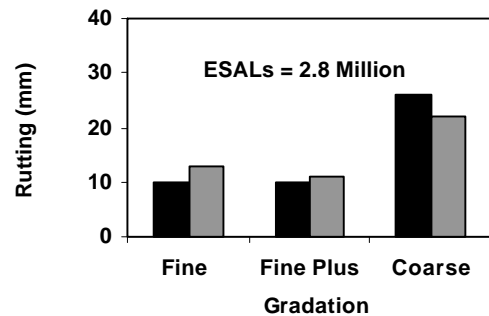


Figure 9. Optimum Asphalt Binder Content at 8% Air Void Content

conditions available for comparisons. The rutting of the “fine plus” gradation mixture was between the “fine” and “coarse” graded mixture.

Fatigue Cracking. Table 7 contains fatigue cracking information for the 26 test sections. Fatigue cracking is reported as the percent of the wheelpath area with fatigue cracking. This information is presented below.

“Fine” Gradation Mixtures. Figure 10 shows the relationship between fatigue cracking and initial in-place air voids for mixtures at the optimum asphalt binder content. A small amount of fatigue cracking is evident in the section that was placed at the initial high air void content. Fatigue cracking percentages less than about 5 percent are considered almost insignificant. The cracking could be the initiation of fatigue cracking or could be a construction inconsistency. Once fatigue cracking started in most sections, it generally progressed rapidly.

The only fatigue cracking in the “fine” gradation sections was below 5 percent of the area cracked and has occurred in the sections with either high air void contents and/or low asphalt binder contents.

“Fine Plus” Gradation Mixtures. Figure 11 shows the relationship between fatigue cracking and initial in-place air voids for mixtures at the optimum asphalt binder content. A small amount of fatigue cracking is evident in two of the sections. The only “fine plus” gradation section with significant fatigue cracking is at high initial air void content and low asphalt binder content (see Table 7).

“Coarse” Gradation Mixtures. Figure 12 shows the relationship between fatigue cracking and initial in-place air voids for mixtures at the optimum asphalt binder content. A significant amount of fatigue cracking is evident at the medium and high initial air void contents. The largest amount of fatigue cracking is associated with the high air void content mixture. Significant amounts of fatigue cracking were also evident in the low asphalt content mixtures at medium and high initial air void contents.

The relationship between fatigue cracking and asphalt binder content at medium air void content is shown on Figure 13. An increase in the amount of fatigue cracking is evident at the lower binder content. Fatigue cracking was not evident in the high asphalt content mixtures as they were “milled and filled” at 1.5 million ESALs.

Comparison of Gradations. Figure 14 shows the relationship between fatigue cracking and gradation at the optimum asphalt binder content and medium initial in-place air voids. The “coarse” graded mixture section has the largest amount of

fatigue cracking. A review of data contained in Table 7 indicates that the “coarse” graded mixtures exhibited the greatest amount of fatigue cracking under all conditions of comparison (asphalt binder content and initial in-place air voids).

**Table 7
Fatigue Cracking Summary**

Section Number	Designation		Fatigue Cracking, % of Wheel Path Area	ESALs, x10 ⁶ **	Status
	Grada-tion	AC/AV Content *			
01	Fine	MM1	0	2.8	In Service
02	Fine	LM	0	2.8	In Service
03	Fine	LH1	5	2.8	In Service
04	Fine	ML	0	2.8	In Service
05	Coarse	MM1	50	2.8	Out of Test
06	Coarse	MH	100	2.8	Out of Test
07	Coarse	HM	0	1.5	Out of Test
08	Coarse	LM	98	2.8	Out of Test
09	Fine Plus	HL2	0	1.5	Out of Test
10	Fine Plus	LH	34	2.8	In Service
11	Fine Plus	MM2	1	2.8	In Service
12	Fine Plus	ML	1	2.8	In Service
13	Fine Plus	HM	0	1.5	Out of Test
14	Fine	HM	0	2.8	In Service
15	Fine	MM2	0	2.8	In Service
16	Fine	LH2	1	2.8	In Service
17	Fine	MH	3	2.8	In Service
18	Fine	HL	0	2.8	In Service
19	Fine Plus	MM1	0	2.8	In Service
20	Fine Plus	MH	0	2.8	In Service
21	Fine Plus	HL1	0	1.5	Out of Test
22	Fine Plus	LM	0	2.8	In Service
23	Coarse	ML	0	2.8	In Service
24	Coarse	MM2	0	2.8	Out of Test
25	Coarse	HL	0	1.5	Out of Test
26	Coarse	LH	69	2.8	Out of Test

* Where L stands for Low, M stands for Medium (Optimum), and H stands for High.

**For out-of-test sections, this is the cumulative ESALs at the time the section was removed from test.

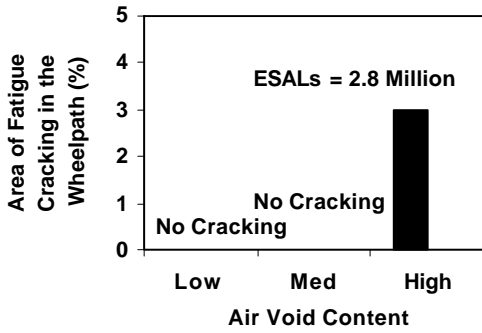


Figure 10. Fine Gradation at Optimum Asphalt Binder Content

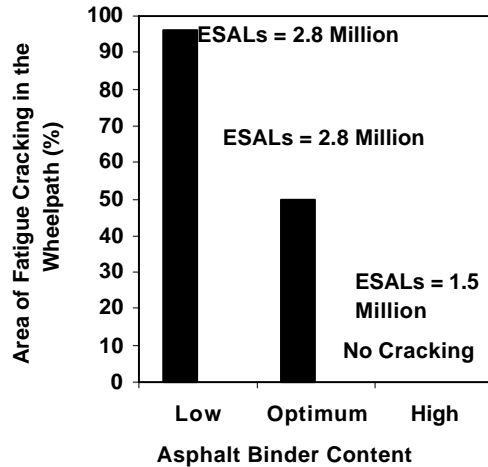


Figure 13. Coarse Gradation at 8% Air Void Content

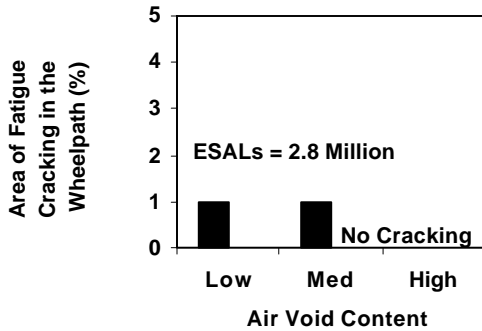


Figure 11. Fine Plus Gradation at Optimum Asphalt Binder Content

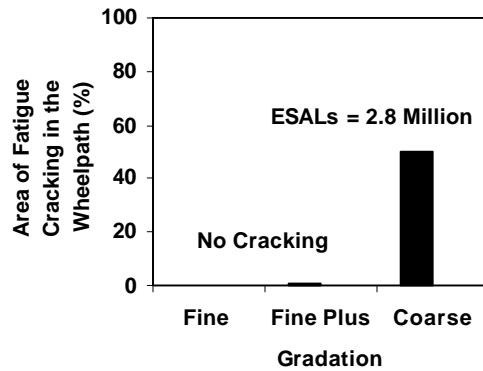


Figure 14. Optimum Asphalt Binder Content at 8% Air Void Content

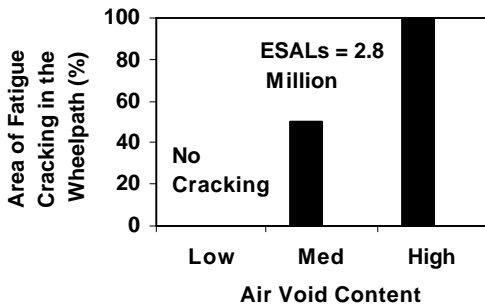


Figure 12. Coarse Gradation at Optimum Asphalt Binder Content

MAINTENANCE AND REHABILITATION

Pavement maintenance and rehabilitation operations have been performed on the track in areas from which samples were removed and in areas where “failure” has occurred.

Slippage between the two layers of hot-mix asphalt occurred in one small area of the track. A relatively small, full-depth hot-mix asphalt patch was placed to correct the problem. Many of the patches initially placed to repair the sampling areas experienced pumping along the edges of the patch. Subsequently, the failed patches were replaced with “T” patches of HMA which, so far, have performed acceptably.

After 1.5 million ESALs, five sections were milled to a depth of 50 mm (2 in) and replaced with hot-mix asphalt. The five sections were the high asphalt binder content sections for the “fine plus” and the “coarse” gradations. The type of failure was rutting in excess of 25 mm (1 in). Fatigue cracking was not evident on any of these sections at the time of rehabilitation. These rehabilitated sections carried traffic through the winter and spring (to the

2.8 million ESAL level) and no fatigue cracking was observed.

In May of 1997, ten sections were rehabilitated. The full depth of the hot-mix asphalt was removed and replaced on nine of the sections. On one of the sections (21) the top 150 mm of HMA was removed and replaced. This section is one of the two sections rehabilitated with Nevada Department of Transportation (NDOT) mixes described below. Seven of the original eight sections which contained the “coarse” gradation and three of the sections which contained the “fine plus” gradation at higher asphalt contents were removed and replaced. All three of the sections that contained the “fine plus” gradation at high asphalt binder contents were removed due to excessive rutting. The only section which contained the “coarse” gradation which was not removed was that placed at the optimum asphalt binder content and the low air void content. The sections with the “coarse” gradation were either rutted (primarily the high asphalt binder content mixtures) or exhibited excessive fatigue cracking.

Eight of the ten rehabilitated sections were replaced with a “coarse” graded mixture which contained a 100 percent crushed aggregate (Lockwood). The other two sections were replaced with NDOT mixtures which contained the same aggregates that were used for original construction and for rehabilitation. The NDOT mixtures were dense- graded and contained polymer modified asphalt binders.

Early performance of the “coarse” graded mixtures used for rehabilitation indicates that rutting is a problem. A team of experts from across the United States has been formed and will review the design, construction, traffic, and performance of these mixtures in August 1997.

MATERIALS SAMPLING AND TESTING

Table 8 presents an overview of the extensive materials sampling and testing program associated with the WesTrack project. Sampling and testing associated with preconstruction, construction, and postconstruction phases of the project are identified.

Preconstruction Sampling and Testing. Preconstruction testing included determination of asphalt binder and aggregate properties as well as mixture design and performance prediction testing. Both Superpave and conventional asphalt binder properties were determined as previously discussed. Binder and aggregate properties were also determined from samples of materials obtained during construction.

Table 8
Overview of Materials Sampling and Testing

Project Phase	Purpose	Type of Test
Preconstruction	Asphalt Binder Properties	Superpave; Conventional
	Aggregate Properties	Superpave; Conventional
	Mixture Design	Superpave Volumetric; Hveem; Marshall
	Performance Prediction	Permanent Deformation; Fatigue; Thermal Cracking; Water Sensitivity
Construction	Material Properties	Superpave; Conventional
	Process Control and Quality Assurance	Asphalt Content; Aggregate Gradation; Volumetrics; In-place Air Voids
	Performance Prediction	Permanent Deformation; Fatigue; Thermal Cracking; Water Sensitivity
Postconstruction	Performance Prediction	Permanent Deformation; Fatigue; Thermal Cracking; Water Sensitivity

The Superpave volumetric design method was used for establishing the optimum asphalt binder content and aggregate gradation. A limited amount of Hveem and Marshall tests were performed during the mixture design process.

Performance prediction testing is scheduled on the laboratory mixed-laboratory compacted samples. SHRP developed test methods will be used. The repeated shear, constant height test performed on the Superpave Shear Tester (SST) will be the primary prediction test for permanent deformation or rutting. Beam fatigue tests will be used for fatigue or alligator cracking prediction. The thermal stress restrained specimen test (TSRST) will be used for thermal crack prediction. The modified Lottman test (AASHTO T 283) will be performed on gyratory compacted samples to determine water sensitivity.

Construction Sampling and Testing. The major purposes for construction sampling and testing were to control the construction process, to ensure that the mixtures produced were near their target values (quality assurance) and to determine material properties that could be used for performance prediction. Field mixed-laboratory compacted samples will be used for performance prediction testing.

Postconstruction Sampling and Testing. The primary purpose of postconstruction sampling and testing is to characterize the field mixed-field compacted samples for performance prediction purposes. Samples have or will be removed immediately after construction (within one or two weeks), after approximately 9 months of trafficking, and at the end of the service life of the pavement section or after 2 years of trafficking.

PERFORMANCE PREDICTION

The performance prediction effort and the mechanical characterization of the hot-mix asphalt are being performed at the University of California at Berkeley and at Oregon State University. An outline of the approach used to predict fatigue and permanent deformation is briefly discussed below.

Fatigue Prediction. The approach used to predict fatigue cracking is similar to that described in reference 4. The approach involves flexural fatigue testing of the hot-mix and asphalt performance prediction based on the technology developed as a part of SHRP⁽⁵⁾ extended to efficiently treat insitu temperatures⁽⁶⁾, calibrated to the Caltrans flexible-pavement design methodology⁽⁷⁾, extended to incorporate construction variability⁽⁸⁾, and used in interpreting the first California heavy vehicle simulator (HVS) testing of the CAL/APT program⁽⁹⁾.

The system specifically considers the means and variances of the following asphalt concrete construction quantities: asphalt binder content, air-void content, and asphalt concrete thickness. Results of WesTrack will allow for the inclusion of aggregate gradation effects. Damaging strains under traffic loading are determined from a multilayer, elastic system. The performance model computes the distribution of pavement fatigue life using Monte Carlo simulation techniques.

The process embedded within the performance model is outlined schematically in Figure 15. Central to this process is the random selection from

typical normal distributions of air-void content, asphalt binder content, and asphalt concrete thickness for each simulation. Although not shown in Figure 15, a random selection is also made of the foundation modulus representing the composite effects of base, subbase, and subgrade layers in an “equivalent” two-layer system.

These random selections assume normally distributed random variables with known or assumed means and variances. Of particular significance are the variances that might be expected under normal construction operations. Estimates of these variances were obtained from a combination of literature review, moduli back-calculations of FWD measurements, and data collected as part of the WesTrack project.

A multilayer elastic program is used to simulate the stress and strain states within the simulated pavement structures. Loading consists of a dual-tire assembly representative of the trucks used at WesTrack. Stiffnesses and fatigue response for mixes in each of the tests sections are being developed for use in the analyses.

Each of the Monte Carlo simulations produces an independent estimate of the laboratory fatigue

$$\text{In situ reps} = \frac{N * SF}{TCF} \quad (1)$$

life, N . The corresponding simulated in situ life, *insitu reps*, is computed by applying a shift factor, SF , and a temperature conversion factor, TCF , as follows:

The shift factor is an empirically derived factor that accounts for differences between the laboratory and the in situ pavement in the rate at which fatigue damage accumulates with each load application. Observed cracking in the various test sections will permit the development of this factor for the WesTrack environment.

Permanent Deformation Prediction. The approach used to predict permanent deformation (rutting) is based on SHRP-developed technology. The hot-mix asphalt samples will be tested over a range of temperatures and stress levels in the constant height, repeated simple shear test (RSST-CH).

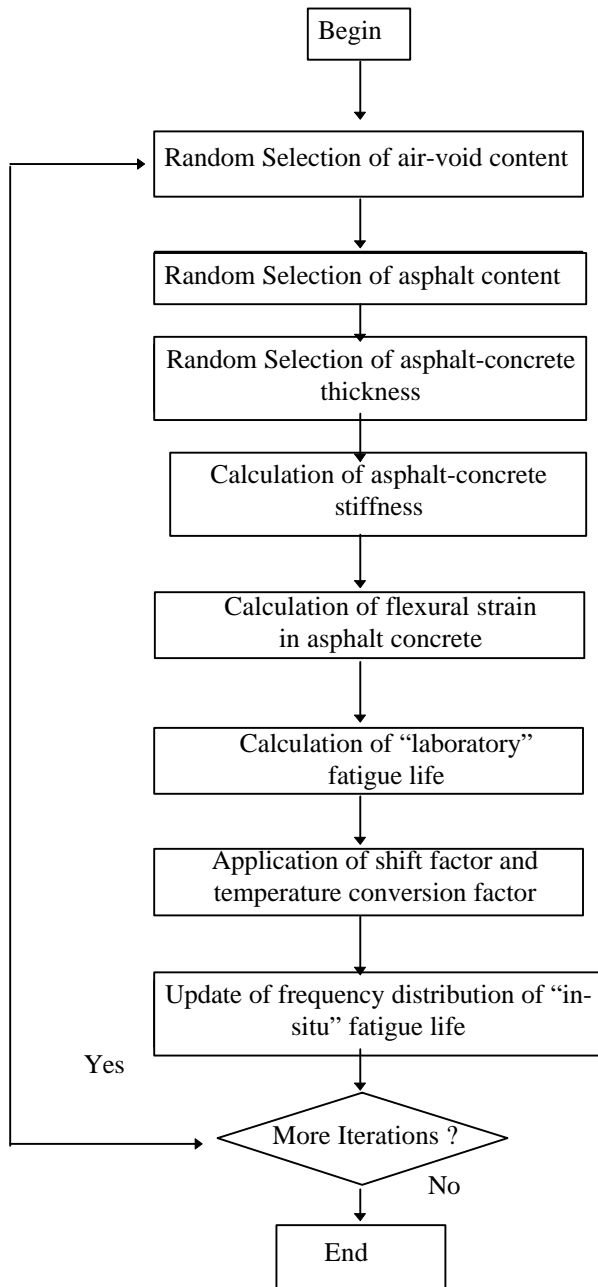


Figure 15. Outline of the Pavement Performance Model Simulation

From these test results, mix stiffness can be formulated as a function of temperature with an equation of the form:

$$S_{mix} = \exp(C_1 - C_2T) \quad (2)$$

where:

$$S_{mix} = \text{mix stiffness,}$$

$$T = \text{temperature } (^{\circ}\text{C}), \text{ and}$$

$$C_1, C_2 = \text{experimentally determined coefficients}$$

The RSST-CH results can also be used to formulate a model for permanent strain development with load repetitions of the form:

where:

$$g_i^p = an^b \quad (3)$$

$$g_i^p = \text{cumulative permanent shear strain,}$$

$$n = \text{stress repetitions, and}$$

$$a, b = \text{experimentally determined coefficients.}$$

In this expression, the coefficient a is dependent on the shear stress and the elastic strain while the coefficient b is sensibly independent of stress and temperature.

To estimate the rutting in the hot-mix asphalt layer, the elastic shear stress and shear strain at 50 mm (2 in) depth directly beneath the outside edge of the tire are determined using an elastic layer program. Since the mix stiffness varies with pavement temperature, the stresses and strains are computed on an hourly basis during the traffic loading periods. From these conditions, the permanent shear strains are estimated according to equation 3.

Accumulation of shear strains are then determined using the "time-hardening" cumulative damage hypothesis, i.e.,

$$g_j^p = a_j [\Delta N]^b \quad (4)$$

for first hour, and

$$g_j^p = a_j \left[g_{j-1}^p (a_j)^{1/b} + \Delta n \right]^b \quad (5)$$

for remaining hours.

Rut depth (rd) is determined using the relationship:

$$rd = k g^p \quad (6)$$

Where “k” is a conversion factor and “ γ ” is the permanent shear strain.

The development of this relationship is described in reference 10.

Results of the first simulation for WesTrack results are illustrated in Figure 16 for sections containing the “coarse” mix at optimum asphalt content and medium air void content.

RSST-CH tests have been performed at 50°C on a number of the mixes using a stress of 69 kPa. Repetitions to a value of $\gamma^p = 5$ percent are summarized in Figure 17. These data illustrate the differences in permanent deformation characteristics of a number of mixes used in the WesTrack pavements.

PERFORMANCE RELATED SPECIFICATION

In addition to providing a basis for verifying and/or calibrating the current SHRP Superpave volumetric mix design procedures, this project will produce an advanced prototype performance related specification (PRS) system for hot-mix asphalt pavement construction.

A performance related specification system for pavements is a method or model that permits pavement engineers to prepare practical specifications for pavement construction that focus heavily on the actual materials and construction practices that have the most effect on the long-term performance of the pavement. By considering the multitude of costs associated with the design, construction and future performance of a pavement, the system not only provides a means for identifying/specifying a cost-effective “target” pavement to build initially, it also provides a means for equitably rewarding or penalizing the contractor for the “as constructed” pavement delivered. Under such a system, the contractor on a given job could be penalized for being slightly above the target specification for air void content and be rewarded for exceeding the target specification for initial smoothness. Assuming that the predicted long-term performance of the pavement is dependent more upon its initial smoothness than the air void content being slightly off-target, it is likely that (for this simple example) the net effect would be reward for the contractor and assurance for the client (road agency) that its funds were well-spent.

Under the current plan for PRS development, two types of systems will be developed. The first will be a sophisticated computer program that will have the ability to treat all design materials and construction factors to a high level of detail. The second will likely be a relatively simple equation or nomograph that will be somewhat less precise, but considerably easier to use. The latter will focus only on those factors that have the greatest impact on pavement performance.

Performance prediction models which are dependent upon material properties and quantities will be used with life-cycle cost methods to develop the performance related specification.

SUMMARY

A 3 km (1.8 mi) full scale pavement test track has been designed and constructed and is presently under operation near Reno, Nevada. Four driverless trucks are used to traffic the pavements and are capable of applying approximately 350,000 ESALs per month of operation.

The primary purpose of the test track is to develop a performance related specification for hot-mix asphalt and to provide for early field verification of the Superpave volumetric mixture design process.

The test track consists of 26 test sections each 70 m (230 ft) in length. The original 26 sections placed were constructed with a single asphalt binder and a single primary aggregate. Three gradations were placed (“fine,” “fine plus,” and “coarse”). For each gradation, three levels of asphalt binder content and three levels of initial in-place air voids were placed. Five replicate test sections were also placed. During rehabilitation of the track, a second aggregate and asphalt binder source were utilized to place eight sections of another “coarse” graded mixture.

Extensive sampling and testing and performance monitoring are associated with the project. Information on rutting and fatigue performance has been presented. The greatest amount of rutting has been associated with the high asphalt content mixtures. In general, the high air void content mixtures also experienced slightly higher rutting. The test sections containing “coarse” graded mixtures had higher rut depths than the “fine plus” graded and the “fine” graded hot-mix asphalt mixtures.

The largest amount of fatigue cracking was associated with those mixtures placed at initial high in-place air void contents. Mixtures at low asphalt binder contents also experienced more fatigue cracking than mixtures at higher asphalt binder contents. The test sections containing “coarse” graded mixtures had higher amounts of fatigue

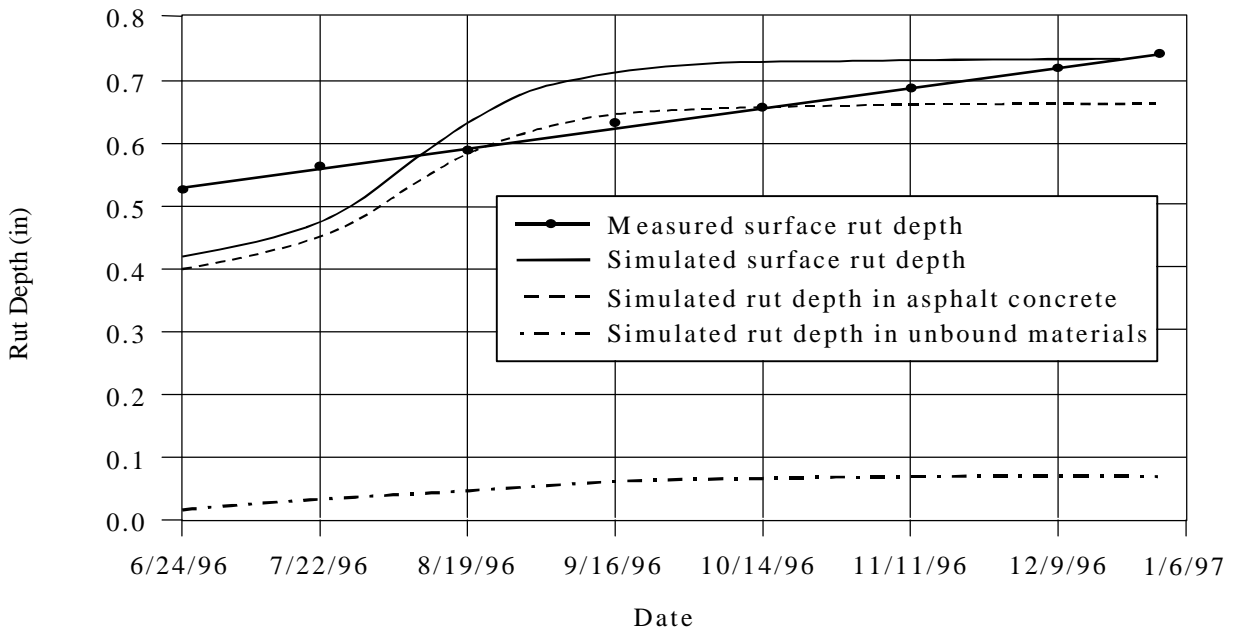


Figure 16. Rut Depth vs. Time; Coarse Mix, Medium Asphalt Content

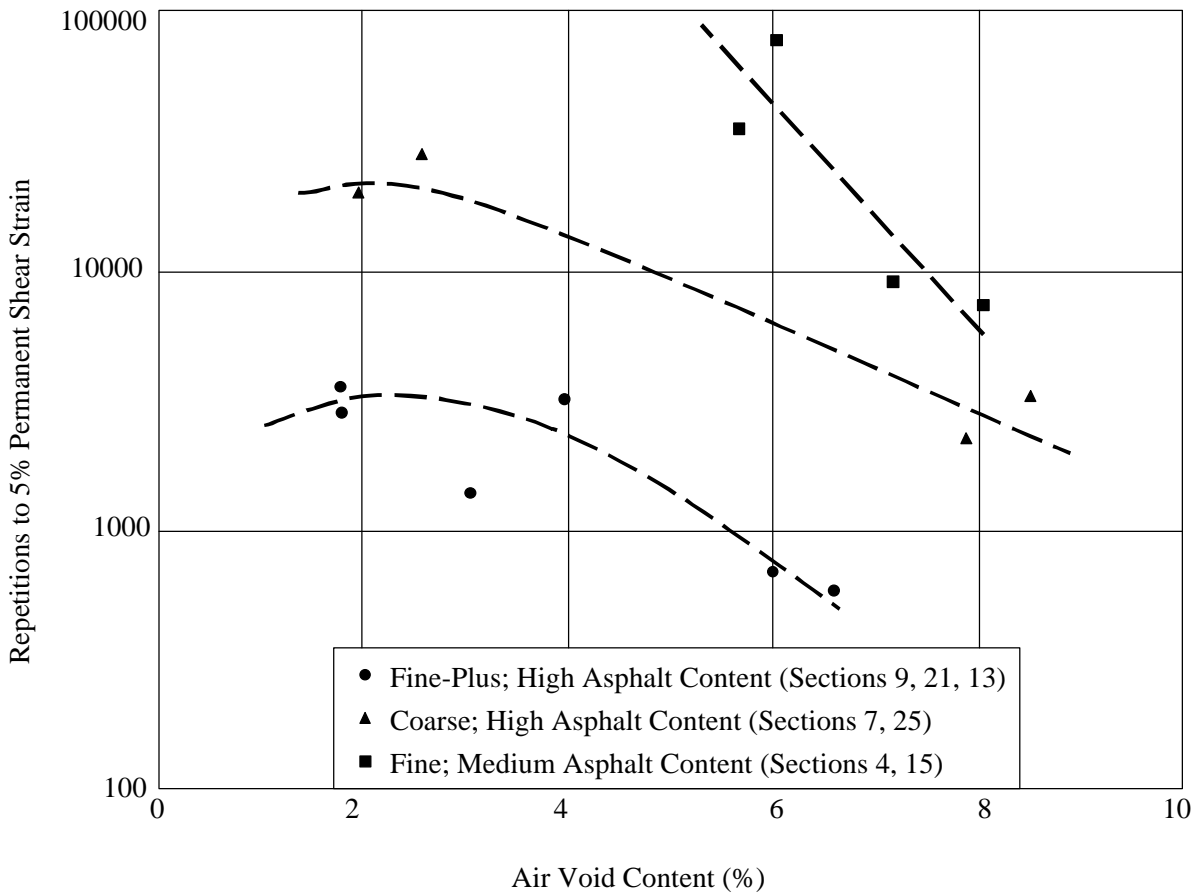


Figure 17. WesTrack RSST-CH Results

cracking than the “fine plus” and “fine” graded hot-mix asphalt mixtures.

Performance prediction models and performance related specification will be developed from result from the test track. Extensive laboratory test programs are in progress. The reason for the relative performance differences of the mixtures at WesTrack are awaiting the results of the laboratory test programs and extensive analysis.

According to the present schedule, the traffic will be placed on the facility through the mid-summer of 1998 (approximately 7 million total ESALs). Performance monitoring and sampling will continue during this period. Laboratory testing, analysis and report preparation will continue to April 1999.

ACKNOWLEDGEMENT

The authors wish to express their appreciation to several members of the WesTrack team for their efforts in accomplishing the research.

From Nichols Consulting Engineers, we would like to acknowledge Weston Ott, Allen Coldani, Magdy Mikhail, and Carol Chiappetta for their efforts in project coordination, data collection and processing, analysis and overall technical support. From the University of Nevada, we would like to express our appreciation to Adam Hand and Peter Sebaaly for their respective efforts in laboratory testing/mix design and instrumentation. From the University of California at Berkeley, we would like to recognize John Harvey for his work in SHRP Superpave testing and prediction model development and from Oregon State University, Rita Leahy for her work in developing the laboratory test plan and data analysis. From Nevada Automotive Test Center, we would like to thank Paul Pugsley for his work in contract management and oversight of driverless vehicle research and truck loading. Lastly, we especially want to recognize the advice and support of all the FHWA personnel who have been involved, particularly Ray Bonaquist, John D’Angelo and Chris Williams.

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