Mix Design Methodology for a Warrantied Pavement: Case Study

J. HARVEY, B. A. VALLERGA, AND C. L. MONISMITH

The application of a mix design procedure developed as part of Strategic Highway Research Program (SHRP) Project A-003A for a warrantied pavement project in California is described. Two mixes were designed for overlay of a "cracked and seated" portland cement concrete pavement, one a dense-graded asphalt concrete with a PBA-6 specification modified binder and the other an asphalt-rubber hot mix with a gap gradation. Both mixes were designed to meet rutting specifications for the pavement warranty. The mix design method considers mix performance measured using repeated load simple shear testing at constant height, traffic, site-specific temperatures, and reliability of test results and traffic predictions. The mixes were also evaluated for moisture sensitivity, using moisture-conditioning procedures developed as part of Project SHRP A-003A to determine the need for, and suitability of, using an antistripping additive. The mix design method developed in SHRP A-003A provided the contractor with a tool to predict the performance of the mix in terms of anticipated traffic during the warranty period and for site-specific temperature conditions. Both mixes were constructed as part of the overlay project in July 1993 and performed successfully during 1994.

During the 1993 construction season, the California Department of Transportation (Caltrans) decided to call for bids on state highway work using the principle of warranted pavements on several overlay construction projects. One of these projects was located on Interstate 5 north of Redding, California, running from 2 km (1.3 mi) south to 1.3 km (0.8 mi) north of the Sims Road undercrossing, hereinafter referred to as the "Sims Project." Essentially, the construction was to consist of placing two lifts of an asphalt-concrete overlay on existing portland cement concrete (PCC) pavement, which was to be "cracked and seated." Both lifts were to be 46 mm (0.15 ft) thick with the first lift to be Caltrans asphalt concrete (type A), hereinafter referred to as DGAC, and the second lift Caltrans rubberized asphalt concrete-gap graded (type G, asphalt rubber), hereinafter referred to as ARHM-GG.

The warranty was limited to the asphalt-concrete paving itself, in which the contractor was to agree to warrant the performance of the asphalt-concrete paving over a period of 5 years. Enforcement of the warranty was to be based on defined performance criteria incorporated in the special provisions of the project. Terms of the warranty are described by Vallerga (*1*).

The performance criteria include rutting, raveling, flushing, delamination, and cracking.

The contractor awarded the contract in consultation with B. A. Vallerga, Inc., and decided to use the mix design methodology developed as a part of Strategic Highway Research Program (SHRP) Project A-003A at the University of California at Berkeley (UCB) and Oregon State University (OSU). The procedure used to arrive at the designs selected for the two mixes, which have now been in service on Interstate 5 for over 1 year, is described in this paper.

GENERAL APPROACH

Figure 1 illustrates the framework for a comprehensive mix design and analysis system that has been proposed by the SHRP A-003A researchers (*2*). The extent of testing varies with the functional capacity of the roadway. For design situations with unusual traffic demand or unconventional materials, or both, extensive testing is recommended.

This comprehensive system consists of a series of subsystems in which the mix components, asphalt (or binder) and aggregate, and their relative proportions are selected in a step-by-step procedure to produce a mix that can be evaluated to ensure that it will attain the desired level of performance in the specific pavement section in which it is to function. Although three subsystems have been developed (to examine fatigue, permanent deformation, and low-temperature cracking), only the permanent deformation system was used in this investigation. The framework for this subsystem is briefly outlined in the following paragraphs (*3*).

Distinguishing characteristics of the permanent deformation system are shown in Table 1. For this project, the Level A procedure was selected. It involves simplified testing with the cyclic shear test at one temperature and includes the following steps, which are shown schematically in Figure 2. (It should be noted that the level A analysis system was developed using information determined from the Level B procedure, which uses a nonlinear viscoelastic three-dimensional constitutive relationship and a finite element analysis.)

The steps in the Level A procedure are as follows:

1. *Determine design requirements for reliability and performance.* The analysis system outlined here permits the designer to select a level of reliability commensurate with the pavement site for which the mix will be used. Performance requirements for permanent deformation generally call for the amount of rutting not to exceed some level, for example, 10 to 13 mm (0.4 to 0.5 in.) in order to minimize the potential for hydroplaning.
2. *Determine expected distribution of in situ temperature.* Pavement analysis in the abridged procedure requires that the mix be evaluated at the critical temperature (T_c) the temperature at which the maximum amount of permanent deformation occurs (*3*). For this mode of distress it is important to emphasize that temperatures in the upper part of the temperature range have a significant influence on the development of permanent deformation. The site-specific

J. Harvey and C. L. Monismith, Institute for Transportation Studies, 1301 S. 46th Street, Building 452, Richmond, Calif. 94804. B. A. Vallerga, BA Vallerga, Inc., 1330 Broadway, Suite 1044, Oakland, Calif. 94612.

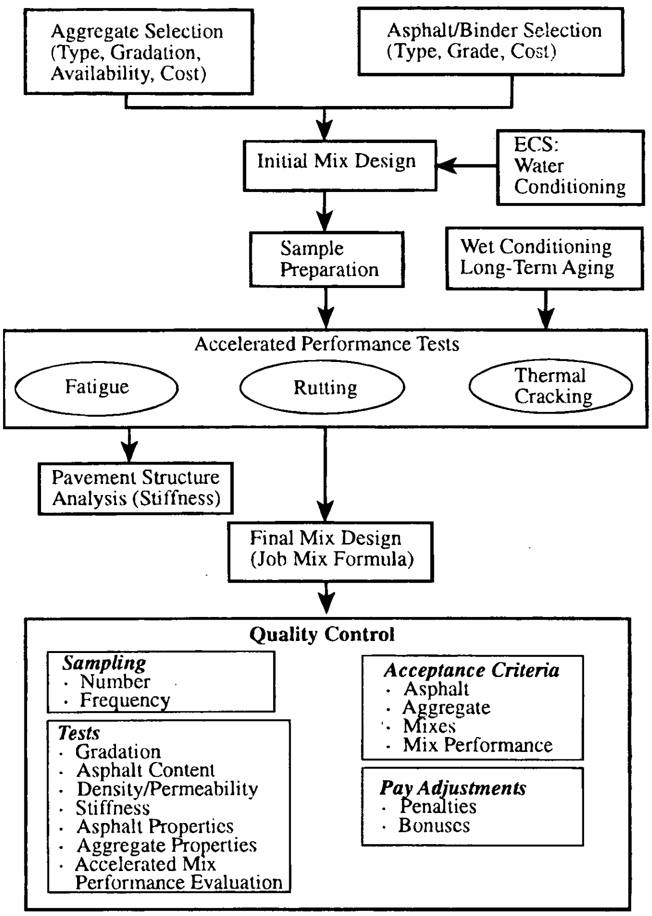

FIGURE 1 Accelerated mix performance evaluation.

critical temperature can be calculated following the procedure described by Deacon et al. (*4*). It is necessary that these computations be performed only once for a specific region or project area.

3. *Estimate design traffic demand [equivalent single axle loads (ESALs)].* For this procedure it is necessary to estimate the number of design-lane ESALs at the critical temperature using temperature conversion factors (*4*). These factors need only be computed once for specific regions.

$$\mathrm{ESALs}_{T_c} = \mathrm{ESALs} \cdot \mathrm{TCF} \tag{1}$$

where TCF is the temperature conversion factor.

4. *Select trial mix.* With a binder and aggregate, a trial mix is selected. This might be done according to the Superpave methodology or by any procedure that the responsible agency considers appropriate. Changes and redesigns are evaluated at the discretion of the design (materials) engineer.

5. *Prepare test specimens and condition as required.* Cylindrical specimens 15 cm (6 in.) in diameter by 5 cm (2 in.) high are obtained from slabs prepared by rolling wheel compaction with procedures such as those used at UCB (*5–7*). These specimens are cored and then sawed so that the end surfaces are smooth and parallel.

6. *Perform cyclic shear tests.* In the level A procedure, cyclic shear tests [also referred to as repetitive simple shear test at constant height (RSST-CH)] are performed at the critical temperature, T_c, for the specific site. At this time, the recommended procedure is to use a shear stress of 69 kPa (10 psi) [associated with tire pressures of about 690 kPa (100 psi)], which is repeatedly applied with a duration of 0.1 sec and a time interval between loadings of 0.6 sec. The repeated loading is continued for 1 hr, permitting the specimen to be subjected to a total of about 5,000 stress repetitions.

7. *Determine the resistance of the trial mix to permanent deformation.* From finite element analyses it has been determined that there exists a reasonably constant ratio between the vertical rut depth obtained in representative asphalt-bound layers and the permanent shear strain obtained in the RSST-CH for the 690-kPa (100-psi) tire-loading condition (*3*). At this time N_{supply} for the given mix can be estimated using the design rut depth and the corresponding permanent shear strain from the following:

$$\text{Rut depth (in.)} = K \cdot (\gamma_p) \tag{2}$$

where (γ_p) is the permanent shear strain, and K is the conversion factor with a value of 254 to 279 (mm) [10 to 11 (in.)].It is likely that K will be somewhat dependent on the structural pavement section; that is, there may be a different conversion factor for a 10-cm (4-in.) asphalt-concrete overlay on a PCC pavement compared with a comparatively thick asphalt-concrete layer for which the factor shown in Equation 1 had been determined.

8. *Apply a shift factor to the traffic demand (ESALs).* The design traffic volume, that is, the laboratory-equivalent repetitions of the standard load, N_{demand} is determined from

$$N_{\mathrm{demand}} = \mathrm{ESALs}_{T_c} \cdot \mathrm{SF} \tag{3}$$

where ESALs_{T_c} is the design ESALs adjusted to the critical temperature, T_c, and SF is the empirically determined shift factor. At

TABLE 1 Distinguishing Characteristics of Permanent-Deformation Analysis System

Variables		Level A	Level B
		Abbreviated analysis with limited cyclic shear testing	Comprehensive analysis with full testing
Testing	Type	Cyclic shear	Constant height simple shear, uniaxial strain, volumetric shear frequency sweep (with damage evaluation)
	Temperature	Critical temperature, T_c	40°C with frequency sweeps at 4°, 20°, 40°, and 60°C
In-Situ Conditions	Traffic	Equivalent ESALs at T_c, 85th percentile tire pressure	ESALs by temperature class, 85th percentile tire pressure
	Structure	Critical shear stress under "standard" load at T_c	Complete stress/strain pattern from finite element analysis
	Temperature	Frequency distribution at 50 mm (2 in.) depth	Frequency distribution throughout surface layer
Analysis	Mechanistic	Finite element analysis with nonlinear viscoelastic surface properties[a]	Finite element analysis with nonlinear viscoelastic surface properties
	Damage	Preanalysis (temperature equivalency factors for design ESALs)	Integral part of finite element analysis

[a]It is possible that sufficiently accurate results for shear stress may be determined using multi-layer elastic analysis as experience is developed.

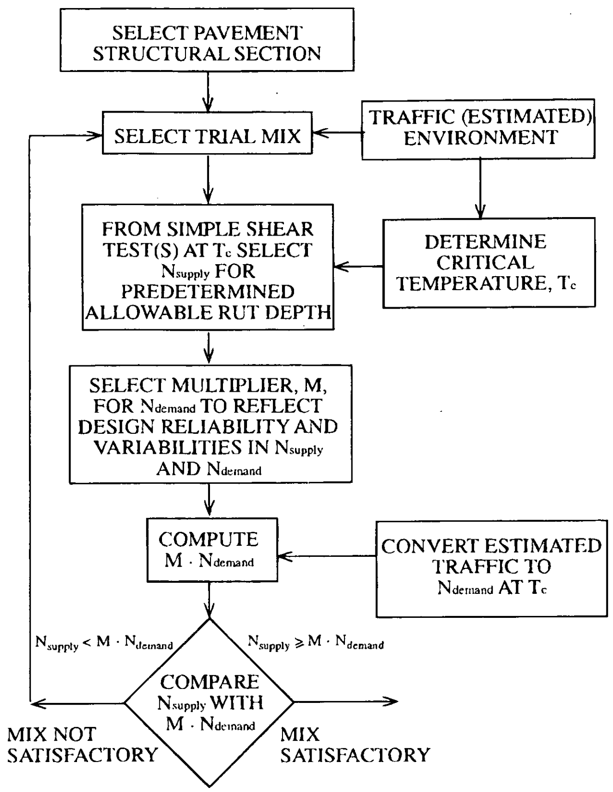

FIGURE 2 Level A mix design and analysis system.

this time, it is recommended that a shift factor of 0.04 be used. This shift factor was determined from analyses of a limited number of SHRP General Pavement Studies test sites (*3*).

9. *Compare traffic demand (N_{demand}) with mix resistance (N_{supply}).* Satisfactory performance requires that the mix resistance (N_{supply}) equal or exceed the traffic demand (N_{demand}). Accordingly a multiplier, M, is applied to N_{demand} since neither N_{supply} nor N_{demand} is known with certainty. This factor permits the incorporation of an appropriate level of design reliability as well. For a mix to be satisfactory,

$$N_{\text{supply}} \geq M \cdot N_{\text{demand}} \tag{4}$$

where M is a multiplier whose value depends on the design reliability and on the variabilities of the estimates of N_{supply} and N_{demand}, Table 2.

10. *If mix is inadequate, alter trial mix and iterate.* If the particular mix is determined to be inadequate, a number of alternatives are available to the designer, including adjusting the asphalt content, adjusting the aggregate gradation, using a modified binder, selecting another aggregate source, or making combinations of the above.

The Level A methodology can be used as a mix design procedure to select the initial binder content. Mixes can be prepared over a range in binder contents by rolling wheel compaction to the air-void content at which maximum permanent shear strain resistance occurs (about 3 percent for the mixes included in this project). For each mix the procedure described in the previous section would be followed to select N_{supply}. The mix with the highest binder content that satisfies $M \cdot N_{\text{demand}}$ (adjusted traffic) is selected for further evaluation.

PROJECT INFORMATION

The site of the Sims Project [total length of about 3.3 km (2.0 mi)] is on Interstate 5 in Shasta County, California, near the town of Castella. The site is in a mountainous area, and consisted of only the northbound lanes, which contain both flat and uphill grade (5 percent maximum) sections. The mixes were designed for an overlay to be placed on a cracked and seated PCC pavement, with the overlay structure design consisting of 46 mm (0.15 ft) of dense-graded asphalt concrete with a PBA-6 binder (DGAC-PBA6) underneath 46 mm (0.15 ft) of asphalt-rubber hot mix having a gap-graded aggregate component (ARHM-GG).

A material and workmanship warranty for a period of 5 years from the date of completion of the construction was required. The limiting rut depth could not exceed 13 mm (0.04 ft or 0.5 in.) at any time during the warranty period. It was expected that approximately 10 million 80-kN (18-kip) ESALs would traffic the design lane during that period.

Because of the thick layer of cracked and seated PCC beneath the overlay, it was calculated that fatigue cracking would not occur during the warranty period. An antistripping agent was considered for use with both mixes because water sensitivity problems have been experienced in Caltrans District 2.

SIMPLE SHEAR TEST TEMPERATURE, T_C

The temperature used for testing in the repeated load simple shear test is termed the critical temperature, T_c, and represents the temperature at a depth of 50 mm (2 in.) below the surface of the pavement. This depth has been found to be the approximate location at which maximum shear stresses occur below the edge of the tire (*3.*)

A value of T_c of 45°C (113°F) was determined for the test site according to the procedure described by Deacon et al. (*4.*)

MATERIALS AND SPECIMEN PREPARATION

Aggregate

Aggregates for both mixes were produced from the Fawndale quarry. Aggregate was received from three bins for the ARHM-GG

TABLE 2 Reliability Multipliers

Sample Size	Variance of Ln(N_{demand})	Reliability Multiplier			
		60 Percent Reliability (Z_R=0.253)	80 Percent Reliability (Z_R=0.841)	90 Percent Reliability (Z_R=1.28)	95 Percent Reliability (Z_R=1.64)
1	0.2	1.349	2.704	4.545	6.957
	0.4	1.377	2.896	5.046	7.955
	0.6	1.404	3.090	5.567	9.022
	1.0	1.455	3.480	6.673	11.381
2	0.2	1.304	2.416	3.830	5.587
	0.4	1.334	2.609	4.305	6.490
	0.6	1.363	2.802	4.797	7.456
	1.0	1.417	3.188	5.839	9.592
4	0.2	1.280	2.270	3.482	4.945
	0.4	1.312	2.464	2.946	5.805
	0.6	1.342	2.657	4.425	6.723
	1.0	1.397	3.042	5.437	8.754
8	0.2	1.267	2.197	3.313	4.640
	0.4	1.300	2.392	3.772	5.479
	0.6	1.331	2.585	4.245	6.375
	1.0	1.388	2.970	5.243	8.356

mix and four bins for the DGAC-PBA6 mix. After drying, the aggregate was batched in 7-kg (15.4-lb) samples using the following percentages (by dry weight of aggregate):

	Percent Passing	
Sieve Size	*DGAC-PBA6*	*ARHM-GG*
7/8 in.	35	45
5/8 in.	5	—
3/8 in.	21	34
Minus No. 4	39	21

Wet sieve analyses (ASTM C-117 and C-136) of the batched aggregate were performed for each mix, the results of which are presented in Table 3. It can be seen that the actual gradations were generally close to the target gradations, except for the fraction passing the 0.075-mm (No. 200) sieve for DGAC-PBA6, which was higher than the target. A higher fines content would be expected to reduce the permanent shear deformation resistance of the mix (*7*).

Mixing

DGAC-PBA6 Material

The aggregate batches were mixed with PBA-6 binder supplied by Telfer Sheldon Oil of Martinez, California. Just before mixing with the aggregate, 0.5 percent (by weight of asphalt) PaveBond PC antistripping agent was stirred into the PBA-6. Binder contents were 4.5, 5.0. 5.5, and 6.0 percent by weight of aggregate (4.3, 4.8, 5.2, 5.7 percent by weight of mix). The aggregate was heated at 152°C (305°F) for at least 2 hr before mixing. The binder was heated at the same temperature for at least 90 min before mixing.

ARHM-GG Material

The aggregate batches were mixed with asphalt-rubber binder supplied by International Surfacing Inc. (ISI) of Chandler, Arizona. Before shipment to UCB, ISI mixed 0.5 percent (by weight of binder) PaveBond PC antistripping agent into the asphalt rubber. Binder contents were 6.0, 7.0, 8.0, and 9.0 percent by weight of aggregate (5.7, 6.5, 7.4, and 8.3 percent by weight of mix). The aggregate was heated at 163°C (325°F) for at least 2 hr before mixing. The binder was heated for at least 3 hr at the same temperature before mixing.

Aging and Compaction

All mixes were short-term oven aged for 4 hr at 135°C (275°F) to simulate aging that occurs in a typical batch or drum plant (*8*). Rice maximum specific gravity tests (ASTM D2041) were performed on the mixes for each binder content.

The mixes were compacted in "ingots," each weighing approximately 20 kg (44 lb), using UCB rolling wheel compaction (*5–7*). The target air void content was 3.2 percent, as measured using parafilm. This value was selected because it appears to provide the maximum rutting resistance for the mixes included in this project and most dense-graded asphalt concrete and dense- and gap-graded asphalt-rubber mixes. If the mix can sustain the anticipated traffic at this air void content without excessive deformation, it can be concluded that satisfactory performance will be obtained in situ (*3,9*).

The compaction temperature was 141°C (285°F) for the dense-graded mixes and 146°C (295°F) for the asphalt-rubber mixes. One ingot of ARHM-GG, with an asphalt content of 6.0 percent, was compacted at 157°C (315°F) because the previous six attempts to achieve air void contents of less than 4 percent using the 146°C (295°F) compaction temperature had failed. This indicates that somewhat higher compaction temperatures are needed to compact this mix to low air void contents in the field.

After cooling overnight, the ingots were cored and cut to produce three 150-mm (6-in.) diameter, 50-mm (2-in.) tall cylindrical specimens. The specimens were tested for air void content, with the results shown in Tables 4 and 5 for the DGAC-PBA6 and ARHM-GG mixes, respectively. Only those specimens selected for testing are shown.

SIMPLE SHEAR TEST RESULTS

The cyclic shear tests were performed using the Universal Testing System developed as part of SHRP A-003A and manufactured by James Cox and Sons. For the RSST-CH, the specimen is bonded to platens that are in turn clamped to the actuators. The vertical actuator is used to maintain the specimen at a constant height, whereas

TABLE 3 Aggregate Gradations

Sieve Size mm	DGAC-PBA6 Percent Passing	Specified Percent Passing	ARHM-GG Percent Passing	Approx Target Percent Passing
26 (1 in.)	100	100	100	100
19 (3/4 in.)	98	95	98	98
13.2 (1/2 in.)	83	80	83	
9.5 (3/8 in.)	71	68	71	68
4.75 (#4)	51	48	38	34
2.36 (#8)	41	35	24	21
1.18 (#16)	29	25	16	
0.60 (#30)	19	17	10	9
0.30 (#50)	12	12	7.0	
0.15 (#100)	8.9	8	5.4	
0.075 (#200)	7.4	4	4.6	3

TABLE 4 Constant Height Simple Shear Repeated Load Tests: DGAC-PBA6 Mixes

Asphalt content by weight of aggregate — percent	Air-void content — percent	N_{supply} (at $\gamma=0.045$) $\times 10^3$	N_{supply}average $\times 10^3$
Laboratory prepared specimens			
4.5	3.9	120.4	1,015
	3.8	22.9	
	3.1	2900	
	2.6	3041	
5.0	4.2	5.1	4,973
	4.1	30.0	
	2.7	14884	
	2.5	1270	
5.5	3.3	8.8	153.5
	3.1	20.5	
	3.0	70.7	
	1.4	196.9	
	1.2	470.9	
6.0	4.2	10.4	75.1
	3.3	96.5	
	2.9	118.5	
Field Cores			
5.2	7.8	1931	1,492
	8.4	1053	
Field Mix Compacted in Laboratory			
5.2	5.5	88	57
	6.8	35	
	7.7	48	

TABLE 5 Constant Height Simple Shear Repeated Load Tests: ARHM-GG Mixes

Binder content by weight of aggregate — percent	Air-void content — percent	N_{supply} (at γ=0.045) $\times 10^3$	N_{supply}average $\times 10^3$
Laboratory prepared specimens			
6.0	2.5	4256	172.2
	2.5	2576	
	4.3	7849	
	4.4	2995	
7.0	2.9	1647	59.8
	3.0	772	
	3.9	5235	
8.0	2.8	1063	12.6
	2.9	586	
	2.9	471	
	3.4	384	
9.0	2.7	673	12.0
	3.0	781	
Field cores			
7.5	11.3	29	43.0
	12.4	57	
Field Mix Compacted in Laboratory			
7.5	9.4	29	37.2
	10.1	19	
	11.6	39	
	12.8	54	
	14.1	45	

the horizontal actuator applies a repetitive haversine shear stress. For this project, the RSST-CH was performed using a 68.9-kPa (10-psi) shear stress, with a 0.1-sec loading time followed by a 0.6-sec rest period. Each specimen was subjected to approximately 5,000 load repetitions.

During the test, the permanent shear strain increases with each load repetition. As noted earlier, permanent shear strain in the RSST-CH has been related to rut depth, according to Equation 1. For example, using a value of K equal to 279, the shear strain corresponding to a rut depth of 13 mm (0.5 in.) is 0.045 or 4.5 percent. Tables 4 and 5 summarize the number of RSST-CH repetitions to 4.5 percent permanent shear strain, N_{supply}.

BINDER CONTENT SELECTION

To select the design binder content for each mix, the procedure outlined earlier was followed.

The design traffic volume, N_{demand}, was determined from Equation 3. The design number of ESALs, adjusted to the critical temperature ($ESAL_{T_c}$), was determined by multiplying the design ESALS by the TCF for the site; in this instance a value of TCF = 0.1158 was used. A value of 0.04 was used for the shift factor, as follows:

$$N_{demand} = [(10 \times 10^6) \cdot (0.1158)] \cdot (0.04) = 46{,}230 \text{ reps}$$

To determine binder contents corresponding to different levels of reliability, N_{supply} was determined from Equation 3. Values for M were selected from Table 2 and are based on variabilities in the estimate of the natural logarithm of N_{demand} = 0.2 and a sample size of 4. Table 2 was determined for a mean square error of 0.602 from simple shear test results for one mix over a range in binder contents using Equation 5:

$$M = \exp (Z_{R} \cdot [\text{var}\{\ln \text{traffic estimate}\} + \text{var}\{\ln \text{RSST-CH results}\}]^{1/2} \quad (5)$$

where

R = desired confidence level,
Z_R = standard normal deviate,
var = variance, and
exp = antilog of Naperian base.

The values for M are as follows:

Reliability Level	M	$N_{demand} \times 10^5$
80	2.270	1.05
90	3.482	1.61
95	4.945	2.29

The results of the simple shear tests, Tables 4 and 5, are plotted in Figure 3 for the mixes containing the PBA-6 and asphalt-rubber binders.

These values were compared with the N_{supply} values determined from RSST-CH results for each binder content for the design rut depth [13 mm (0.5 in.)], which are also plotted in Figure 3. It can be seen that maximum binder contents of 5.4 and 5.9 percent by dry weight of aggregate for the DGAC-PBA6 and ARHM-GG mixes, respectively, would produce an asphalt concrete with 95 percent probability of not exceeding the design rut depth under the projected traffic loading of 10 million ESALs for the Sims Project.

The binder content for the DGAC-PBA6 mix determined from this analysis is approximately the same as that found acceptable from past experience with similar mixes. In contrast, the binder content for the ARHM-GG mix at this level of reliability is lower than considered acceptable for similar mixes. A 6.5 percent binder content, however, would provide N_{supply} exceeding N_{demand} with a reliability level of 80 percent.

PAST EXPERIENCE AND SELECTION OF BINDER CONTENTS

Past experience had indicated that a specified binder content of 5.2 percent by weight of dry aggregate would be successful for the same aggregate type and gradation under similar conditions. Based on the analyses presented above and past experience, a job-mix formula binder content of 5.2 percent was recommended for the mix containing the PBA-6 binder.

Limited experience (up to 4 years) on the part of advocates of asphalt-rubber binders indicated that asphalt-rubber contents of 8.1 to 8.7 percent by dry weight of aggregate have been used with no signs of excessive rutting. The calculations for the Sims Project, using air void content criteria from specimens prepared using the Hveem method (Caltrans Test 367), indicate that a binder content of 8.5 percent by dry weight of aggregate would be acceptable (although stabilometer S-values were in the range of 13 to 18, values that are considered unacceptable for conventional mixes). However, accepting the fact that limited experience has shown that asphalt-concrete mixes made with asphalt rubber can tolerate higher binder contents than asphalt-concrete mixes made with conventional asphalts, for whatever reason, a binder content of 7.5 percent by dry weight of aggregate was recommended for the ARHM-GG mix.

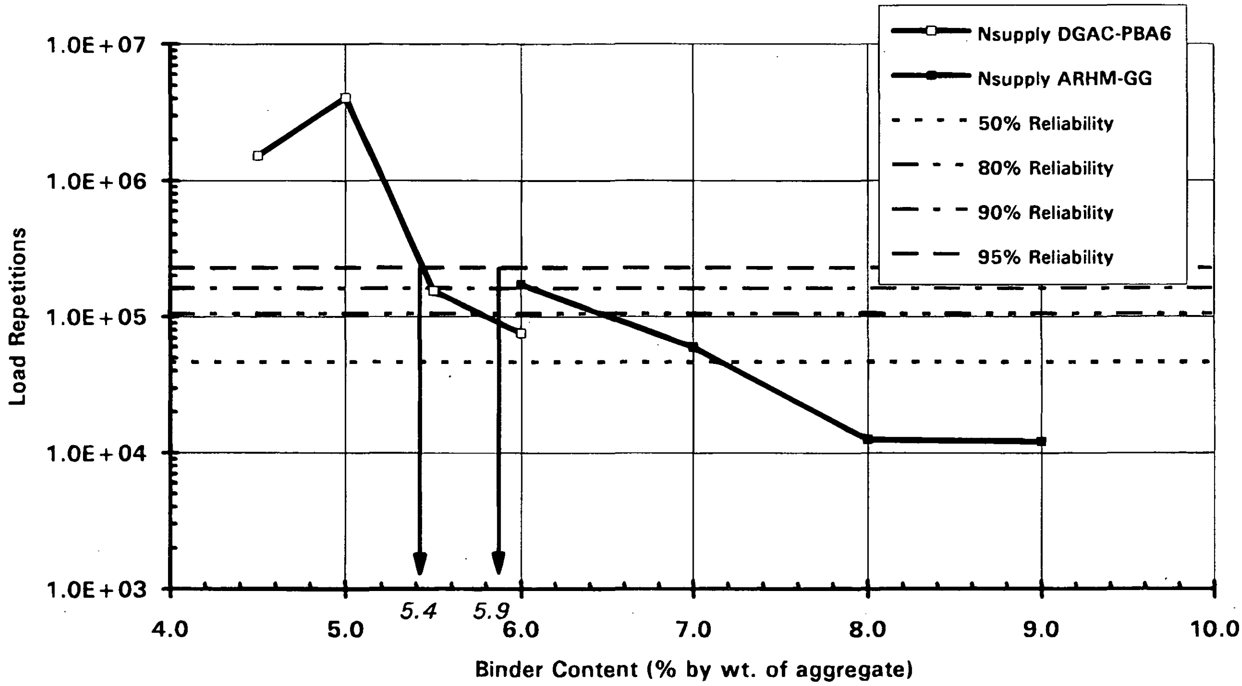

FIGURE 3 **Relationship between N_{supply} (repetitions to $\gamma_p = 0.045$) and binder content for DGAC-PBA6 and ARHM-GG mixes.**

MOISTURE SENSITIVITY TESTING

Moisture sensitivity of the DGAC-PBA6 and ARHM-GG mixes was evaluated at OSU using the Environmental Conditioning System, developed as part of SHRP A-003A (*10*).

Mixes were prepared with the following variations: DGAC-PBA6 mixes with 4.5 and 5.0 percent binder contents, both with and without 0.5 percent PaveBond antistripping additive; and ARHM-GG mixes with 7.0 and 8.0 percent binder contents, both with and without 0.5 percent PaveBond antistripping additive. Specimens were compacted using kneading compaction. Air void contents were approximately 8.2 ± 0.5 percent for the DGAC-PBA6 mixes and 10.6 ± 1.0 percent for the ARHM-GG mixes. These air void contents represent conditions that allow access of water into the specimens for maximum detrimental effect (*10*).

Figures 4 and 5 present the findings from the results of tests on the DGAC-PBA6 and ARHM-GG mixes, respectively. In the plots, each line connects a series of resilient moduli (M_R) ratio values obtained on a given specimen at one to four cycles of exposure in the environmental chamber of the ECS. The first three cycles consist of 6 hr in water at 60°C (140°F) followed by 4 hr in water at 25°C (77°F), and the fourth cycle consists of 6 hr in water at −18°C (0°F) followed by 4 hr in water at 25°C. The ratio values are determined by dividing the M_R after conditioning by the M_R of the original unconditioned specimen.

The results plotted in Figure 4 indicate that the use of the PaveBond additive was effective in decreasing the water sensitivity of the DGAC-PBA6 mix at both binder contents. A similar, although less effective, decrease in water sensitivity was also obtained without the additive by increasing the binder content to 5.0 percent.

The water sensitivity of the ARHM-GG mixes did not appear to be significantly affected by either binder content (7.0 and 8.0 percent) or the presence of the PaveBond antistripping additive, as can be seen in Figure 5.

On the basis of these findings, the following conclusions were drawn regarding the moisture sensitivity of the DGAC-PBA6 and ARHM-GG mixes tested:

Mix	*Binder content (%)*	*0.5% Additive*	*Moisture Sensitive?*
DGAC-PBA6	4.5	No	Yes
	4.5	Yes	No
	5.0	No	Borderline
	5.0	Yes	No
ARHM-GG	70	No	No
	70	Yes	No
	70	Yes	No
	80	No	No
	80	Yes	No

Because DGAC-PBA6 was to be placed as the lower layer of the overlay and had shown water sensitivity, it was recommended that the mix include 0.5 percent of PaveBond antistripping additive. Because the ARHM-GG mix had not shown moisture sensitivity and was to be placed as the upper layer of the overlay, it was recommended that it not include the additive; however, at the discretion of the mix producer, the additive might be included as a precautionary measure because it could significantly improve the M_R ratio values.

FIELD PERFORMANCE TO DATE

The DGAC-PBA6 and ARHM-GG mixes were placed at the site in July 1993. During 1994 no visible rutting or cracking was observed.

Two cores were taken by Caltrans outside of the wheel path after construction and tested using the RSST-CH under the same conditions used for the mix design. Those results are presented in Tables 4 and 5. It can be seen that the construction air void contents for the

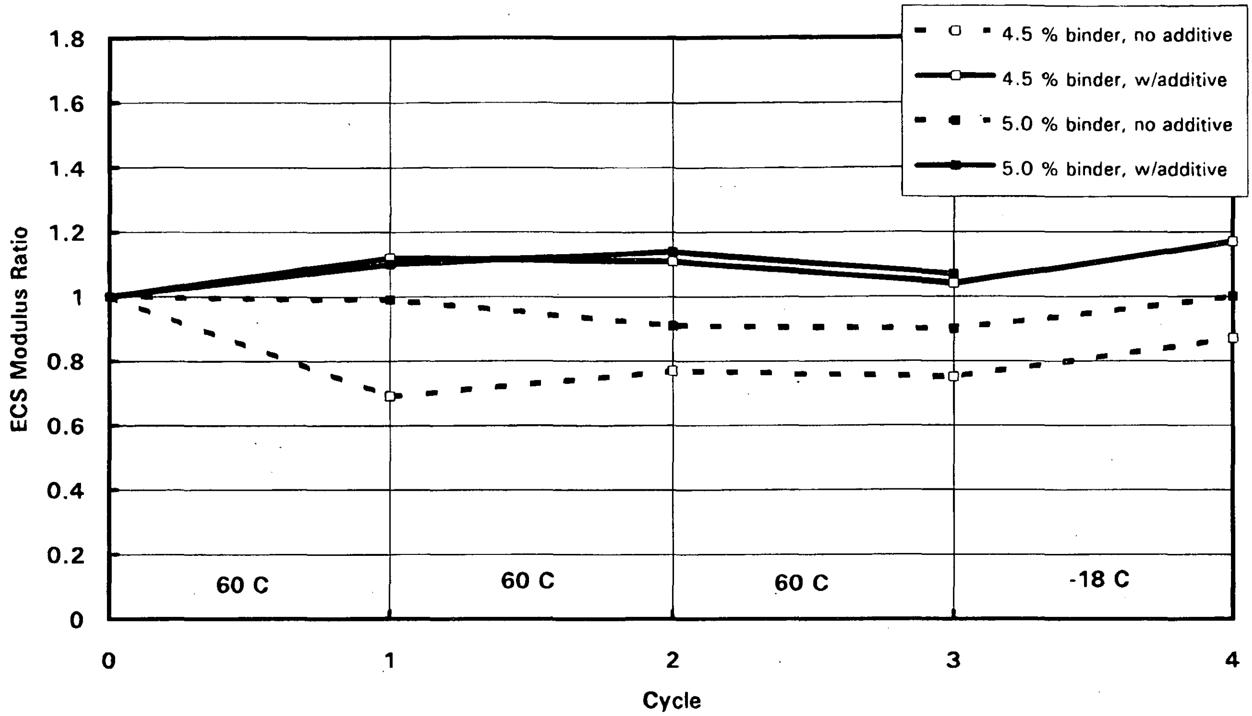

FIGURE 4 Environmental conditioning system results for DGAC-PBA6 mix.

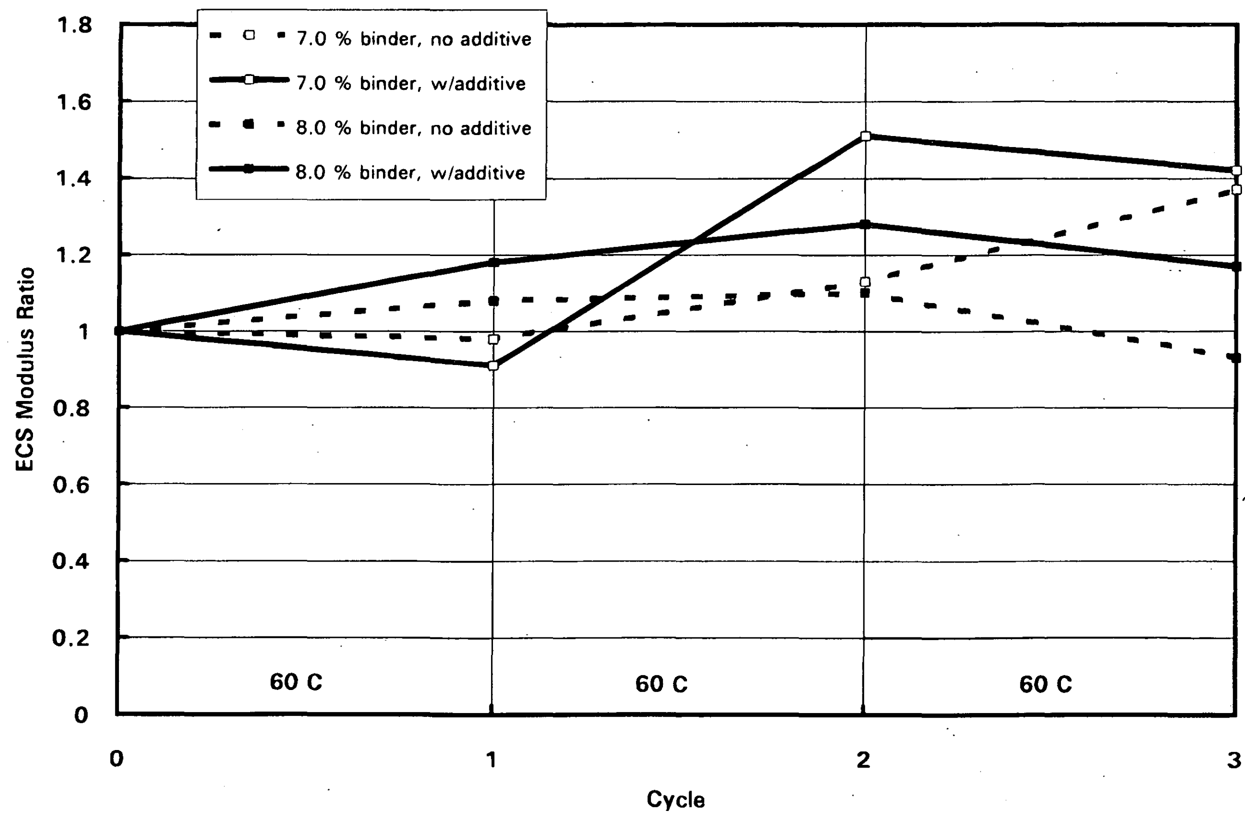

FIGURE 5 Environmental conditioning system results for ARHM-GG mix.

DGAC-PBA6 and ARHM-GG mixes were approximately 8.1 and 11.6 percent, respectively.

Field mix was also collected by Caltrans during construction, from which specimens were prepared to approximate the construction air void contents using rolling wheel compaction and tested using the RSST-CH under the same conditions used for the mix design. These results are also presented in Tables 4 and 5.

The DGAC-PBA6 results, shown plotted in Figure 6 with the original mix design data, indicate that the field cores had greater permanent shear deformation resistance than did the original mix design specimens and laboratory specimens compacted from field mix. A possible cause of the difference may be the low height of the field cores (approximately 35 to 40 mm) relative to the maximum aggregate size. The latter results correspond well with the original mix design results, considering the difference in air-void contents. It would be expected that the mix in situ would undergo additional compaction because of trafficking, resulting in higher permanent shear deformation resistance.

The ARHM-GG results, plotted in Figure 7, match well with the mix design data after accounting for the difference in air void contents. The field cores and laboratory-compacted field mix also have corresponding results.

SUMMARY

The project discussed in this paper used an application of a mix design method developed in the SHRP A-003A project. With this method, binder contents were selected for two mixes—ARHM-GG and DGAC-PBA6—that should meet the performance required by the warranty for the project.

There are a number of features of this mix design approach that differ from current procedures and that should be emphasized:

- Use of test temperature corresponding to the critical temperature for the specific site,
- Application of the primary distress mechanism for permanent deformation using the RSST-CH,
- Compaction to the critical air void content expected in the field after trafficking using a laboratory compaction procedure that produces mix characteristics similar to those produced by field compaction, and
- Use of reliability concepts that allow the mix designer to include an appropriate level of risk for the project under consideration.

In addition, the water sensitivity testing methods developed as part of the SHRP A-003A project demonstrated the suitability of, and evaluated the need for, an antistripping additive for both mixes.

It is recommended that evaluation of the mix design method presented in this paper continue by application to additional projects. Through this process the authors believe that the advantages of this methodology can be demonstrated; at the same time, further refinements can be made if required.

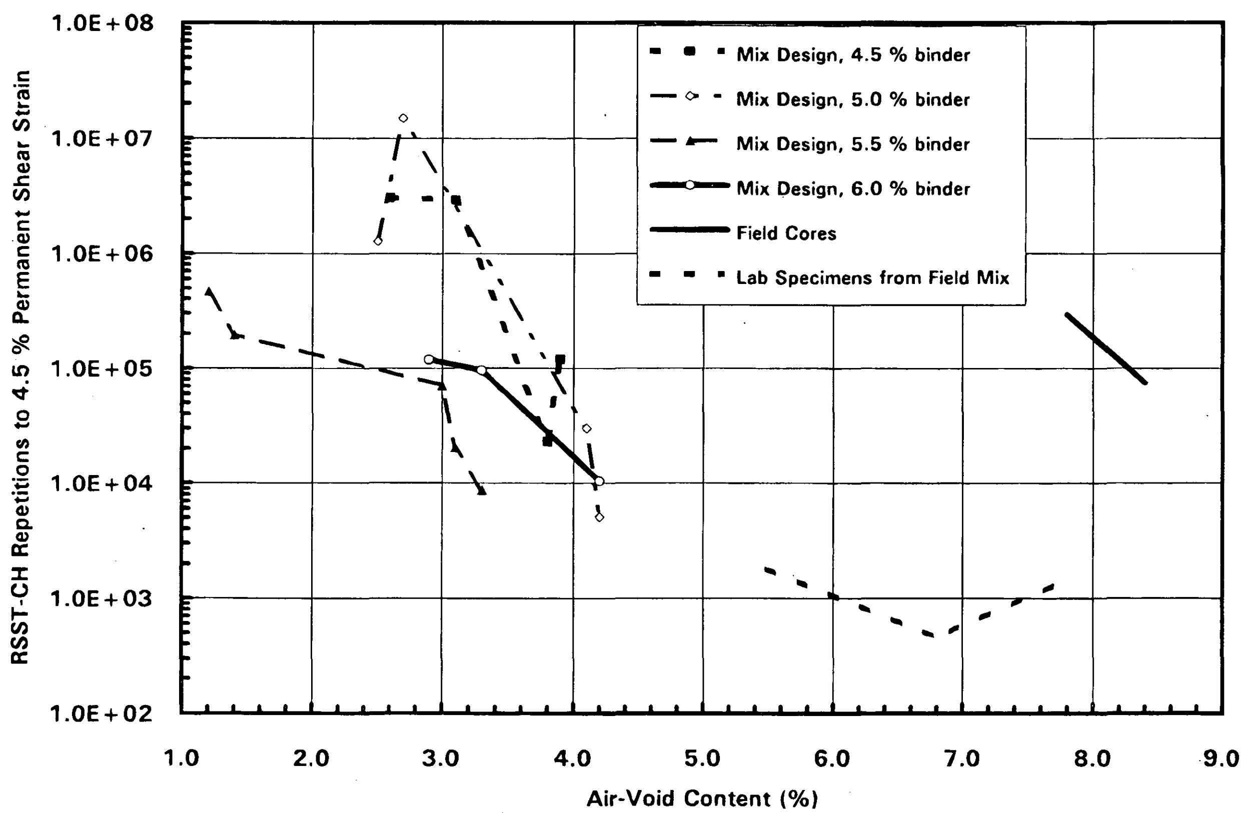

FIGURE 6 Comparison of mix design and field specimen permanent shear deformation resistance for DGAC-PBA6.

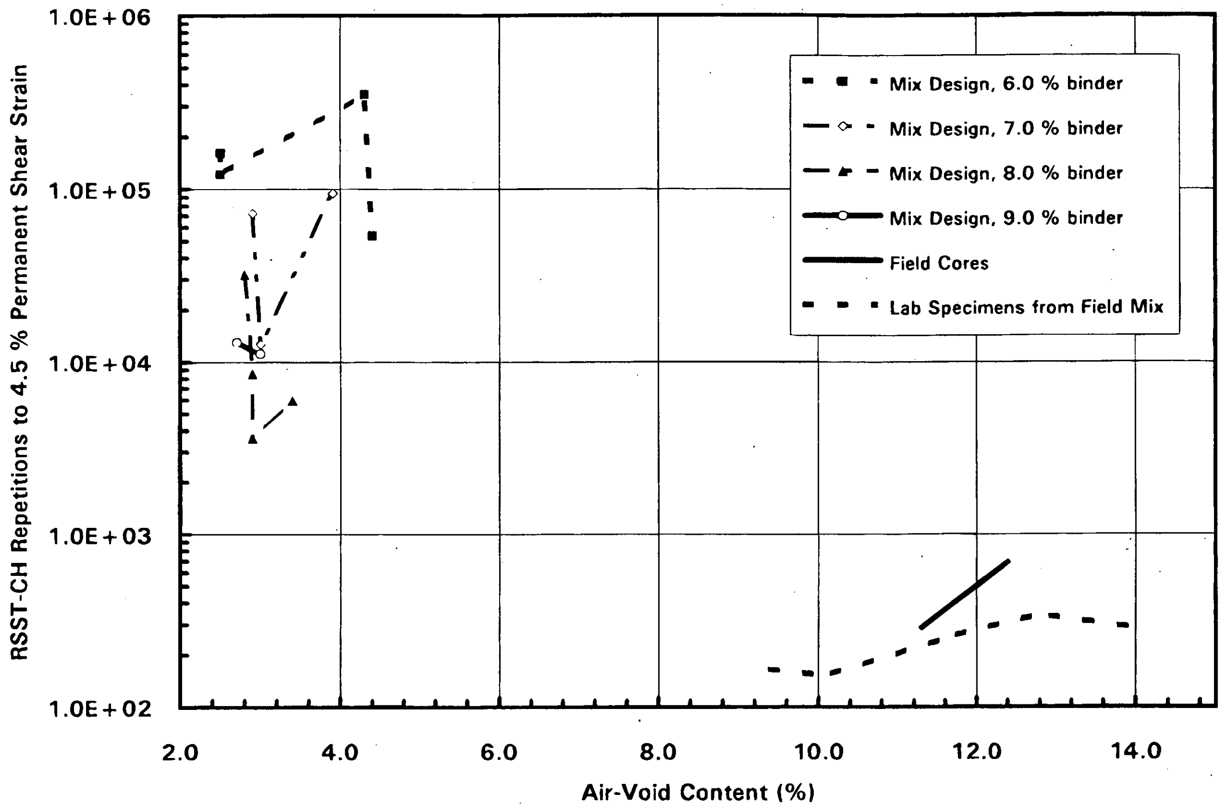

FIGURE 7 Comparison of mix design and field specimen permanent shear deformation resistance for ARHM-GG.

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