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CAL/APT Program – Construction of the Goal 3 Overlays and Recommendations for Improved Overlay Performance in California

Report Prepared for

CALIFORNIA DEPARTMENT OF TRANSPORTATION

By

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1.0 INTRODUCTION

This report describes the construction of the CAL/APT Goal 3 overlays and details observations regarding current Caltrans procedures which are intended to help improve the performance of Caltrans overlays. The main objective of Goal 3 is the comparison of the performance of a Gap Graded Asphalt Rubber Hot Mix (ARHM-GG) overlay with that of a conventional Dense Graded Asphalt Concrete (DGAC) overlay. Based on Caltrans design procedures, ARHM-GG overlay thicknesses are typically half of the equivalent DGAC overlay. These overlays represent typical pavement structures currently in use throughout California (*1*). The complete plan for HVS and laboratory testing and associated analyses is outlined in the Goal 3 test plan (*9*).

The overlays were placed over existing asphalt concrete sections constructed for CAL/APT Goal 1. The Goal 1 sections were subjected to accelerated trafficking under the Heavy Vehicle Simulator (HVS) to determine the structural response of two different base structures: *drained*, consisting of an asphalt-treated permeable base (ATPB) and unbound aggregate base material, and *undrained*, consisting of unbound aggregate base material.

It should be noted that the terms “drained” and “undrained” refer to whether the section includes an asphalt treated permeable base (ATPB) or not, respectively. The sections were tested in the dry condition at constant temperature as part of CAL/APT Goal 1.

This report discusses:

- the Caltrans overlay design method as used for this project (Caltrans Test Method 356 [*1*, *8*]);
- mix designs for the ARHM-GG and DGAC and resulting compaction specifications;
- construction procedures, control methods, and tests; and
- pavement condition before and after construction of the overlays, including layer thicknesses and air-void contents.

The design of the overlays was performed in the fall of 1996. Mix designs were completed in the winter of 1996-97. Construction was delayed until 26 March 1997 due to months of heavy rain that flooded the quarry selected by the contractor, as well as competing quarries.

2.0 CONDITION OF THE HVS SECTION PRIOR TO CONSTRUCTION OF THE GOAL 3 OVERLAYS

Prior to the construction of the Goal 3 overlays, all four Goal 1 test sections were "failed" under HVS loading (*3*-*6*), by one or more of the following criteria: fatigue cracking, surface deflections, and/or surface rutting. This section discusses the condition of these failed sections at the end of Goal 1 testing in terms of various parameters, including the failure criteria.

2.1 Air-Void Contents

Typical average air-void contents (California Test Method 308 A, modified to use Parafilm instead of paraffin wax, [*2*]) for the two asphalt concrete lifts measured prior to and after HVS testing are given in Table 1.

Table 1 Typical air-void contents before and after Goal 1 HVS testing

	Before Trafficking [1]		After Trafficking	
Section	**Top Lift**	**Bottom Lift**	**Top Lift**	**Bottom Lift**
500RF	7.8	4.4	6.2	3.7
501RF	7.2	5.6	6.9	6.3
502CT	4.1	2.4	5.2	2.2
503RF	4.8	4.4	5.4	4.6

[1] Cores were taken in proximity of the test sections; the sections will be trenched at a later date.

Very good compaction of the asphalt concrete was obtained during Goal 1 construction largely due to the short length (about 70 m) of the two 3.7-m wide lanes of pavement, as well as thick lifts and lack of wind. All of these factors permitted the contractor to make multiple passes with rolling compactors while the mix was still hot. The air-void contents in both lifts were significantly lower than the typical 8 to 10 percent permitted by Caltrans specifications, and considerably less than is obtained on many method specification projects. The aim for the Goal 3 overlays was to obtain air-void contents that are more representative of typical field pavements than were obtained during the Goal 1 construction.

2.2 Permanent Deformation

The Caltrans failure criterion for permanent deformation at the surface is an average maximum rut depth of 13 mm (0.5 inches). At the completion of Goal 1 HVS testing, both drained sections (500RF and 502CT) had failed by the Caltrans surface rut criterion, as shown in Table 2. Table 2 shows distribution of permanent deformation by pavement layer, based on Multi-Depth Deflectometer (MDD) measurements.

Table 2 Percent of vertical permanent deformation occurring in each layer

Layer	**500RF**	**501RF**	**502CT**	**503RF**
Asphalt Concrete	52%	52%	68% [1]	48%
ATPB	7%	-		-
Aggregate Base	17%	26%	16%	33%
Aggregate Subbase	12%	11%	6%	17%
Subgrade	12%	11%	10%	2%
Rut depth (mm)	15	11	14	11

[1] includes asphalt concrete and ATPB

2.3 Elastic Deformation

At completion of HVS testing, all four sections exhibited 80th percentile deflections measured with the Road Surface Deflectometer (RSD) in excess of 610 microns (24 mils), which is the criterion for a 76-mm (3-inch) AC overlay for this structural section and design traffic (per California Test Method 356 [*2*]). This is discussed further in the overlay design section. The RSD is similar to the Benkelman beam or traveling deflectometer.

2.4 Fatigue Cracking

Cracking was found to have propagated through the upper lift of the asphalt concrete after HVS trafficking, however, no cracks were present in the lower lift. A greater density of cracking occurred in the undrained sections than in the drained sections (Table 3), which is to be expected due to the increased structural support provided by the ATPB in the drained section (*5, 6*).

Table 3 Average crack length per area at completion of Goal 1

Section	**500RF**	**501RF**	**502CT**	**503RF**
Crack Length/Area (m/m^2)	2.5	9.6	4.0	6.5

3.0 CALTRANS OVERLAY DESIGN METHOD

3.1 Design of Goal 3 Overlays

The Caltrans method for rehabilitation of flexible pavements (California Test Method 356 [*2*]) is based on elastic surface deflection criteria as measured with a Benkelman Beam or Traveling Deflectometer under an 80-kN single axle load. Deflections on the Goal 1 sections were measured using a Dynaflect, Falling Weight Deflectometer (FWD), and Road Surface Deflectometer (RSD). All deflection measurements were taken at a pavement surface temperature of about 20°C, but at different times. The Dynaflect deflections were converted to equivalent deflectometer deflections using procedures from CTM 356. The FWD deflections, measured using a 300-mm (11.8-inch) diameter 40-kN (9,000-lb.) load are considered by Caltrans to be directly equivalent to deflectometer deflections per CTM 356 (*2*). Due to the stiffness of the pavement structure, the deflection basins on the test sections were within the limits that make RSD readings equivalent to Benkelman Beam readings.

Deflections were obtained on two of the four HVS test sites for use in the overlay design. One of the sites, Section 500RF, was a drained pavement, and the other, Section 501RF, was an undrained pavement. Deflections could not be obtained in the replicate sections for the drained and undrained pavements (502CT and 503RF) because HVS testing was in progress on those sections at the time. It was considered essential that the designs for the overlays be completed and construction scheduled before the HVS testing was completed on Sections 502CT and 503RF in August or September, 1996 in order to minimize HVS idle time.

The deflections on 500RF were assumed to be representative of those measured at the completion of HVS testing on the other drained pavement site, 502CT. Similarly, the deflections on 501RF were assumed to be representative of those measured at completion of HVS testing on the other undrained pavement site, 503RF. These assumptions are based on the following:

1. the only difference in structural cross-section between the replicate pavement sites, 500RF and 502CT, and 501RF and 503RF, is a difference in the thickness of the subbase (*13*); and
2. the HVS testing on the replicate sites would be stopped when there was approximately the same amount of cracking observable on the surface.

All deflections were taken after completion of HVS testing, and were measured along the centerline of the HVS wheelpath.

The Dynaflect deflections were measured on Sections 500RF and 501RF on 28 May, 1996. The FWD deflections were measured on both 500RF and 501RF on 28 February, 1996. The RSD deflections were measured on 500RF on 8 November, 1995 and on 501RF on 26 February, 1996. All deflection measurements were taken at a pavement surface temperature of about 20°C (67°F).

The 80th percentile deflections (1/1000 of an inch [mils]) for each device are summarized in Table 4.

Table 4 80th percentile deflections on Sections 500 RF and 501RF, used for overlay designs

Pavement Structure	80th Percentile Deflections (mils)
Drained 500RF	Dynaflect: 8 [1] FWD: 9 RSD: 29
Undrained 501RF	Dynaflect: 10 [1] FWD: 23 RSD: 35

[1] Converted to Traveling Deflectometer per CTM 356 (*2*).

The deflection measurements reflect the fact that comparisons of deflections between different measuring devices and techniques must be used with care. Epps and Monismith (*10*) indicate, for example, that differences of as much as a factor of 2 may be evident between Benkelman Beam measurements at the same point using the rebound method (wheel moving away from measurement point) and the WASHO method (wheel moving towards measurement point). The RSD measurements reflect a slow moving load deflection with the wheel load moving towards the measuring point, similar to the WASHO method for a Benkelman Beam. The Dynaflect imposes a steady-state vibratory load of approximately 1,000 ft. lb. peak-to-peak at a frequency of 8 Hz. The FWD applies a transient dynamic load pulse of 25-35 ms duration and a peak load of approximately 9,000 ft. lb. intended to simulate a moving wheel load on an 18,000-lb. standard axle. All measurements were converted to equivalent Traveling Deflectometer readings using procedures from CTM 356.

The tolerable deflection for a Traffic Index of 9 (1 million Equivalent Single Axle Loads [ESALs]) and an asphalt concrete thickness of 150 mm (0.5 ft.) was found to be 35 microns (14 mils), per CTM 356. Section 500RF was therefore considered to have acceptable deflections from the Dynaflect and FWD, and unacceptable deflections from the RSD. Section 501RF was considered to have acceptable deflections from the Dynaflect, and unacceptable deflections from the FWD and RSD.

The percent reduction in deflection that would yield unacceptable deflections was calculated using CTM 356. The calculated values were used to find the required increase in gravel equivalent using Figure 18 of CTM 356. The required overlay thicknesses were then calculated, assuming a gravel factor of 1.9 for the Dense Graded Asphalt Concrete (DGAC). The Gap Graded Asphalt Rubber Hot Mix (ARHM-GG) overlay thicknesses for the replicate sections were calculated from the required DGAC thickness per the Caltrans Guideline (Appendix A). The overlay thicknesses based on deflection reduction are given in Table 5.

Table 5 Overlay thicknesses per CTM 356 for all four test sections

Pavement Structure	**Overlay Type**	**Section**	**Overlay Thickness, ft. (mm) DGAC**
Drained	*DGAC*	*500RF*	*Dynaflect: not necessary* *FWD: not necessary* *RSD: 0.34 (104)*
	ARHM-GG	*502CT*	*Dynaflect: not necessary* *FWD: not necessary* *RSD: 0.20 (60) **
Undrained	*DGAC*	*501RF*	*Dynaflect: not necessary* *FWD: 0.21 (64)* *RSD: 0.43 (131)*
	ARHM-GG	*503RF*	*Dynaflect: not necessary* *FWD: 0.10 (30) *** *RSD: 0.15 (45) ARHM on 0.15 (45) DGAC ****

* 0.20ft. (60 mm) ARHM-GG = 0.35 ft. (105 mm) DGAC
** 0.10 ft. (30 mm) ARHM-GG = 0.2 ft. (60 mm) DGAC
*** 0.15 ft. (45 mm) ARHM-GG on 0.15 ft. (45 mm) DGAC = 0.45 ft. (135 mm) DGAC
(Note: The subsequently measured deflections on sections 502CT and 503RF are also shown, although they were not used in the overlay design process, which was completed before these deflections were available.)

Based on the 500RF and 501RF information, an overlay thickness of 15 mm (0.5 ft.) was selected using the deflection analyses as well as reflection cracking considerations from CTM 356.

Site 500RF had approximately 13 mm of rutting, as well as surface cracking. A leveling course was prescribed to fill the rut following typical Caltrans procedures for similarly distressed pavements, to be followed by a DGAC overlay of 60 mm (0.2 ft.). The total amount of overlay material placed on 500RF is therefore 76 mm (0.25 ft.), including the leveling course. The equivalent ARHM-GG overlays would be about 30 to 37 mm (0.10 to 0.12 ft). No leveling course was required on the other sections.

Given that the leveling course on 500RF is relatively thin, a 9.5-mm (3/8-inch) maximum aggregate size mix was recommended for the leveling material. The effect of the reduced size material on the fatigue life of the section may depend to some extent on the fatigue properties of the leveling course mix even though it comprises only 20 percent of the total overlay thickness.

The final overlay thicknesses selected for the four test sites, shown in Table 6, are a compromise between the thicknesses calculated for deflection reduction using CTM 356 from the Dynaflect, FWD, and RSD deflections, and the thicknesses recommended to reduce reflection cracking.

The thickness of the ARHM-GG overlay was increased to 0.20 ft. (60 mm) in an area between Sections 502CT and 503RF. This was done in order to provide an area where cores and slabs of adequate thickness could be obtained for laboratory testing of

Table 6 Final overlay thickness solutions for all four fatigue sections

Pavement Structure	Section	Overlay
Drained	500RF	Level up rut, then overlay 0.2 ft. (60 mm) for a total of 0.25 ft. (75 mm) DGAC
	502CT	0.12 ft. (37 mm) ARHM-GG
Undrained	501RF	0.25 ft. (75 mm) DGAC
	503RF	0.12 ft. (37 mm) ARHM-GG

The 0.25-ft. overlay thickness allows construction in a single lift. The Caltrans standard specification for thickness allows ± 0.02 ft. variation during construction (*12*).

the fatigue and permanent deformation properties following SHRP procedures.

Subsequent to the original overlay designs using 500RF and 501RF data, detailed final RSD data on all four sections became available and is presented in Table 7.

Table 7 RSD deflections (microns) at start and completion of Goal 1 testing under a 40-kN wheel load

Section	Deflections at Start			Deflections at End			Required DGAC Overlay
	Average	Standard Deviation	80^{th} Percentile	Average	Standard Deviation	80^{th} Percentile	
500RF	320	38	352	703	84	774	61 mm
501RF	322	12	332	803	123	906	75 mm
502CT	267	29	291	878	79	944	80 mm
503RF	218	12	228	930	52	974	85 mm
						Average:	***75 mm***

Inspection of these results and the calculated overlay thicknesses supports the original overlay designs developed using only the 500RF and 501RF data and the assumption that the 500RF and 501RF data was reasonable.

3.2 Influence of Temperature on Caltrans Overlay Thicknesses

The current Caltrans mix design procedure does not take pavement or air temperature into account when analyzing the deflection data. The HVS test site at the University of California Berkeley Pavement Research Center provided a unique opportunity to evaluate the effects of pavement temperature on measured deflections because of the ability to control temperature by means of the temperature control system. An experiment was performed in March 1999 to evaluate the effects of pavement temperature on overlay thickness as determined by CTM 356. The target pavement temperatures for deflection measurement were 10°(50°F), 20°(67°F) and 30°C (86°F) at the surface of the asphalt concrete.

The range of pavement surface temperatures used for this experiment is within a reasonable range of possible pavement temperatures occurring in California. Pavement temperatures typically vary more than air temperatures due to the added heating effects of solar radiation and the cooling effects of wind. Maximum daily pavement temperatures can vary between 10°C and 30°C from month to month in the coastal, mountain and valley climate regions of California. In the desert areas, pavement temperatures can vary between 10°C and 30°C over the course of one day.

Deflections were measured on three successive days (10-12 of March, 1999). Deflections were measured on Test Section 518RF. As described elsewhere in this report and in Reference (*13*), this test section consists of an asphalt concrete layer about 175 mm thick, on a Class 2 Aggregate Base, Aggregate Subbase, and clay subgrade. Pavement and air temperatures were measured by four thermocouples: one at each end of the HVS test section and one on each side.

The original test section underlying the overlaid section on which deflection measurements were taken (501RF) had been subjected to 1,426,467 dual wheel load repetitions resulting in approximately 59,000,000 ESALs. The surface of Section 501RF was completely cracked at the completion of loading on 501RF in 1995. This experiment was attempted on the cracked Section 501RF in 1997, however, problems recovering the thermocouple data from the test results required that it be repeated in 1999. At the time that deflection measurements at different temperatures were taken in 1999, the overlaid test section, 518RF, had been subjected to 688,120 additional dual wheel repetitions equaling approximately 22,700,000 ESALs, and cracks were visible on the surface.

The air temperature in the temperature control box on Section 518RF was cooled to 10°C for a three-day period (8-10 March, 1999). Deflections were measured on March 10, 1999 using the Road Surface Deflectometer (RSD) and Multi-Depth Deflectometers (MDD) with a 40-kN dual wheel load. The RSD produces deflections that are considered equivalent to those of the Benkelman Beam for the pavement structures tested in this experiment. The MDD measures deflections relative to an anchor 3 m below the pavement surface, and serves as an independent check on the RSD measurements.

The pavement was subjected to 886 40-kN load repetitions immediately prior to deflection measurement in order to eliminate any temporary stiffness gains. The air temperature and pavement temperature profiles at the beginning and end of the hour during which the deflection measurements were taken are shown in Figure 1.

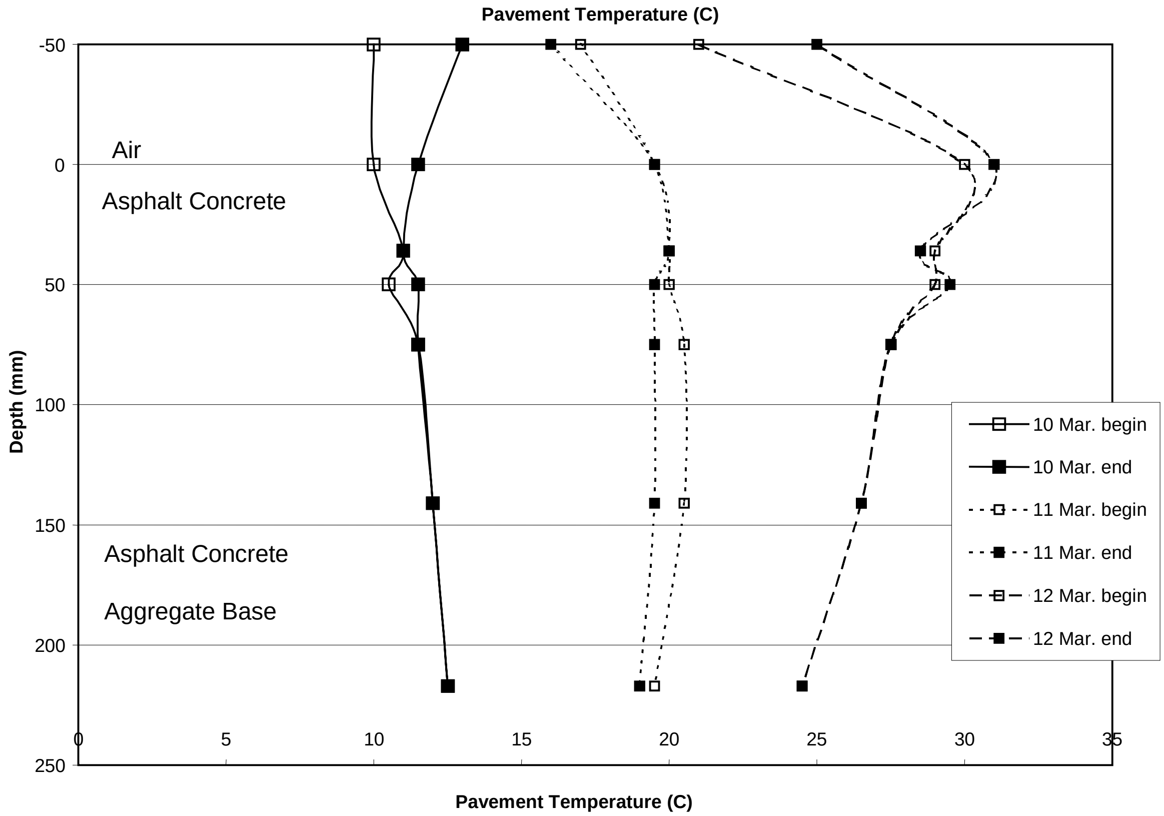

Figure 1. Air and pavement temperature profiles at time of deflection measurements.

Table 8 Section 518RF RSD and MDD deflections (microns) at different pavement temperatures.

	RSD			**MDD**		
Date:	**10 March**	**11 March**	**12 March**	**10 March**	**11 March**	**12 March**
Average Surface Temp. (°C)	11	20	31	11	20	31
Repeat 4	655	787	866			
Repeat 6	668	777	869	764	869	938
Repeat 8	557	713	829			
Repeat 10	552	617	714	587	641	726
Repeat 12	660	625	737			
Average	*619*	*704*	*803*	*675*	*755*	*832*
Standard Deviation	*53*	*72*	*65*			

A heating apparatus consisting of infrared heat lamps and resistor air heaters was placed in the temperature control box immediately after deflection measurements were completed on March 10. On March 11, after 18 hours of heating, the temperature at the surface of the pavement was close to 20°C (Figure 1). The test section was subjected to 673 wheel load repetitions before deflections were measured. A similar process was repeated until March 12 when the surface temperature was close to 30°C. The test section was subjected to 836 repetitions prior to deflection measurements at 30°C.

The measured deflections are shown in Table 8. The RSD deflections show an increase of approximately 30 percent with the increased pavement temperature between 10 March and 12 March, while the MDD deflections increase by about 23 percent. MDD deflections are less than 10 percent higher than the comparable RSD deflections for these tests.

3.2.1 Determination of Asphalt Concrete Overlay Thicknesses Using CTM 356

Asphalt Concrete overlay thicknesses were calculated for the RSD deflections following CTM 356 at each of the three pavement temperature regimes. For the calculations, shown in Table 9, the means and standard deviations of the RSD deflections were calculated from the fifteen data points obtained from three repetitions at five locations on Test Section 518RF (centerline at Points 4, 6, 8, 10, and 12, each 1 meter apart). The RSD deflections were converted to Traveling Deflectometer deflections using the equation given in Figure 13 of CTM 356; 80th percentile deflections were calculated for each measurement date.

Table 9 Calculation of required AC overlay thicknesses for different pavement surface temperatures.

Location	Average Surface Temperature (°C)	Average 40-kN RSD Deflections (microns)	Standard Deviation 40-kN RSD Deflections (microns)	80^{th} percentile 40-kN RSD Deflections (mils)	CTM 356 Figure 13 Deflectometer Deflection (mils)	CTM 356 Figure 17 Tolerable Deflection (mils)	Deflection Reduction (percent)	Gravel Equivalent Increase (ft.)	Overlay G_f	Overlay Thickness [ft. (mm)]
CL12	11	619	53	26.1	25.8	14	45.8	0.6	1.89	0.32 (97)
CL12	20	704	72	30.1	29.8	14	53.0	0.85	1.89	0.45 (137)
CL12	31	803	65	33.8	33.4	14	58.1	1.02	1.89	0.54 (164)
* Traffic Index = 9, Existing AC thickness = 0.5 ft.										
		m3	tons							
		358	31327							
		507	44379							
		609	53255							

The tolerable deflection was determined using Figure 17 of CTM 356, assuming an asphalt concrete layer 150 mm thick (0.5 ft.) and a design Traffic Index of 9, equivalent to about 1,000,000 expected ESALs. The asphalt concrete thickness on Section 518RF is 175 mm thick including the overlay, however, the maximum thickness of existing asphalt concrete that is considered in CTM 356 Figure 17 is 150 mm. (Note: The limitation on existing AC thickness in CTM356 is based on the maximum AC thickness evaluated during development if CTM 356 in the 1950s and 1960s. Many current Caltrans AC pavements are thicker than 150 mm, and CTM 356 must be extrapolated, which is another important limitation of the method.)

The required increases in gravel equivalent for the AC overlays were selected from Figure 18 of CTM 356. Required AC overlay thicknesses were calculated assuming a gravel factor for the asphalt concrete overlay of 1.89.

Pavement temperatures have a significant effect on measured deflections and therefore on AC overlay thicknesses, as shown in Table 9. The required overlay thickness changes from 97 mm at a surface temperature of 11°C, to 137 mm at 20°C, to 164 mm at 31°C. This is reasonable only if the temperature at the time of deflection measurement is representative of the pavement temperature during the pavement service life. If not, it seems reasonable to normalize deflections to a standard temperature, or to a temperature representative of expected service conditions.

These differences in overlay thickness affect both the initial cost of the overlay, as well as the fatigue life of the overlay. The pavement fatigue life is also affected by the rest of the pavement structure, climate, and drainage.

The effects on initial construction cost per lane-kilometer can be calculated as shown in Table 10, assuming the cost of asphalt concrete in place is $35 per metric ton, the compacted specific gravity is 2.5 kg/m^3 (156 pcf), and the lane width is 3.7 m (12 ft.).

Table 10 Change in overlay cost per lane-kilometer with pavement surface temperature at time of deflection measurement.

Surface Temperature (°C)	Cost
10	$31,327
20	$44,379
31	$53,255

This study has evaluated the effects of pavement temperature only, and has not considered the effects of seasonal changes in the water contents of underlying layers. In particular, subgrade moisture content has a significant effect on surface deflections. Measurement of pavement deflections considering changes in the water contents of unbound layers will be evaluated in a later goal to be performed by CAL/APT on the RFS test sections.

The results included in this report suggest that the use of a mechanistic-empirical overlay design procedure, which explicitly considers the effects of temperature on asphalt concrete stiffness in terms of asphalt concrete tensile strains and their effect on fatigue life, is warranted. Seasonal effects can also be considered in a mechanistic-empirical procedure.

4.0 MIX DESIGN

This section presents and discusses the results of mix designs for the DGAC and ARHM-GG overlay materials. The materials were tested according to test procedures (Table 11) specified by the Caltrans Standard Specifications (*12*).

The mix used for the DGAC overlay was similar to that used for the Goal 1 sections. Mix designs for both overlays were performed by Reed and Graham, with checks and final recommendations at the Caltrans District 4 laboratory in San Francisco. Details are provided in Appendix B. Both mixes were produced by FiveStar Asphalt in Richmond, California.

4.1 DGAC

4.1.1 Asphalt Cement

Materials for the DGAC mix were Huntway AR-4000 asphalt cement and aggregate from various sources as discussed in the next section. Table 11 contains a summary of test results on the AR-4000 asphalt cement as well as the Caltrans specification limits. The suggested asphalt content range for the DGAC mix design was 5.0 to 5.3 percent. PG classification of this asphalt cement is PG 64-16, as determined by Caltrans TransLab.

4.1.2 Aggregate

The aggregate for the DGAC met the Caltrans Standard Specifications for a 19-mm Type A, coarse gradation asphalt concrete (*12*). The aggregates were obtained from various sources including Tidewater sand, Point Richmond Quarry, and Lone Star Clayton. The aggregates were combined as presented in Table 12. The grading from each bin as obtained from wet sieve analysis is shown in Table 13. The final DGAC aggregate gradation is shown in Table 14. The average preliminary maximum theoretical specific gravity for the DGAC mix was 2.495. The specific gravities of the DGAC aggregate using the Caltrans formula (CTM 208 and 206) were as follows:

Specific gravity of DGAC fines (CTM 208)	=	2.749
Specific gravity of DGAC coarse (CTM 206)	=	2.673
Average specific gravity of DGAC aggregate	=	2.710

Table 11 Asphalt properties for DGAC 1995 standard

Tests on Original Asphalt (Caltrans Specifications)				
Property	**AASHTO Method**	**Range**	**Report**	**Meet Spec.?**
Flash Point	T48	> 225°C	293°C	yes
Solubility in TCE	T44	> 99 %	99.8+ %	yes
Tests on Residue from RTFO AR 4000 (AASHTO T240)				
Absolute Viscosity @ 60°C	T202	4000 ± 1000 poises	4907 poises	yes
Kinematic Viscosity @ 135°C	T201	> 275 poises	425 poises	yes
Penetration @ 25°C 110 g / 5 sec	T49	> 25	36	yes
Percent of original penetration	T49	> 45%	62%	yes
Ductility @ 25°C	T51	> 75 cm	100 + cm	yes

Table 12 Combination of aggregate from various bins for DGAC

Aggregate Source	Bin	Mass Percentage
Tidewater	fine sand	10.0
Pt. Richmond Quarry	7/16 inch	13.0
Lone Star Clayton	1/4 inch dust	45.0
Pt. Richmond Quarry	5/8 inch	32.0

Table 13 Grading from each bin

Sieve Size	Percent Retained on Each Sieve				
	Coarse Sand	Fine Sand	7/16 inch	1/4 inch dust	5/8 inch
19 mm (3/4”)	0	0	0	0	0
12.5 mm (1/2”)	0	0	0	0	9.8
9.5 mm (3/8”)	0	0	6.9	0	60.5
4.75 mm (#4)	4.2	0.4	83.3	13.1	24.6
2.36 mm (#8)	8.9	0.4	5.8	29.9	1.6
1.18 mm (#16)	13.7	0.4	0.4	17.6	0.3
0.6 mm (#30)	19.4	1.6	0.1	10.4	0.1
0.3 mm (#50)	27.0	25.2	0	7.3	0
0.15 mm (#100)	23.3	63.9	0.1	4.6	0
0.075 mm (#200)	2.3	3.9	0.1	2.8	0.1
Pan	1.2	4.2	3.3	14.3	3

Table 14 Aggregate grading for DGAC (percent passing)

Sieve Size (Metric)	Sieve Size (US)	Specification Range	Mix Design
19	3/4 in.	90 - 100	100
12.5	1/2 in.		93
9.5	3/8 in.	60 - 75	73
4.75	No. 4	45 - 55	50
2.36	No. 8	31 - 41	39
1.18	No. 16		27
0.6	No. 30	13 - 23	18
0.3	No. 50		11
0.15	No. 100		6
0.075	No. 200	3 - 7	5

4.2 ARHM-GG

4.2.1 Modified asphalt rubber binder

The modified asphalt rubber cement consisted of 78 percent AR-4000 (Shell), 2 percent extender oil, and 20 percent crumb rubber. The crumb rubber was blended (using the wet process) into the asphalt cement at the plant. An extender was used to aid in the curing process. Caltrans requires a certain amount of natural rubber in asphalt rubber mixes. Two types of rubber were blended to meet this requirement: ground tire rubber and a mix of ground tire rubber and natural rubber. The final crumb rubber mix used consisted of 75 percent tire rubber and 25 percent natural rubber. The asphalt rubber binder was prepared off site by Sylvia Construction Co. and trucked to the production facility in Richmond.

The optimum binder content range for the ARHM-GG mix for the Caltrans mix design was 7.6 to 7.9 percent. The specific gravity of the binder was 1.04. The PG classification for the asphalt rubber binder as determined by Caltrans TransLab is PG 82-28, as shown in Appendix B.

4.2.2 Aggregate

The aggregate met the Caltrans Standard Special Provisions for 12.5-mm (1/2-inch) nominal maximum size Type 2, gap graded. The grading is presented in Table 15. The aggregates were obtained from various sources including Point Richmond Quarry, Lone Star Clayton, and Tidewater sand and combined as shown in Table 16. The average preliminary maximum theoretical specific gravity for the ARHM-GG aggregate mix is

2.387. The specific gravities using the Caltrans (ASTM D2041) tests (CTM method 208 and 206) were as follows:

Specific gravity of ARHM-GG fines (CTM 208)	=	2.76
Specific gravity of ARHM-GG coarse (CTM 206)	=	2.62
Average specific gravity of ARHM-GG aggregate mix	=	2.66

Table 15 Aggregate grading for ARHM-GG

Sieve Size (Metric)	Sieve Size (US)	Specification Range	Mix Design
19	3/4 in.	100	100
12.5	1/2 in.	90 - 100	98
9.5	3/8 in.	80 - 90	85
4.75	No. 4	28 - 38	33
2.36	No. 8	18 - 26	22
1.18	No. 16	----	8
0.6	No. 30	6 - 14	10
0.3	No. 50	----	6
0.15	No. 100	----	4
0.075	No. 200	3 - 7	3

Table 16 Combination of aggregate from various bins for ARHM-GG

Aggregate Source	Bin	Mass Percentage
Tidewater	coarse sand	8.0
Pt. Richmond Quarry	7/16 inch	53.0
Lone Star Clayton	1/4 inch dust	23.0
Pt. Richmond Quarry	5/8 inch	16.0

4.3 Preliminary Theoretical Maximum Specific Gravity Versus More Recent Measurements

The preliminary Theoretical Maximum Specific Gravities for the DGAC and ARHM-GG mixes were measured on samples taken during construction of Goal 3 on March 26, 1997. The measurements followed ASTM D 2041 using the large-size plastic pycnometer equipment.

At later dates after construction – August 1998, for the DGAC mix and February 1999 for the ARHM-GG mix – additional measurements of G_{mm} were made on field mix that had been kept at a constant 20°C since construction. G_{mm} measurements were performed for every box (approximately 50 kg) sampled during construction, as summarized in Table 17. The measurements followed ASTM D 2041 using the weighing in water equipment.

Table 17 Second Set of Rice Measurements

Material	**Preliminary Average G_{mm}**	**Average G_{mm} Tested in 1998-99**	**Range**	**Difference (percent)**
DGAC	2.495 (4/26/97)	2.543 (8/10/98 on)	2.551-2.556	1.9
ARHM-GG	2.387 (4/26/97)	2.450 (2/9/99 on)	2.475-2.472	2.6

The Table 17 results indicate that the G_{mm} measurements are fairly robust, even on mix tested more than a year after construction. The values measured on each box in 1998-99 are varied by less than 0.2 percent for the ARHM-GG and less than 0.1 percent for the DGAC.

4.4 Relative Compaction and Air Voids from Mix Design

CAL/APT reports have strongly recommended that Caltrans stop specifying asphalt concrete compaction relative to Laboratory Test Maximum Density (LTMD). CAL/APT reports have instead recommended that Caltrans specify compaction in terms of Maximum Theoretical Density (MTD), or Theoretical Maximum Specific Gravity (G_{mm}) as determined from a test such as ASTM D 2041 (Rice Method) or its AASHTO equivalent (*3-6, 11*). MTD is the density of the mix with zero air-voids. G_{mm} is the MTD divided by the density of water at a standard temperature and pressure. LTMD is the density of the mix at the optimum bitumen content selected in the design. LTMD therefore varies depending on how the optimum bitumen content is selected.

In the Caltrans method for selecting the optimum bitumen content, three criteria are used:

- Minimum air-void content of 4 percent under standard laboratory kneading compaction,
- Minimum Hveem stabilometer value, 37 for Type A dense graded asphalt concrete, and 23 for the ARHM-GG, and
- The presence of "flushing" in the broken mix design specimens, determined by observation.

The concern with use of LTMD as the compaction reference is that it can permit very large air-void contents in construction. The mix designs for the Goal 3 overlays illustrate this problem.

Under standard laboratory kneading compaction, both air-void content and stability decrease with increased asphalt content. The Caltrans mix design procedure

(CTM 367) has several criteria for selecting LTMD. The largest value that can be used for LTMD occurs when optimum bitumen content is selected on the criterion of when the mix has 4 percent air-voids under the standard laboratory compaction effort. Under this criterion, LTMD is equal to $0.96 \times \gamma_{max}$, where γ_{max} is the maximum theoretical density. The approximation is due to the amount of absorption of asphalt into the aggregate, which is accounted for directly in ASTM D 2041, but not in the Caltrans method of measuring maximum density.

The optimum bitumen content of 7.9 percent for the ARHM-GG overlay was selected based on the 4 percent air-voids criterion (Appendix B). The ARHM-GG stabilometer values and air-void contents under laboratory compaction are shown in Figure 2.

It can be seen that the optimum binder content would have been slightly larger if the minimum Hveem stabilometer value of 23 were critical for this mix. The corresponding permissible air-void contents for various field construction compaction levels relative to LTMD for the ARHM-GG are shown in Table 17. It can be seen that 95 percent relative compaction, which is a typical specification used by Caltrans, permits air-void contents of 8.8 percent. A relative compaction of 96 percent, the target in typical QC/QA specifications used by Caltrans, permits an air-void content of 7.8.

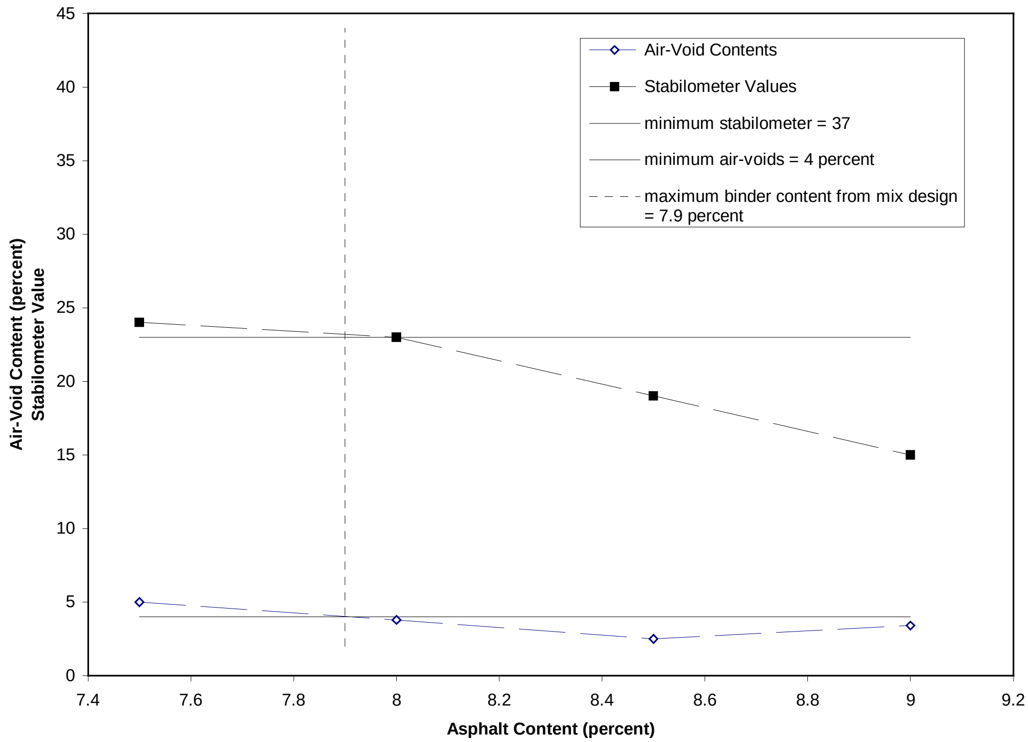

Figure 2. Stabilometer and air-void content versus asphalt content, Goal 3 ARHM-GG mix design.

Table 18 Maximum air-void contents for Goal 3 overlay mix designs and various levels of compaction relative to Laboratory Test Maximum Density (LTMD).

Mix	Mix Design Air-Voids at LTMD	Required Field Air-Voids for Compaction Relative to LTMD			
		95 percent	96 percent	97 percent	98 percent
ARHM-GG	4.0	8.8	7.8	6.9	5.9
DGAC	5.5	10.2	9.3	8.3	7.4

When optimum bitumen content is selected based on the Hveem stabilometer or flushing criteria, LTMD is approximately equal to [1-(percent air voids/100)] × γ_{max}. When compaction is specified relative to LTMD, the allowable air-void content is greater in these cases even though the relative compaction specification is the same. The optimum bitumen content of 5.3 percent for the DGAC overlay was selected based on the flushing criterion. The DGAC stabilometer values and air-void contents under laboratory compaction are shown in Figure 3. It can be seen that the optimum bitumen content would have been 5.9 percent if the flushing criterion were not included in the mix design procedure. The Hveem stabilometer values are all greater than the minimum of 37.

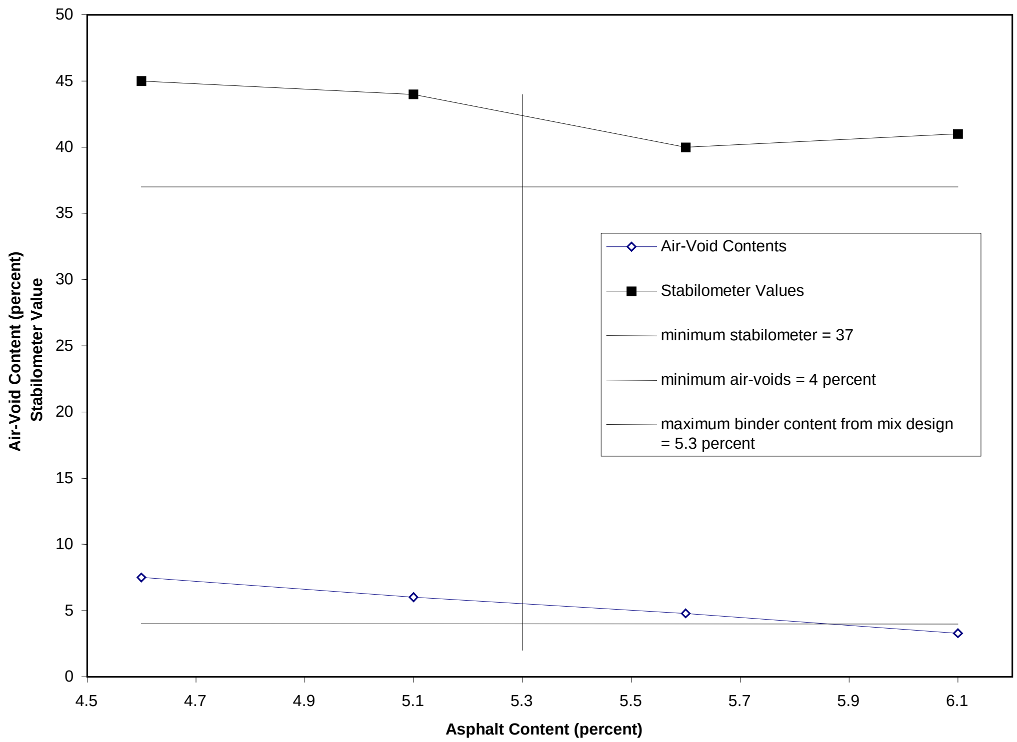

Figure 3. Stabilometer and air-void content versus asphalt content, Goal 3 DGAC Mix Design.

The corresponding permissible air-void contents for various field construction compaction levels relative to LTMD are shown for the DGAC overlay in Table 18. As shown in the table, 95 percent relative compaction permits air-void contents of 10.2 percent, and 96 percent relative compaction permits air-void contents of 9.3 percent. The result is that the flushing criterion for the DGAC mix resulted in permissible air-void contents that are 1.4 to 1.5 percent greater than the laboratory compaction air-void content criterion.

The use of LTMD as the reference for field compaction specifications results in greater air-void contents if the criterion used to select optimum bitumen content is not the laboratory compaction air-voids content. Even when the laboratory compaction air-voids content is used, the resulting 7.8 to 8.8 percent field construction air-void contents required by typical Caltrans specifications are larger than those typically permitted by some neighboring state DOTs, as shown in Table 19. Most of the state DOTs surveyed in 1999 apply heavy penalties to contractors exceeding the compaction specification. Arizona applies bonuses for better compaction provided air-void contents do not go below five percent.

The result of increased air-void contents is reduced pavement fatigue life, and increased life cycle cost (*11*, *14*). There is reduced risk of rutting of the asphalt concrete from smaller air-void contents in addition to the fatigue cracking benefits, provided that construction air-void contents do not go below about 3 to 4 percent.

Table 19 Typical asphalt concrete compaction requirements and results

State DOT	Typical Field Compaction Specification (relative to MTD*)	Resulting Maximum Allowable Air-Void Content	Typical Air-Void Contents Obtained in the Field
Arizona DOT[1]	93 percent	7 percent	5 percent
Nevada DOT[2]	92 percent	8 percent	7 to 8 percent
Oregon DOT[3]	91 percent (other than freeways) to 92 percent (freeways)	9 percent (other than freeways) 8 percent (freeways)	8 percent (other than freeways) 7 percent (freeways)
Utah DOT[4]	93 percent	7 percent	6 to 7 percent**
Washington State DOT[5]	91 percent	9 percent	6 to 10 percent, about 7 percent average

Information gathered from interviews with DOT staff:
[1] George Way 19/Nov/98;
[2] Dean Weitzel 10/Jun/99;
[3] Mike Remily 9/Jun/99;
[4] Steve Niederhauser 9/Jun/99;
[5] Jeff Uhlmeyer 10/June/99)
*Note: All of the state DOTs interviewed use MTD measured using ASTM D 2041, AASHTO T 209, or state equivalent as the basis for field compaction specifications, except Arizona which uses Marshall specimens for field control and measures MTD in the laboratory.
**Note: All Utah DOT mixes meet Superpave requirements.

5.0 CONSTRUCTION

Ghilotti Brothers of San Rafael, who had also constructed the Goal 1 sections, constructed the overlays. The overlay mixes were prepared at the new, computer-controlled volume batch drum plant operated by Five-Star Asphalt in Richmond, California.

5.1 Preparation of Site

The layout of the construction and test sections is included in Appendix C. Prior to construction of the overlays, residual tire rubber deposits from HVS trafficking of the original sections (500RF, 501RF, 502CT and 503RF) were removed by sandblasting. Immediately before construction the test site was swept by hand and then cleaned with compressed air. A tack coat consisting of SS-1 emulsion diluted with water was sprayed over the sections. The tack coat was applied using a truck-mounted spray bar in one application at a rate of 0.226 liters per square meter of surface covered.

5.2 Paving

The DGAC overlay was placed on the east side of the test section, and the ARHM-GG on the west side. Paving was carried out in 4-meter-wide sections (half the width of the test site). Both the overlays were constructed in one lift. Because the ARHM-GG is gap graded, it tends to cool quickly. As a result, all loads of ARHM-GG were covered in an attempt to maintain the temperature. The effect of the more rapid cooling is illustrated by the compaction temperatures for ARHM-GG shown in Table 20. The difference in temperatures between the 37-mm and 60-mm ARHM-GG sections is particularly large. The difference in temperatures and air-void contents between the 60- and 75-mm thick DGAC sections is also large.

Table 20 Average compaction temperatures (standard deviations)

Material	Before Breakdown	After Breakdown	
		Thin (37 mm)	**Thick (60 mm)**
ARHM-GG	223°F (32)	150°F (20)	191°F (14)
		Thin (60 mm)	**Thick (75 mm)**
DGAC	320°F (31)	269°F (23)	310°F (11)

The overlays of like material were oriented end to end, enabling the contractor to place and compact each material in one operation. Therefore, the differences in temperatures and air-void contents are solely attributable to the greater heat retention of the thicker lift.

Different trucks were used to haul ARHM-GG than were used to haul DGAC because ARHM-GG tends to adhere to the dump truck beds and could have contaminated the DGAC.

5.3 Compaction

The overlays were compacted following the Caltrans method specification. This approach lists (Appendix D) all available rollers (makes and sizes) and the number of passes required to achieve satisfactory compaction. Although a method specification does not require a specified density, the aim for the overlay test sections was to reproduce field conditions that typically result in air-void contents of 8 to 10 percent. For the Goal 3 overlay construction, a medium sized vibratory roller (Caterpillar CB-534) was used. The first two passes applied vibratory mode (frequency 2500 Hz, amplitude 0.031, and speed 2.5 mph) while the remaining pass used static mode for compaction. A nuclear density gauge (Caltrans Test Method 375) was used to measure densities for project records. The aim was to obtain a more typical air-void content than was obtained in Goal 1, as explained in Section 2.1. Compaction of the DGAC overlay was stopped after two passes because nuclear gauge densities taken after each pass indicated that the desired compaction had already been exceeded.

Sand was applied to the ARHM-GG after completion of compaction and the mix had cooled off. This is done in the field to reduce adhesion of the ARHM-GG to tires. The sand was swept off the section one day after construction.

6.0 CONSTRUCTION TEST RESULTS

Construction inspection, sample collection, and quality assurance were performed by the University of California Pavement Research Center, Contra Costa County (CCCo), and Caltrans District 4 staff.

6.1 Layer Thicknesses

The design pavement thicknesses were 75 mm for the DGAC and 38 and 60 mm for the ARHM-GG. Transition zones were constructed to allow the sampling of fatigue beams as described in Section 3.1 and shown in Appendix C.

It should be noted that the layer thicknesses vary within the transition zones. This is relevant to the permanent deformation study, which was carried out in the transition zone. Detailed layer thicknesses were not available for this report and will be reported with results of HVS tests in later reports.

6.2 Air-Void Contents

Nuclear gauge readings were taken at completion of compaction (Appendix F) and summarized in Table 21 with corresponding air-void contents calculated using the preliminary MTD values.

Air-void contents were also determined in the laboratory from extensive coring performed in the rutting test sections in 1999, and using the final MTD values developed in 1998 and 1999 (Table 22). The results of these tests are presented in Appendix G.

Table 21 Summary of air-void contents from nuclear density gage

Material	Nominal Thickness (mm)	Average Air Voids (percent)	Standard Deviation (percent)
DGAC Overlay	37 60	NA [1] 8.9	NA [1] 1.5
ARHM-GG Overlay	60 75	7.8 6.3	0.6 1.1

[1] The nuclear gage was not used on the 37-mm portions of the ARHM-GG overlay because it was too thin.

Table 22 Summary of air-void contents determined from rutting section cores before trafficking

Material	Thickness (mm)	Air-Void Content (percent)	
		Average Mean	Standard Deviation
ARHM-GG	37 60	16.6 11.2	2.1 1.4
DGAC	60 75	6.3 4.7	1.2 1.1

The air-void contents show that lift thickness has a profound effect on compaction results because of the cooling rate. This suggests that the method specification can have very different results depending on lift thickness and ambient temperature conditions, with thicker lifts and higher ambient temperatures providing greater opportunity for good compaction. These results also indicate that the ARHM-GG and DGAC overlays have very different air-void contents, which must be considered when calculating their relative performance under HVS loading and in the laboratory.

6.3 Asphalt Extraction from Field Mix

Caltrans TransLab tested field samples for asphalt content and gradation. The results are shown in Tables 23 and 24. The average asphalt content of the extracted DGAC samples is 5.2 percent, which falls within the design range of 5.0-5.3 percent.

The average asphalt content of the extracted ARHM-GG samples is 6.9 percent, which is significantly lower than the mix design asphalt content of 7.6 to 7.9 percent. The ARHM-GG air-void contents may have been affected by the low binder content and the rapid heat loss noted in Section 6.2 of this report.

The mix design aggregate gradations, contract compliance ranges determined following Caltrans standard specifications, and results of extractions from belt samples taken at the plant are also shown in Tables 23 and 24. Both mix design gradations were within Caltrans specifications for target limits. The average extracted gradations are within specification, except for the 9.5-mm sieve of the DGAC gradation, which is slightly out of specification on the fine side. The DGAC gradation was finer than the mix design, particularly for the smaller sieves.

Table 23 Summary of extracted gradation and binder content for nine samples of DGAC overlay mix

Percent Passing Sieve Size (mm)	Mix Design	Permissible Operating Range **	Extracted (average)	Extracted (Standard Deviation)
19	100	90-100	99.8	0.6
12.5	93		95.2	1.9
9.5	73	60-75	76.4	2.6
4.75	50	45-55	52.3	2.0
2.36	39	34-44	36.6	1.5
1.18	27		27.4	1.1
0.60	18	13-23	22.3	1.0
0.30	11		17.2	0.7
0.15	5		9.3	0.5
0.075	3	3-7	6.8	0.3
Binder Content* (%)	5.0 - 5.3		5.2	0.1

* Percent by mass of aggregate
** Per Section 39 Caltrans Standard Specifications

Table 24 Summary of extracted gradation, binder content and rubber content for three samples of ARHM-GG mix

Percent Passing Sieve Size (mm)	Mix Design	Permissible Operating Range ***	Extracted (average)	Extracted (Standard Deviation)
19	100	100	100.0	
12.5	98	90-100	97.3	1.2
9.5	86	81-91	84.4	2.6
4.75	33	28-38	34.0	2.5
2.36	22	18-26	22.7	1.8
1.18	16		16.7	1.4
0.60	11	7-15	12.7	1.2
0.30	7		9.2	0.9
0.15	5		6.1	0.8
0.075	4	3-7	4.6	0.6
Binder Content* (Percent)	7.6-7.9		6.9	0.5
Rubber Content** (Percent)	21		15.9	3.3

* Percent by mass of aggregate
** Percent by mass of binder
*** Per applicable Caltrans Special Provisions

7.0 DEFLECTIONS AND BACK-CALCULATED MODULI

Deflection tests using a Dynatest 8081 Heavy Weight Deflectometer (HWD) were performed before and after construction of the overlays. Four rows designated A, B, D and E were tested using a 10-ft. spacing. Rows A and B were positioned on the ARHM-GG sections and rows D and E on the DGAC overlay sections. Row C is the center line between the overlays, which cannot be tested due to the thickness difference at the interface between the two different overlays. The results were normalized to a 9,000-lb. load. Table 25 shows average deflections before and after construction of the overlays. This data is also plotted in Figures 4, 5, and 6.

It is of interest to note in Table 25 that deflections generally increased between 01/29/97 and 03/28/97 in spite of the fact that structural thickness increased. This increase is due to temperature effects. Pavement surface and air temperatures measured during FWD testing on 01/29/97 were on the order of 18°C (65°F) to 13°C (55°F) respectively, while these temperatures were 29°C (85°F) to 24°C (75°F) on 03/28/97; and 27°C (81°F) to 23°C (73°F) on 04/21/97. This again illustrates the need for recognizing the effect of temperature when evaluating deflections, as discussed in Section 3.

The test data gathered by the HWD were analyzed by Dynatest using the ELMOD (*15*) program to calculate elastic moduli for the different layers in the pavement structure. The average stiffness moduli backcalculated for the various pavement layers are summarized in Table 26. In this analysis, the various asphalt concrete layers were combined into one layer, while the base and subbase were combined into a second layer. The pavement structure was therefore simplified into three layers consisting of an asphalt

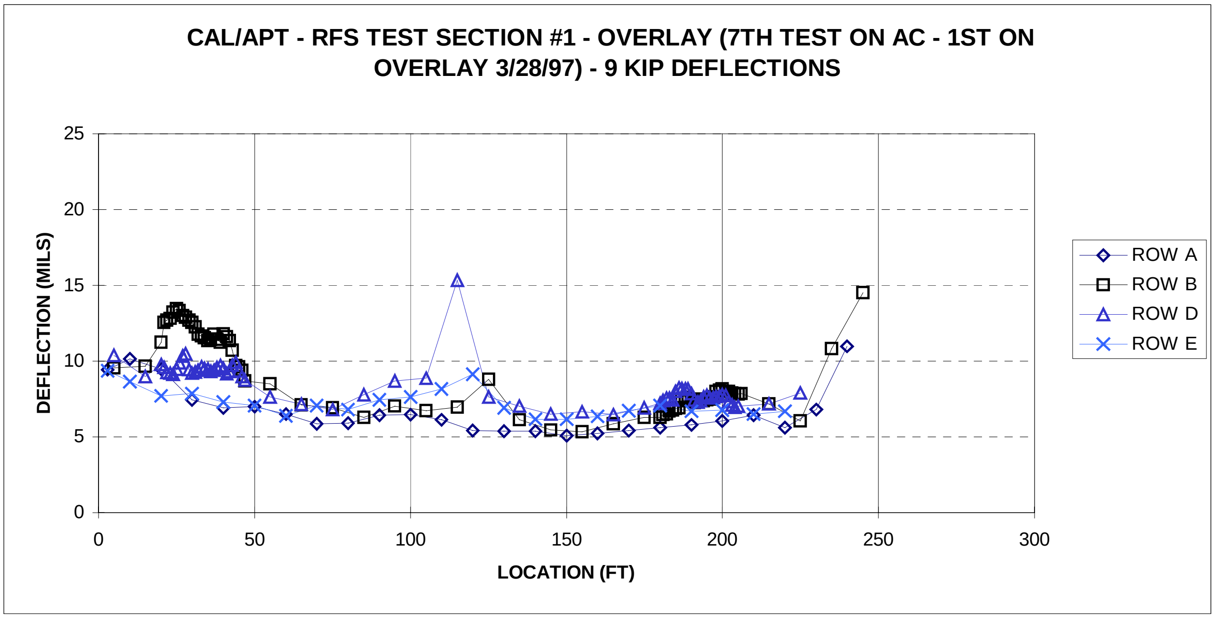

Figure 4. HWD sensor one deflections prior to overlay (Note: locations of more intense data collection on rows B and D are HVS test sections 500RF, 501RF, 502CT and 503RF).

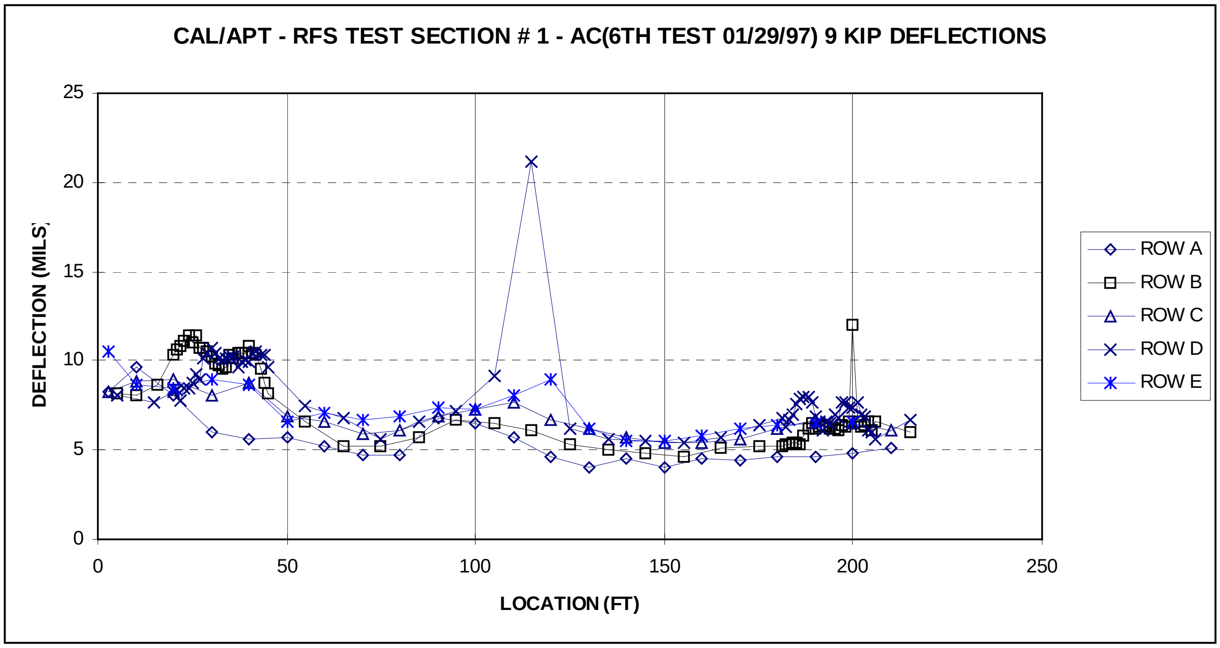

Figure 5. HWD sensor one deflections after overlay (Note: locations of more intense data collection on rows B and D are HVS test sections 500RF, 501RF, 502CT and 503RF).

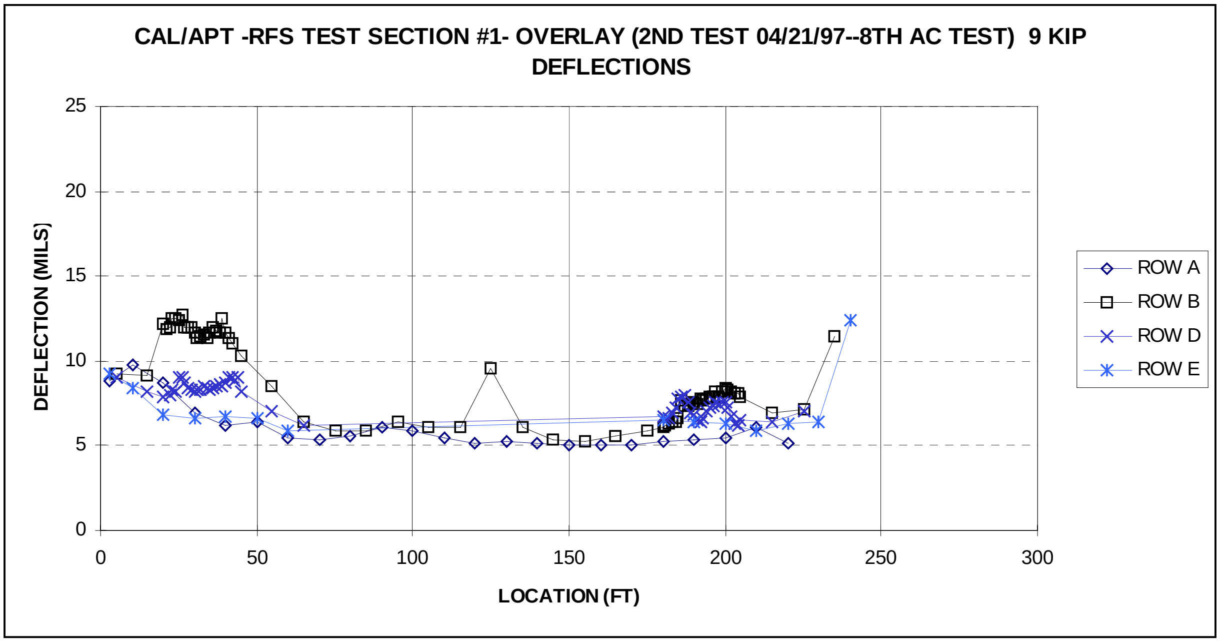

Figure 6. HWD sensor one deflections approximately one month after overlay (Note: locations of more intense data collection on rows B and D are HVS test sections 500RF, 501RF, 502CT and 503RF).

Table 25 Normalized 40-kN (9,000-lb.) deflections

Section	Date	Average	Standard Deviation	84th Percentile	n
500RF/ 514RF	01/29/97	178.9	15.3	194.86	25
	03/28/97	193.2	9.02	203.2	25
	04/21/97	179.2	13.17	193.0	25
501RF/ 517RF	01/29/97	245.9	21.45	263.9	25
	03/28/97	242.4	8.45	248.4	25
	04/21/97	216.1	8.53	228.4	25
502RF/ 515RF	01/29/97	159.9	32.51	164.7	25
	03/28/97	187.8	13.66	202.9	25
	04/21/97	190.8	18.34	207.3	25
503RF/ 518RF	01/29/97	261.6	18.97	275.8	25
	03/28/97	302.5	25.57	327.9	25
	04/21/97	299.9	13.35	314.6	25

concrete layer (AC), a granular base layer (base) and the subgrade (SG).

The measurements shown in Table 26 illustrate one of the problems associated with using deflection reduction approaches for overlay designs, particularly if temperatures are not taken into consideration. For 3 of the 4 sections, deflections after overlaying are higher than before due to higher ambient temperatures after overlaying.

Table 26 Backcalculated moduli

Layer	**Modulus (MPa) at 24°-29°C (uncorrected for temperature)**	
	Average	**Standard Deviation**
DGAC, drained	4010	896
DGAC, undrained	3271	1392
ARHM-GG, drained	5333	2500
ARHM-GG, undrained	4291	2626
base, drained	237	85
base, undrained	293	98
subgrade	145	11

8.0 CONCLUSIONS AND RECOMMENDATIONS

This report presents information regarding the design and construction of two overlays at the CAL/APT test site located at the University of California Berkeley Pavement Research Center in Richmond, California. One overlay was a conventional Dense Graded Asphalt Concrete (DGAC), and the other was Gap Graded Asphalt Rubber Hot Mix (ARHM-GG). The mix overlay designs, thicknesses and construction followed Caltrans standard specifications. The following are conclusions and recommendations developed from observations and measurements taken during the design and construction of the overlays.

8.1 Conclusions

The following conclusions are drawn from information presented in this report:

1. The overlays were designed and constructed following Caltrans standard specifications and procedures applicable to 1996-1997. Results of sampling and testing indicate that the mixes generally met Caltrans specifications. The most notable deviation from the specifications is the 6.9 percent average binder content of the ARHM-GG mix, which is below the design range of 7.6 to 7.9 percent.

2. The Caltrans method for design of overlay thicknesses was originally developed using the Benkelman Beam and Traveling Deflectograph, which are essentially interchangeable. The current method (CTM 356) converts Dynaflect deflections to deflections under the Traveling Deflectograph. Side-by-side measurements of deflections using the Dynaflect and Road Surface

Deflectometer (RSD, same as Benkelman Beam and Traveling Deflectograph) indicate that the conversion relation given in CTM 356 may not work well on some pavements. In particular, the relatively small loads applied by the Dynaflect probably do not apply much stress to underlying layers of pavements with thick asphalt concrete layers.

3. It was shown that pavement temperature has a significant effect on pavement deflections and the resulting asphalt concrete overlay thicknesses. Pavement temperature in California varies well within the range of temperatures evaluated in this report, 10°C to 30°C. By not considering pavement temperatures when designing AC overlays, considerable variation in overlay thickness must occur. These results suggest that there is large variance in the cost and performance of AC overlays of flexible pavements using California Test Method 356.

   The study included in this report evaluated the effects of pavement temperature only, and did not consider the effects of seasonal changes in the water contents of underlying layers. Measurement of pavement deflections considering changes in the water contents of unbound layers will be evaluated by CAL/APT Goal 5 on the RFS test sections.

4. The ARHM-GG overlay cooled relatively quickly due to the gap gradation and the reduced thickness of material used in the overlay. The cooling results in difficulty obtaining good compaction. The ARHM-GG showed higher air-void contents than the DGAC overlay after construction. Thin lifts tend to cool more quickly as well, and the 38-mm ARHM-GG layer had significantly

greater air void contents than did the 62-mm ARHM-GG layer. The 60- and 75-mm DGAC overlay showed a similar trend, with faster cooling and higher air-void contents in the thinner layer.

The use of Laboratory Test Maximum Density (LTMD) for compaction specification also contributes to higher air-void contents in both DGAC and ARHM-GG compared to the use of Maximum Theoretical Density (MTD) (e.g., ASTMD2041 or "Rice Method") for specifying relative compaction. As discussed in Section 4.3, and recommended in other reports to Caltrans, compaction specifications based on Maximum Theoretical Density (MTD) will provide a more consistent constructed pavement in terms of air-void contents and is therefore preferred to the current procedure. A survey of five state DOTs near California showed all of them using MTD.

5. The "flushing" criterion included in the current Caltrans mix design method (CTM 367) can result in design binder contents considerably lower than those determined by the original criteria of air-void content under standard compaction, and Hveem stabilometer value. The flushing criterion in combination with the use of LTMD for compaction specification can result in poor compaction in the field, which can have large negative impacts on fatigue life.

8.2 Recommendations

The following recommendations are based on the results presented in this report, and the conclusions drawn from them.

8.2.1 Recommendations related to overlay compaction:

- Compaction should be specified relative to the Maximum Theoretical Density (MTD) as determined by ASTM D2041 or its AASHTO/SHRP equivalent.
- The use of thicker lifts, covered trucks, and any other practices that retain heat should be encouraged whenever possible to improve compaction and reduce air-void contents. This is particularly important for ARHM-GG mixes, which cool faster than DGAC mixes due to their gap gradation.
- Compaction specified in terms of percent of Maximum Theoretical Density (ASTM D2041 or equivalent) should be checked by cores or nuclear gauge (CTM 375). The method specification for compaction should be avoided whenever possible.
- These compaction recommendations should be made applicable to both contracted work and work performed by Caltrans Maintenance forces.
- The negative and positive effects of the "flushing" criterion included in the Caltrans mix design method (CTM 367) should be seriously re-evaluated. It can have negative effects on pavement fatigue performance, resulting in increases in maintenance costs. The uniformity of its application across the state is questionable because it is a subjective evaluation of mix appearance, and its contribution towards reducing the incidence of mix rutting is not documented.

8.2.2 Recommendations regarding deflection testing and design of overlay thicknesses for flexible pavements:

- The method of converting Dynaflect deflections to Traveling Deflectometer deflections cannot be expected to provide good results. Use of deflection measuring equipment that applies loads closer in magnitude to those applied by traffic, as do the Benkelman Beam and Traveling Deflectograph, should be used with the current CTM 356. The current state-of-the-practice equipment is the Falling Weight Deflectometer (FWD), which applies loads of the magnitude required. It is recommended that Caltrans move towards replacement of the Dynaflects with FWDs. However, full use of full range of data available from the FWDs is not possible within the current Caltrans overlay design method.
- Under the currently used method for deflection testing using the Dynaflect and overlay thickness design (CTM 356), deflection measurements should be adjusted for pavement temperature. Temperature adjustments can be developed from Caltrans deflection measurement records if temperatures have been recorded, or from other data sets or analytical procedures. If implemented, CAL/APT can assist Caltrans in development of an adjustment procedure.
- Caltrans should begin preparing for use of a mechanistic-empirical overlay design procedure that will explicitly account for pavement temperatures and other variables not considered in the current procedure. A mechanistic-empirical procedure is currently being developed for Caltrans by CAL/APT

and should be delivered in about two years. Steps that can be taken in the meantime include the following:

- train pavement designers and pavement specialists in the principles of mechanistic-empirical design
- develop plans and then upgrading laboratory and field materials and pavement structure test equipment
- develop pavement structure database from existing as-built records
- develop pavement performance data through changes in pavement condition data collection and the pavement condition database that will allow calibration of empirical performance models

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8. Hannon, J., Moussavi, H., Harvey, J., Scheffy, C., Guada, I., Hung, D., Diaz, E., Long, F. Memorandum generated from meeting to discuss CAL/APT Program Goal 3 overlay designs held at the University of California, Berkeley Richmond Field Station, 7 June, 1996. Companion "Memorandum of Understanding" signed by Hannon., J., Harvey, J., Nokes., W., Monismith, C., and Stolarski, P.

9. University of California at Berkeley, Dynatest Consulting Inc., and CSIR, Division of Roads and Transport Technology, *Test Plan for CAL/APT Goal 3,* prepared for California Department of Transportation, May 1997.

10. Epps, J.A. Monismith, C.L., Equipment for Obtaining Pavement Condition and Traffic Loading Data, NCHRP Synthesis of Highway Practice 126, TRB, Washington DC, 1986.

11. Harvey, J., J. Deacon, B. Tsai, and C. Monismith, *Fatigue Performance of Asphalt Concrete Mixes and Its Relationship to Asphalt Concrete Pavement Performance in California*, CAL/APT Program, Institute of Transportation Studies, University of California, Berkeley, January 1996, 189 pp.

12. California Department of Transportation. Standard Specifications. Sacramento, July, 1995.

13. Harvey, J., L. du Plessis, F. Long, S. Shatnawi, C. Scheffy, B. Tsai, I, Guada, D. Hung, N. Coetzee, M. Reimer, and C. L. Monismith, *Initial CAL/APT Program: Site Information, Test Pavement Construction, Pavement Materials Characterizations, Initial CAL/HVS Test Results, and Performance Estimates*, Pavement Research Center, CAL/APT Program, Institute of Transportation Studies, University of California, Berkeley, June 1996, 350 pp.

14. Cooper, D., Gillen, D., Harvey, J., Hung, D. *Assessing the Economic Benefits from the Implementation of New Pavement Technology Recommendations*, Pavement Research Center, CAL/APT Program, Institute of Transporations Studies, University of California, Berkeley, October, 1999.

15. ELMOD/ELCON Evaluation of Layer Moduli and Overlay Design User's Manual. Dynatest Engineering A/S, Denmark, March, 1990.

APPENDIX A: ARHM-GG OVERLAY THICKNESS DETERMINATION

STATE OF CALIFORNIA—BUSINESS, TRANSPORTATION AND HOUSING AGENCY GEORGE DEUKMEJIAN, Governor

DEPARTMENT OF TRANSPORTATION
DIVISION OF CONSTRUCTION
OFFICE OF TRANSPORTATION LABORATORY
5900 FOLSOM BLVD., P.O. BOX 19128
SACRAMENTO, CA 95819
(916) 739-2403

April 12, 1983

R. N. Stubstad
President and Consulting Engineer
DYNATEST CONSULTING, INC.
P.O. Box 71
Ojai, CA 93023

Dear Mr. Stubstad:

With reference to your letters of March 16 and 28, 1983, we have completed the results of a review of available correlation data indicating that a satisfactory direct correlation exists between the Falling Weight Deflectometer (FWD) and the Dynaflect converted to California Traveling Deflectometer values providing a peak force of 9,000 pounds and a base plate of 12 inches in diameter are used with the FWD. Accordingly, I have advised all District Materials Engineers that data developed with FWD under the above conditions should be considered suitable for overlay design provided that the analysis is made in accordance with California Test Method 356, as is presently required for FHWA participation in local agency projects. I would point out that the test procedure is in the process of being modified in accordance with the attached memo of June 18, 1982, to the District Directors of Transportation from G. L. Russell, Chief of the Transportation Laboratory.

I am not prepared to pass judgment on the real merits of the FWD vis-a-vis the Dynaflect or Traveling Deflectometer as a deflection measuring device or upon your method of overlay design. Caltrans has been heavily involved in pavement deflection research since 1938 when permanently installed LVDT gages were used for deflection measurement. Our method of overlay design was introduced initially in 1964 and has been the subject of continuing evaluation and modification since that time. Follow-up studies on projects designed by the procedure since the mid 1960's have clearly demonstrated that it provides satisfactory cost effective rehabilitation alternatives. We will, however, as we have in the past, continue to evaluate new testing equipment procedures and methods of analysis by maintaining an awareness of what is "buzzing through the halls and conference rooms" of the Transportation Research Board Meeting, continuing review of the literature and, if warranted, field evaluations.

RAYMOND A. FORSYTH
Acting Chief
Office of Transportation Laboratory

Attachment

State of California

Business, Transportation and Housing Agency

ATSS 497-2364

Memorandum

To : All District Directors of Transportation

Date: June 18, 1982

File :

From : DEPARTMENT OF TRANSPORTATION
Transportation Laboratory

Subject: AC Pavement Rehabilitation

Although the determination of overlay needs for rehabilitating asphalt concrete pavements is now (Watkins and Kassel memo of 10/28/80) the responsibility of the Transportation Laboratory, personnel in various District assignments (materials, planning, design, programs & budgets, etc.) occasionally use deflection data as the basis for developing estimates for planning purposes.

During the past two years, there have been some changes made in the overlay design procedures. The most significant of these are as follows:

- Use of Figure 12 of the Overlay Design Guide* has been discontinued primarily because it does not address the reflective crack problem or the condition of the existing surfacing, i.e., whether the thickness of overlay alone or the combined thickness of the existing pavement and overlay should be utilized to establish critical deflection level.

The effect of traffic (TI) on overlay design is addressed in the Tolerable Deflection Chart (Figure 11). It is not believed necessary, therefore, to vary the gravel factor with TI as is done in the design of new flexible pavement sections. Thus, Figure 14 is no longer used. A gravel equivalency value of 1.9 for new AC is appropriate for use in all overlay designs.

The Asphalt Concrete Overlay Design Manual is being revised so as to reflect these and other changes. Also, it will address the development of recycling alternatives. When the revised manual is completed, copies will be furnished to the Districts.

G. I. RUSSELL
Chief, Transportation Laboratory

JTW:EH

Attachments

cc: WHAmes, CBartell, DME's, HSchmitt, FHWA, PMason

*Asphalt Concrete Overlay Design Manual dated January, 1979.
The Figures referred to are attached for information.

State of California Business, Transportation and Housing Agency

Memorandum

To: ALL DISTRICT DIRECTORS

Date: February 28, 1992

Attention District Materials Engineers

File:

From: **DEPARTMENT OF TRANSPORTATION**
Division of New Technology, Materials and Research

Subject: **DESIGN GUIDE FOR ARHM-GG**

Attached is a Guide for your use when considering one type of asphalt concrete containing reclaimed tire rubber that is eligible for Federal funding on pavement rehabilitation projects. The Guide contains the procedure we will be using to select asphalt rubber hot mix-gap graded (ARHM-GG) design thicknesses. ARHM-GG is the only type of rubber modified pavement addressed herein because it appears to be the most promising of those we have studied. The use of ARHM-GG as set forth in this Guide should be considered non-experimental. ARHM-GG pavement designs that do not conform to this Guide should, therefore, be considered as experimental. Other types of asphalt concrete containing reclaimed tire rubber are also eligible for Federal funding. However, the data currently available regarding these other mixes is inconclusive. When data supports their routine use, a design guide will be developed for them.

FHWA has approved our proposal to use this Guide. However, it is important to note that this is an Interim Guide and that it will be modified as suggested by the results of current and future research by Caltrans and others. We must, therefore, continue to construct experimental sections based on equivalences other than those implied by this Interim Guide. If you have any questions regarding the use of this Guide, contact Joe Hannon or Jack Van Kirk of my staff at 8-497-2353 and 8-497-2357 respectively.

The attached specifications should be used for ARHM-GG. If you have any questions regarding these specifications, please contact Jack.

EARL SHIRLEY, Chief,
Division of New Technology,
Materials and Research

Attachments

cc: JBednar - FHWA
JMassucco - FHWA
BManning - LSR
DMayer - OE
KMori - OPPD
TBressette
JHannon
JVanKirk

March 1992

Asphalt Rubber Hot Mix-Gap Graded
Thickness Determination Guide
(Interim)

Procedure:

1. Determine the thickness of conventional DGAC required for the structural needs of the pavement (based on deflections and structural section stiffening using current Caltrans procedures).

2. Determine the thickness of conventional DGAC required to retard reflection cracking (using current Caltrans procedure).

3. Select a DGAC overlay thickness that satisfies the requirements of 1 and 2 above.

4. Use either Table 1 or Table 2 to determine the ARHM-GG equivalent sections, with and/or without SAMIs. Use Table 1 if structural needs control and Table 2 if reflection crack retardation controls.

5. If the ride score of the pavement to be rehabilitated is greater than the allowable maximum and there is no structural need per 1 above, select one of the following:

   a) Place two 0.10' thick lifts of ARHM-GG or

   b) Cold plane to a depth of 0.10', then place ARHM-GG as determined per Steps 1 thru 4 above.

Table 1
Structural Equivalencies

THICKNESS (ft.)

DGAC	ARHM-GG[1]	ARHM-GG on a SAMI
0.15	0.10[2]	-
0.20	0.10	-
0.25	0.15	0.10
0.30	0.15	0.10
0.35	0.20	0.15
0.40	0.20	0.15
0.45	0.15[3]	0.20
0.50	0.15[4]	0.20
0.55	0.20[3]	0.15[3]
0.60	0.20[4]	0.15[4]

Notes:

1. The maximum allowable non-experimental equivalency for ARHM-GG is 2:1.
2. The minimum allowable ARHM-GG lift thickness is 0.10'.
3. Place 0.15' of new DGAC first.
4. Place 0.20' of new DGAC first.
5. ARHM-GG may not prevent cold weather induced transverse cracks.

Table 2
Reflection Crack Retardation Equivalencies

THICKNESS (ft.)

DGAC	ARHM-GG	ARHM-GG on a SAMI
0.15	0.10[1]	-
0.20	0.10	-
0.25	0.15	-
0.30	0.15	-
0.35[2]	0.15 or 0.20[3]	0.10[4]

Notes:

1. The minimum allowable ARHM-GG lift thickness is 0.10'.
2. A DGAC thickness of 0.35' is the maximum thickness recommended by Caltrans for reflection crack retardation.
3. Use 0.15 if the crack width is <1/8" and 0.20 if the crack width is ≥1/8".
4. Use if the crack width is ≥1/8". If <1/8", use another strategy.
5. ARHM-GG may not prevent cold weather induced transverse cracks.

APPENDIX B: MATERIALS TESTING DATA

Date: December 2, 1996

State of California
Department of Transportation
Materials Laboratory

Subject: CAL/APT Goal 3 HVS Study Test Job, University of California

Source: Bauman Landscape, Five Star Asphalt Plant, Richmond CA

Gentlemen,

Bauman Landscape Inc., Five Star Asphalt proposes to supply 3/4" max coarse type "A" asphaltic concrete to the above referenced project. The aggregate source will be the Point Richmond Quarry and Tidewater sand. The asphalt oil will be Huntway AR-4000.

The feeder percentages and "X" values are as follows:

Feeder one =	12%	coarse sand (Tidewater)
Feeder two =	0 %	fine sand (Tidewater)
Feeder three =	13%	7/16" x 3/16" (Pt. Rich. Quarry)
Feeder four =	40%	3/16" x 0" (Pt. Rich. Quarry)
Feeder five =	0%	3/16" x 0" (Pt. Rich. Quarry)
Feeder Six =	35%	5/8" x 7/16" (Pt. Rich. Quarry)

"x" Values =	#4	50
	#8	36
	#30	18

If you have any questions, please contact Tim Pinelli Quality Control Manager at 510-236-1212

Sincerley,

Tim Pinelli

Tim Pinelli

STATE OF CALIFORNIA - DEPARTMENT OF TRANSPORTATION
FACSIMILE COVER
MR-1009 (Rev 7/92)

Caltrans

Attention: John Harvey	From: DISTRICT 4 LABORATORY, 325 SAN BRUNO AVENUE, SAN FRANCISCO, CA 94103
Unit / Company: U.C. Berkeley	Sender's Name: LES TOKUSHIGE
	Date: 12/16/96
	Total Pages (including cover sheet): 5
District / City:	FAX # (area code): (415) 557-0140
	ATSS FAX #:
	Phone # (area code): (415) 557-1370
	ATSS #:
Phone # (area code): (510) 231-9589	FAX # (area code):
Disposition of Original: ☐ DESTROY ☐ RETURN ☐ CALL FOR PICKUP	

COMMENT

RE: DIST 04 MATLS LAB 3/4" CSE, TYPE A DESIGN MIX.

DIST 04 MATLS LAB PAGE 01

TEST NO. 500-603

DATE RECEIVED DEC 0 5 1996
CALC. ____ APPROV. ____
DATE REPORTED DEC 1 6 1996

☐ DISTRICT ENGINEER ☐ M & R DEPT.
☐ DIST. MAT'LS. ENGINEER ☐ PAYMENT
☐ RESIDENT ENGINEER ☐ ACCOUNTING
☐ CONSTRUCTION DEPT. ☐

REPORT OF TESTS ON

Drier Drum A.C Aggregate

IF CONTRACT, USE CONTRACT ITEM

SOURCE	CHARGE	EXPENDITURE AUTHORIZATION

SPECIAL DESIGNATION (USE WHEN APPLICABLE)	ACTIVITY OR OBJECT	AMOUNT

Test		Test	
☒	310 202.2, EXT. & GRADE	☒	308 SP. GR.
☐	217 S.E.	☒	305 SWELL
☐	302 FILM STRIP	☒	206 SE; ~~311 MOIST.~~
☒	304.1 STAB. (CONTROL)	☒	208 SE; 303 CK.E
☒	304.2 STAB. (DESIGN)	☒	205 crushed part.
☒	307 M.Y.S.	☒	204 Lart.

Sieve	AS RECEIVED	RET. CRUSHED	AS USED BY VOL.	AS USED BY WT.	SPECIF. LIMITS SOUGHT	SURFACE AREA FACTORS	SURFACE AREA
2						NOTE:	
1½						ALL SURFACE	
1					100	AREA FACTORS	
¾	100				90-100	MUST BE USED IN CALCULATIONS	
½	93						
⅜	73				60-75		
¼	–						2.0
4	50				45-55	2	1.0
8	39				31-41	4	1.6
16	27					8	2.2
30	18				13-23	14	2.5
50	11					30	3.3
100	6					60	3.6
200	5				3-7	160	8.0
BITUMEN						SURFACE AREA SQ. FT./LB.	24.2

SPECIMEN	A	B	C *	D *	E
TEMPERATURE	—	140°	—		
MOISTURE					
BIT. GRADE	—	AR	4000	—	
BIT. RATIO	4.6	5.1	5.6	6.1	
SP. GR. BRIQ.	2.33	2.35	2.36	2.38	
SPECIF.	STABILOMETER				
37	45	44	40	41	
	VOIDS				
	7.5	6.6	4.8	3.3	
SPECIF.	SWELL				
0.030"		0.005			

MOISTURE VAPOR SUSCEPT

HOURS	75			SPECIF.
MOIST. ABSORB.	0.5			
STABILOMETER	35			30
BIT. RATIO				
SP. GR. BRIQ.				

Kc = 1.1 Kf = 1.1 Km = 1.1 spec 1.7

SPECIFIC GRAVITY AGGREGATE

AS RECEIVED F 2.79 C-2.62

RET. CRUSHED F C-

ABRASION TESTS	% LOSS	SPECIF.
LOS ANGELES–100R	4	10
LOS ANGELES–500R "B"	15	45

FILM STRIPPING

CRUSHED PARTICLES

(+) 4 100 spec 90 (–) 4 100 spec 70 COMB.

SAND EQUIVALENT VALUE = 69 SPECIF. = 50

RECOMMENDED BITUMEN CONTENT 5.0-5.3

GRADING AS USED WAS OBTAINED BY COMBINING SAMPLES AS FOLLOWS

% WT.	% VOL.	TEST NO.	DESCRIPTION

REMARKS:
*Specimen "C" flushed asphalt moderately and specimen "D" flushed asphalt heavily while being compacted.

TL-101 (REV. 8-76)
STATE OF CALIFORNIA
DEPARTMENT OF TRANSPORTATION

SAMPLE IDENTIFICATION CARD NO. C[illegible]

☐ PRELIMINARY TESTS
☐ PROCESS TESTS
☐ ACCEPTANCE TESTS
INDEPENDENT ASSURANCE TESTS
☐ DIST. LAB
☐ TRANS. LAB
☐ SPECIAL TESTS

SAMPLE SENT TO
☐ HDQTRS. LAB
☐ BRANCH LAB.
☐ DIST. LAB

FIELD NO. ____
DIST. LAB NO. 500-603
LOT NO. ____
SHIPMENT NO. ____
P. O. OR REQ. NO. ____
AUTHORIZATION NO. ____

SAMPLE OF Drier Drum A.C Aggregate
FOR USE IN 3/4" max Coe A.C Type "A"
SAMPLE FROM Bauman Landscape, Five Star Asphalt plant, Richmond.
DEPTH ____
LOCATION OF SOURCE Pt Richmond & Tide Water.
THIS SAMPLE IS SHIPPED IN ____ (NO. CONTAINERS) AND IS ONE OF A GROUP OF ____ SAMPLES REPRESENTING ____ (TONS, BALS., BBLS., ETC., ETC.)
OWNER OR MANUFACTURER Bauman Landscape Inc.
TOTAL QUANTITY AVAILABLE ____ TEST RESULTS DESIRED ☒ NORMAL ☐ PRIORITY DATE NEEDED ____
REMARKS A.C mix design
AR-4000 Asphalt oil
COVER ADDITIONAL INFORMATION WITH LETTER
DATE SAMPLED –
BY – TITLE –
DIST., CO., RTE., P.M. CAL/APT Goal 3 HVS Study Test Job, U.C.
LIMITS ____
CONT. NO. –
FED. NO. –
RES. ENGR. OR SUPT. ____
ADDRESS 1353 South 46th St Richmond, CA 94804.
CONTRACTOR Bauman Landscape Inc

MAIL TO SAME DESTINATION [illegible]

E. R. SOWKO
MATERIALS ENGINEER

California Test 367
November 1984

AIR VOIDS DETERMINATION
(CALCULATION SHEET)

ASPHALT GRADE AR 4000

TEST CARD NO. 500-503

PLANT BAUMAN

BRIQUETTE 1.

STEP A: $\dfrac{100\% + \%\ \text{ASPHALT IN BRIQ. } (104.6)}{\dfrac{\%\ \text{FINES } (50)}{\text{FINE SP.GR. } (2.79)} + \dfrac{\%\ \text{COARSE } (50)}{\text{COARSE SP. GR. } (2.62)} + \dfrac{\%\ \text{ASPHALT } (4.6)}{\text{ASPHALT SP. GR. } (1.02)}} = \dfrac{X\ (104.6)}{{}^{*}Y\ (41.50)} = \text{MD } 2.52$

17.92
19.08
4.50
41.50

STEP B: $RD = \dfrac{\text{SP. GR. BRIQ. NO. 1 } (2.33)}{MD\ X\ (2.52)} = 92.5\ \%$

STEP C: V = 100 − RD (100 − 92.5) = 7.5 → % VOIDS 7.5

BRIQUETTE 2.

STEP A: $MD = \dfrac{100 + \%\ \text{ASPHALT } (105.1)}{Y + 0.49\ (41.99)} = 2.50$

STEP B: $RD = \dfrac{\text{SP. GR. BRIQ. NO. 2 } (2.35)}{MD\ (2.50)} = 94.0\ \%$

STEP C: V = 100 − RD (100 − 94.0) = 6.0 → % VOIDS 6.0

BRIQUETTE 3.

STEP A: $MD = \dfrac{100 + \%\ \text{ASPHALT } (105.6)}{Y + 0.98\ (42.48)} = 2.48$

STEP B: $RD = \dfrac{\text{SP. GR. BRIQ. NO. 3 } (2.36)}{MD\ (2.48)} = 95.2\ \%$

STEP C: V = 100 − RD (100 − 95.2) = 4.8 → % VOIDS 4.8

BRIQUETTE 4.

STEP A: $MD = \dfrac{100 + \%\ \text{ASPHALT } (106.1)}{Y + 1.47\ (42.97)} = 2.46$

STEP B: $RD = \dfrac{\text{SP. GR. BRIQ. NO. 4 } (2.38)}{MD\ (2.46)} = 96.7\ \%$

STEP C: V = 100 − RD (100 − 96.7) = 3.3 → % VOIDS 3.3

NOTE: MD = MAXIMUM THEORETICAL DENSITY
RD = RELATIVE DENSITY
V = VOIDS
SP. GR. ASPHALT = 1.02 FOR PAVING GRADES AR 1000, 2000, 4000, 3000
0.96 FOR LIQUID GRADES RC, MC, SC, 70, 250, 800
* VALUE OF "Y" INCREASES BY: 0.49 WITH EACH 0.5% OF PAVING ASPHALT
0.52 WITH EACH 0.5% OF LIQUID ASPHALT

FIGURE 1

2

TRANSPORTATION LABORATORY

ASPHALT CONCRETE MIX DESIGN

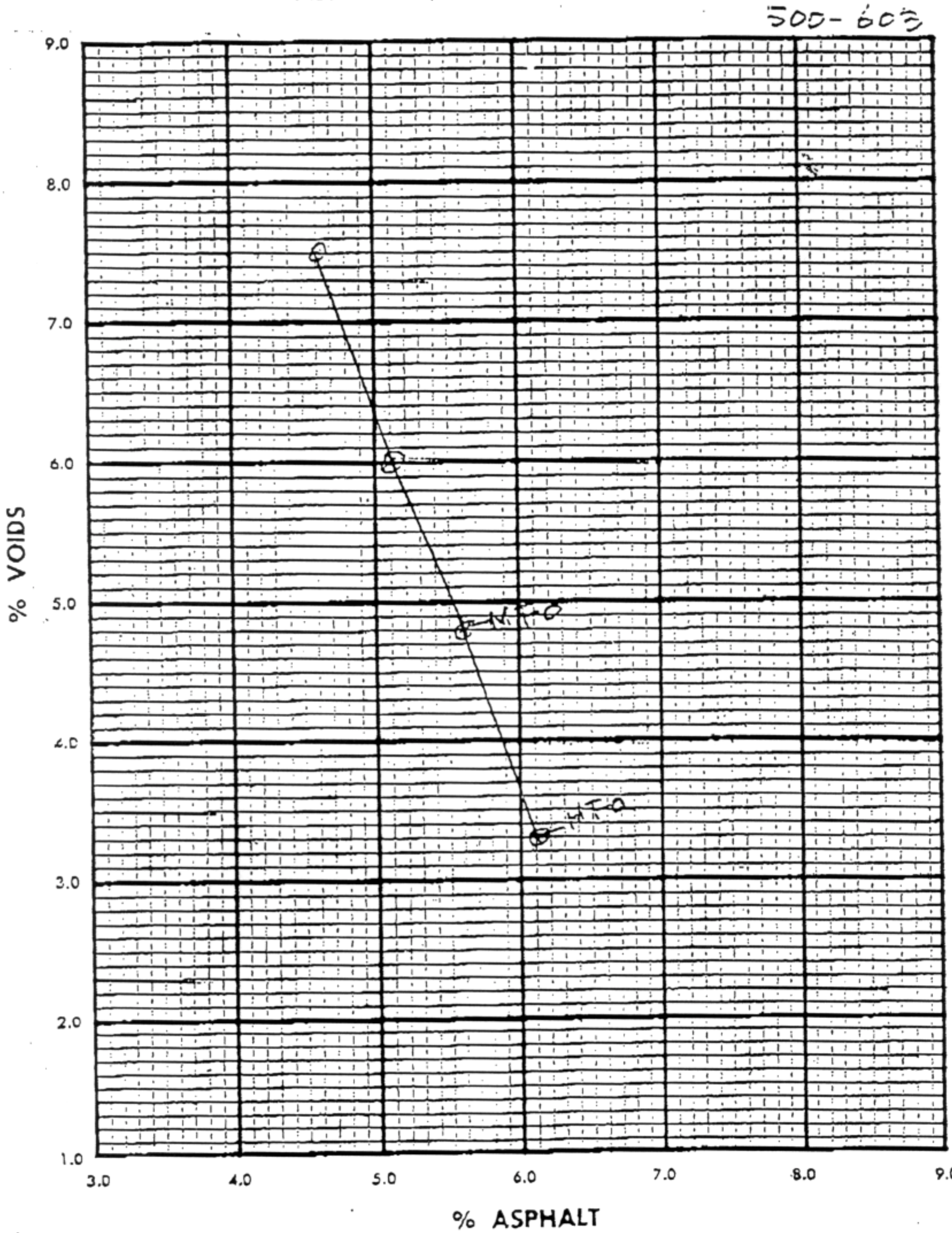


FIGURE 3

TL-306 (Rev. 4/76)

TRANSPORTATION LABORATORY
ASPHALT CONCRETE MIX DESIGN

TEST NO. 500-603

SOURCE BAUMAN - Pt Richmond

ASPHALT GRADE AR 4000

ABSORPTION Kc=1.1 Kf=1.1 Km=1.1

SURFACE AREA 24.2

SPECIFIC GRAVITY:

COARSE 2.62

FINE 2.79

AVERAGE 2.70

RECOMMENDED RANGE 5.0-5.3

STEP 4 MAX. ASPHALT CONTENT WITH 4 OR MORE % VOIDS	5.3			OBC*
STEP 3 SPECIMENS MEETING MIN. STABILITY REQUIREMENT	4.6	5.1		
STEP 2 SPECIMENS WITH NO FLUSHING	4.6	5.1		
STEP 1 DESIGN SET	4.6	5.1	5.6	6.1

RECOMMENDATION IS BASED ON THE GRADING CURVE SHOWN.

THIS IS NOT A VALID RECOMMENDATION IF THE MAXIMUM ASPHALT CONTENT USED IN THE DESIGN SET (STEP 1) IS FINALLY RECOMMENDED. IN THIS EVENT, ADDITIONAL SAMPLES MUST BE PREPARED WITH INCREASED ASPHALT CONTENT IN 0.5% INCREMENTS AND A NEW ANALYSIS MADE.

*Optimum Bitumen Content

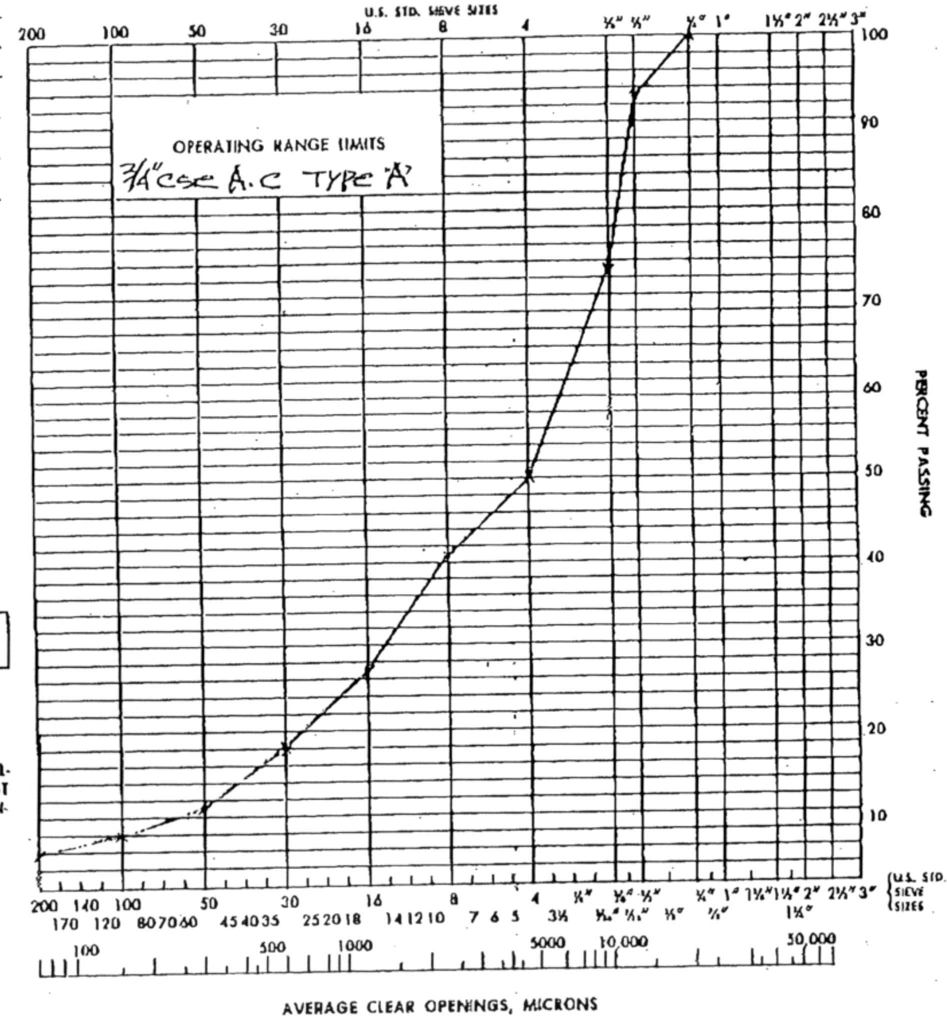


FIGURE 2

TL-3157 (Rev. 7-74)

3

F-712 T-020 P-001/005 JAN 10 '97 14:27

REED & GRAHAM LABORATORY SERVICES

550 SUNOL STREET

SAN JOSE, CALIFORNIA 95126

Phone: (408) 287-7722 Fax: (408) 294-1959

To: Tim Pinelly

From: Punya P. Khanal

Company: 5 Star Asphalts/Bauman Landscaping

Date: 1/10/97

Fax Number: (510) 215 - 4022

Phone Number: (510) 215 - 1555

Total Number of Pages Including Cover: 5

RGLS Reference Number: 5STR-1

RE: Rubberized AC mix design

Your Reference Number:

☐ URGENT ☐ FOR REVIEW ☐ Please COMMENT

☐ Please REPLY ☐ Please RECYCLE

Hard copy to follow: ☐ No ☐ Yes

Notes / Comments:

Tim:

Here is the revised mix design with binder sp. gr. = 1.04 and changed name of crumb rubber supplier. Hope, this satisfies Caltrans requirements.

Punya P.

cc: Dr. John Harvey @ UC Berkley, Fax No: (510) 231-9589

REED AND GRAHAM LABORATORY
S E R V I C E S
550 SUNOL STREET
SAN JOSE, CA 95126
TEL: (408)287-1415, FAX: (408)294-1959

CALTRANS HVEEM MIX DESIGN

Customer Name:	**BAUMAN LANDSCAPING/5 STAR ASPHALTS**
Customer Project No:	**N/A**
Reed & Graham Project No:	**5STR-1**
Mix Design performed by:	**CUONG PHO**
Date Mix Design Completed:	**1/9/97**
Mix Design Reviewed by:	**PPK/DXT**
Binder:	**RUBBERIZED ASPHALT CONCRETE**
Aggregate:	**1/2" NOMINAL MAX. SIZE**

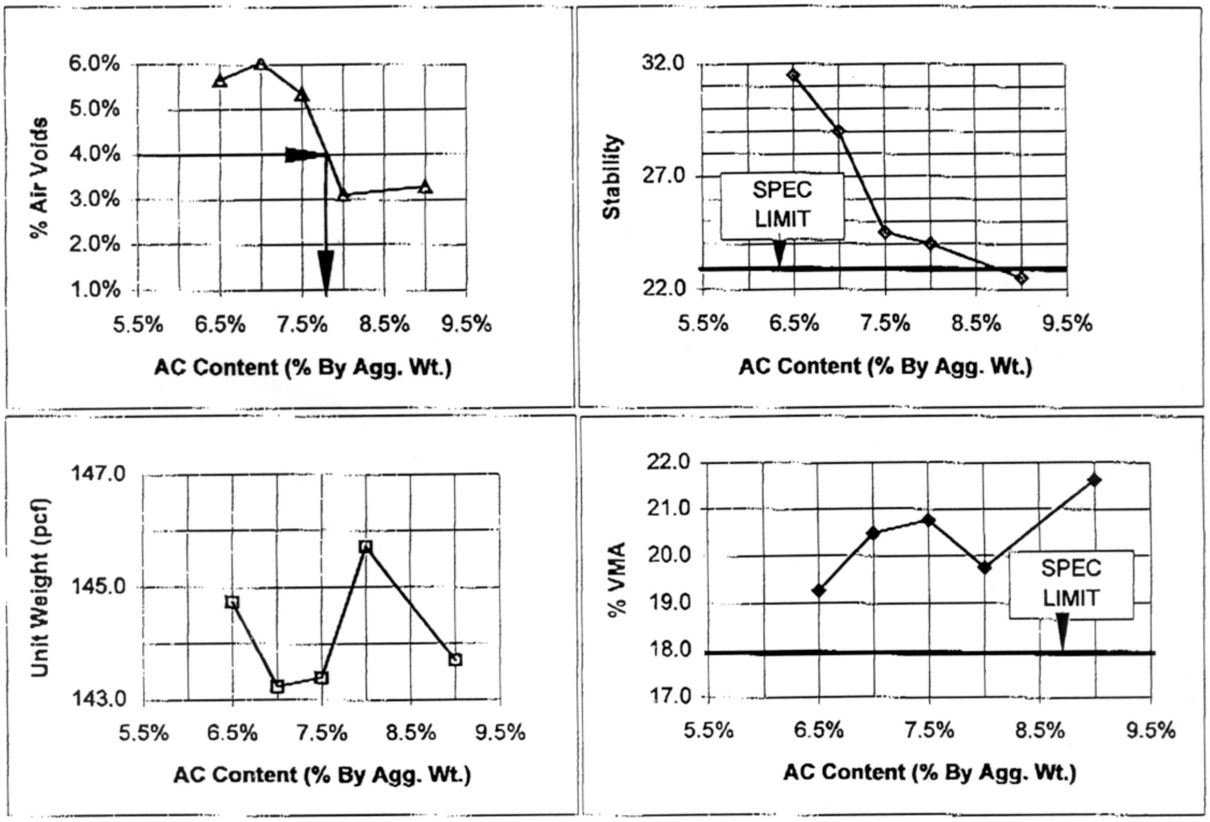
SPECIFIC GRAVITY CALCULATIONS					SIEVE SIZE	PERCENT PASSING	SPEC LIMIT
Agg. Type	% in Blend	Fine Sp. Gr. CTM 208	Coarse Sp. Gr. CTM 206	Specifc Gravity (Blend)	1"	100	100
					3/4"	97	90-100
Coarse	67.0		2.673		3/8"	85	83-87
Fine	33.0	2.749		2.698	# 4	33	33-37
					# 8	22	18-22
					#30	10	8-12
					# 200	3.0	3-7
Nominal Max. Size of Aggregate (mm) =			12.5			SE =	67
Specific Gravity of Binder, G_b =			1.04			Kc =	0.96
Binder Formulation: 76.5% SHELL AR-4000 + 2.5% WITCO CUTTER OIL + 15.75%						Kf =	1.14
10 MESH CRUMB + 5.25% HIGH NAT. RUBBER BOTH BY BAS.						Km =	1.04

Mixture ID: **5STR-1**

% AC	Sp. No.	Thkness (in)	Stability Value	Corrected Stability	Max. Dens. CT 367	G_{mb} CT 308-A	% V_a CT 367	VMA
6.5%	1	2.470	32	32	2.458	2.330	5.2	18.9
6.5%	2	2.550	31	31	2.458	2.309	6.1	19.6
Average				31.5	2.458	2.320	5.7	19.3
7.0%	3	2.550	29	29	2.443	2.300	5.8	20.3
7.0%	4	2.510	29	29	2.443	2.291	6.2	20.6
Average				29.0	2.443	2.296	6.0	20.5
7.5%	5	2.510	24	24	2.428	2.310	4.8	20.3
7.5%	6	2.560	25	25	2.428	2.286	5.8	21.2
Average				24.5	2.428	2.298	5.3	20.8
8.0%	7	2.430	23	23	2.413	2.341	3.0	19.6
8.0%	8	2.460	25	25	2.413	2.335	3.2	19.9
Average				24.0	2.410	2.335	3.1	19.8
9.0%	9	2.500	27	27	2.384	2.303	3.4	21.7
9.0%	10	2.490	19	19	2.384	2.306	3.3	21.6
Average				22.5	2.381	2.302	3.3	21.6

Reed & Graham Laboratory Services
(Caltrans Hveem Mix design for Proj. 5STR-1 contd…)

MIX 5STR001X1 (AGGREGATE GRADATION SUPPLIED BY CLIENT)



Average Values							
Mix ID	% AC	Corrected Stability	Max. Dens CT 367	$G_{mb.}$ CT 367-A	% $V_{a,}$ CT 367	Unit Weight (pcf)	% VMA MS-2
5STR-1	6.5%	31.5	2.458	2.320	5.7%	144.7	19.3
	7.0%	29.0	2.443	2.296	6.0%	143.2	20.5
	7.5%	24.5	2.428	2.298	5.3%	143.4	20.8
	8.0%	24.0	2.410	2.335	3.1%	145.7	19.8
	9.0%	22.5	2.381	2.303	3.3%	143.7	21.6

	7.8%	← AC CONTENT FOR 4% AIR VOIDS				
	7.5%	8.0%	← HIGHEST TWO ACS WITH MINIMUM STABILITY			
	7.0%	7.5%	8.0%	← HIGHEST THREE ACs WITH NO FLUSHING		
% Va:	5.7%	6.0%	5.3%	3.1%	3.3%	
% VMA:	19.3%	20.5%	20.8%	19.8%	21.6%	
Stability:	31.5	29.0	24.5	24.0	22.5	
lushing:	NO	NO	NO	NO	YES	
% AC:	6.5%	7.0%	7.5%	8.0%	9.0%	

Optimum Binder Content Pyramid

Optimum Binder Content = **7.8%**

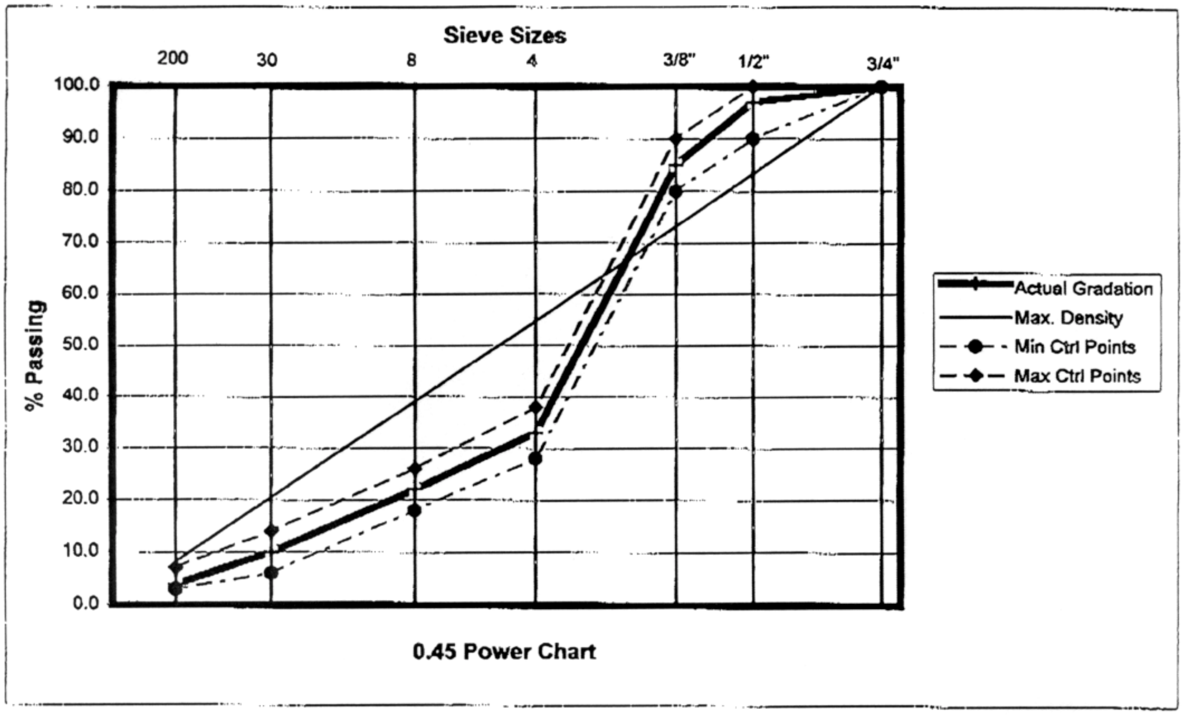
Recommended Range = **7.5 ~ 7.8%**

Estimated Corrected Stability = **24.2**

Air Void at Optimum Binder Content = **4%**

Estimated VMA at 7.8% oil content= **20.2**

Reed & Graham Laboratory Services
(Caltrans Hveem Mix design for Proj. 5STR001 contd...)



0.45 Power Chart for gradation (5STR001GR-1) used in the Mix Design

BAS Recycling, Inc.

January 6, 1997

Silvia Construction, Inc.
9007 Center Ave.
Rancho Cucamonga, CA 91730

Attn: Frank

Re: Test Strip/U.C. Berkley

CERTIFICATE OF COMPLIANCE

BAS Recycling, Inc. Certifies that the Crumb Rubber Modifier (CRM) for both the Scrap Tire CRM and the High Natural CRM was tested at the time of production and meets the gradations, and specifications as provided in specifications under the section heading CRUMB RUBBER MODIFIER (CRM).

A representative sample of Scrap Tire Crumb Rubber Modifier was tested using the protocol of ASTM Designation: 297 with the following results:

SCRAP TIRE RUBBER (CRM)
Caltrans Specification

Test Parameter	Minimum	Max	Reported
Acetone Extract	6.0	16.0	7.4
Ash Content	—	8.0	5.3
Carbon Black Content	28.0	38.0	30.1
Rubber Hydrocarbon	42.0	65.0	57.2
Natural Rubber Content	16.0	39.0	28.2

SCRAP TIRE RUBBER (CRM) - Sample gradations taken at time of production are provided with each truck load shipment of CRM to the Asphalt Rubber production site.

HIGH NATURAL RUBBER (CRM)
Caltrans Specification

Test Parameter	Minimum	Max	Reported
Acetone Extract	4.0	10.0	7.6
Rubber Hydrocarbon	50.0	—	54.5
Natural Rubber Content	40.0	—	42.0

HIGH NATURAL RUBBER (CRM) - Sample gradations taken at time of production are provided with each truck load shipment to the Asphalt Rubber production site.

1400 North H Street, San Bernardino, CA 92405 • (909) 383-7050 • Fax: (909) 383-7055

BAS Recycling, Inc.

CALTRANS SPECIFICATION
CRM GRADATIONS

Sieve Size	Scrap Tire CRM Percent Passing	High Natural CRM Percent Passing
No. 8	100	100
No. 10	98-100	100
No. 16	60-75	95-100
No. 30	2-15	35-85
No. 50	0-2	10-30
No. 100	0-1	0-4
No. 200	0	0-1

If you have any questions or comments on any of the above, please feel free to contact me at your convenience.

Sincerely,

Michael D. Harrington
Sales & Marketing Director

BAS Recycling, Inc.

SIEVE ANALYSIS

1. DATE OF SIEVING 12/17/96
2. DATE OF PRODUCTION 12/06/96
3. TYPE OF RUBBER SIL - IRW - 10 - 01 020
4. SIZE OF RUBBER HIGH NATURAL CRM
5. CONDITION OF BLADES (sharp) average dull
6. WEIGHT OF SAMPLE 105 grams
7. GRADATION OF RUBBER:

			HOLDING (grams)	PASSING
SIEVE	NO.	8		
"	"	10		
"	"	12		
"	"	16	2.9	97.1 %
"	"	20		
"	"	30	42.8	54.3 %
"	"	40		
"	"	50	35.4	18.9 %
"	"	100	16.2	2.7 %
"	"	200	3.4	0 %
"	"	PAN	4.3	

1400 North H Street, San Bernardino, CA 92405 • (909) 383-7050 • Fax: (909) 383-7055

BAS Recycling, Inc.

SIEVE ANALYSIS

1. DATE OF SIEVING 12/17/96
2. DATE OF PRODUCTION 12/06/96
3. TYPE OF RUBBER S|L-IRW-10-01 010
4. SIZE OF RUBBER # 10 MESH
5. CONDITION OF BLADES (sharp) average dull
6. WEIGHT OF SAMPLE 105 grams
7. GRADATION OF RUBBER:

			HOLDING (grams)	PASSING
SIEVE	NO.	8		
"	"	10	1.6	98.4 %
"	"	12		
"	"	16	37.9	60.5 %
"	"	20		
"	"	30	51.8	8.7 %
"	"	40		
"	"	50	8.5	0.2 %
"	"	100	0.4	0 %
"	"	200	0.7	
"	"	PAN	4.1	

1400 North H Street, San Bernardino, CA 92405 • (909) 383-7050 • Fax: (909) 383-7055

STATE OF CALIFORNIA-DEPARTMENT OF TRANSPORTATION
FACSIMILE COVER

Attention	From
John Harvey	**DISTRICT 4 LABORATORY** 325 SAN BRUNO AVENUE SAN FRANCISCO, CA 94103

Unit/Company	Sender'Name	
UC. Ext. Cal APTs	LEE TOKUSHIGE	
	Date	Total Pages (Including Cover sheet)
	01/28/97	5
Office/City	Fax # (Area Code)	[redacted] Fax #
		(415) 557.0140
	Phone # (Area Code)	ATSS #

Phone # (Area Code	Fax # (Area Code)	Disposition of Original
	(510) 2319589	0 Destroy 0 Return

COMMENT

RE: PER YOUR 1/2" Rubberized AC Mix Design Request.

TEST NO. 500-604

DATE RECEIVED JAN 1 7 1997

CALC. ______ APPROV. ______

DATE REPORTED JAN 2 7 1997

REPORT OF TESTS ON

1/2" max Rubberized A.C D.D. Aggregate

IF CONTRACT, USE CONTRACT ITEM

SOURCE	CHARGE	EXPENDITURE AUTHORIZATION

SPECIAL DESIGNATION (USE WHEN APPLICABLE)	ACTIVITY OR OBJECT	AMOUNT

- ☐ DISTRICT ENGINEER
- ☐ DIST. MAT'LS. ENGINEER
- ☐ RESIDENT ENGINEER
- ☐ CONSTRUCTION DEPT.
- ☐ M & R DEPT.
- ☐ PAYMENT
- ☐ ACCOUNTING
- ☐

Tests:

- ☒ 310 202.2 EXT. & GRADE
- ☒ 217 S.E.
- ☐ 302 FILM STRIP
- ☐ 304.1 STAB. (CONTROL)
- ☒ 304.2 STAB. (DESIGN)
- ☐ 307 M.V.S.
- ☒ 308 SP. GR.
- ☐ 305 SWELL
- ☒ 206 SSG / ~~311 MOIST.~~ / 208 SGF
- ☐ 303 CK.E
- ☒ 205 crushed part.
- ☒ 211 Lart.

Sieve	As Received	Ret. Crushed	As Used by Vol.	As Used by Wt.	Specif. / Limits Sought	Surface Area Factors	Surface Area
2						NOTE: ALL SURFACE AREA FACTORS MUST BE USED IN CALCULATIONS	
1 1/2							
1							
3/4	100						
1/2	98						
3/8	85						
1/4	—						2.0
4	33					2	
8	21					4	
16	15					8	
30	10					14	
50	6					30	
100	4					60	
200	3					160	
BITUMEN						SURFACE AREA SQ. FT./LB.	

MOISTURE VAPOR SUSCEPT

HOURS					SPECIF
MOIST. ABSORB.					
STABILOMETER					
BIT. RATIO					
SP. GR. BRIQ.					

Kc = Kf = Km =

SPECIFIC GRAVITY AGGREGATE

AS RECEIVED F 2.76 C 2.62

RET. CRUSHED F C –

ABRASION TESTS % LOSS

	% LOSS	SPECIF
LOS ANGELES – 100R		
LOS ANGELES – 500R	18	40

FILM STRIPPING

CRUSHED PARTICLES

(+) 4 100 (–) 4 100 COMB.

SAND EQUIVALENT VALUE = 70 SPECIF. = 50

RECOMMENDED BITUMEN CONTENT 7.6–7.9

GRADING AS USED WAS OBTAINED BY COMBINING SAMPLES AS FOLLOWS:

% WT.	% VOL.	TEST NO.	DESCRIPTION

SPECIMEN	A	B	C *	D **	E
TEMPERATURE					
MOISTURE					
BIT. GRADE	— Rubber Binder				
BIT. RATIO	7.5	8.0	8.5	9.0	
SP. GR. BRIQ.	2.28	2.30	2.31	2.30	

SPECIF.	STABILOMETER				
23	21	23	19	15	

	VOIDS				
	5.0	3.8	2.5	3.4	

SPECIF.	SWELL				

REMARKS: * Specimen "C" flushed binder slightly and specimen "D" flushed binder moderately.

** 4% voids controlled rubberized asphalt content recommendation

TEST NO.

ATTACH FORM TL-101 HERE

TL-101 (REV. 8-76)
STATE OF CALIFORNIA
DEPARTMENT OF TRANSPORTATION

SAMPLE IDENTIFICATION CARD NO. C [illegible]

- ☐ PRELIMINARY TESTS
- ☐ PROCESS TESTS
- ☐ ACCEPTANCE TESTS
- INDEPENDENT ASSURANCE TESTS
  - ☐ DIST. LAB
  - ☐ TRANS. LAB
- ☐ SPECIAL TESTS

SAMPLE SENT TO

- ☐ HDQTRS. LAB
- ☐ BRANCH LAB
- ☐ DIST. LAB

FIELD NO. ______

DIST. LAB NO. 500-604

LOT NO. ______

SHIPMENT NO. ______

P. O. OR REQ. NO. ______

AUTHORIZATION NO. ______

SAMPLE OF Drier Drum A.C. Aggre.

FOR USE IN 1/2" max Rubberized AC

SAMPLE FROM Bauman Landscaping, 5 ST [illegible] Asphalt

DEPTH ______

LOCATION OF SOURCE ______

THIS SAMPLE IS SHIPPED IN ______ (NO. CONTAINERS) AND IS ONE OF A GROUP OF ______ SAMPLES REPRESENTING ______ (TONS, CU. YDS., LBS., ETC.)

OWNER OR MANUFACTURER U. C. Berkeley

TOTAL QUANTITY AVAILABLE ______ TEST RESULTS DESIRED ☐ NORMAL ☒ PRIORITY DATE NEEDED 1/28/97

REMARKS Rubberized Asphalt Concrete, Design, AR 4000

COVER ADDITIONAL INFORMATION WITH LETTER

DATE SAMPLED ______

BY U ______ TITLE ______

DIST., CO., RTE., P.M. ______

LIMITS Richmond UC Berkeley Test Strip - Richmond Field Station

CONT. NO. ______

FED. NO. ______

RES. ENGR. ~~OR SUPT.~~ John Harvey

ADDRESS 1353 So. 46th St. Richmond Ca.

CONTRACTOR ______

AIR VOIDS DETERMINATION
(CALCULATION SHEET)

ASPHALT GRADE Rubber Binder

TEST CARD NO. 500- 604

PLANT BAUMAN

BRIQUETTE 1.

STEP A: $\dfrac{100\% + \%\text{ ASPHALT IN BRIQ. }(107.5)}{\dfrac{\%\text{ FINES }(33)}{\text{FINE SP.GR. }(2.76)} + \dfrac{\%\text{ COARSE }(67)}{\text{COARSE SP. GR. }(2.62)} + \dfrac{\%\text{ ASPHALT }(7.5)}{\text{ASPHALT SP. GR. }(1.04)}} = \dfrac{X\ (107.5)}{{}^{*}Y\ (44.74)} = \text{MD } \underline{2.40}$

11.96
25.57
7.21
44.74

STEP B: $RD = \dfrac{\text{SP. GR. BRIQ. NO. 1 }(2.28)}{MD\ X(2.40)} = \underline{95.0\%}$

STEP C: V = 100 − RD (100−95.0) = 5.0 → % VOIDS 5.0

BRIQUETTE 2.

STEP A: $MD = \dfrac{100 + \%\text{ ASPHALT }(108.0)}{Y + 0.49\ (45.23)} = \underline{2.39}$

STEP B: $RD = \dfrac{\text{SP. GR. BRIQ. NO. 2 }(2.30)}{MD\ (2.39)} = \underline{96.2\%}$

STEP C: V = 100 − RD (100− 96.2) = 3.8 → % VOIDS 3.8

BRIQUETTE 3.

STEP A: $MD = \dfrac{100 + \%\text{ ASPHALT }(108.5)}{Y + 0.98\ (45.72)} = \underline{2.37}$

STEP B: $RD = \dfrac{\text{SP. GR. BRIQ. NO. 3 }(2.31)}{MD\ (2.37)} = \underline{97.5\%}$

STEP C: V = 100 − RD (100−97.5) = 2.5 → % VOIDS 2.5

BRIQUETTE 4.

STEP A: $MD = \dfrac{100 + \%\text{ ASPHALT }(109.0)}{Y + 1.47\ (46.21)} = \underline{2.36}$

STEP B: $RD = \dfrac{\text{SP. GR. BRIQ. NO. 4 }(2.28)}{MD\ (2.36)} = \underline{96.6\%}$

STEP C: V = 100 − RD (100−96.6) = 3.4 → % VOIDS 3.4

NOTE: MD = MAXIMUM THEORETICAL DENSITY
RD = RELATIVE DENSITY
V = VOIDS
SP. GR. ASPHALT — 1.02 FOR PAVING GRADES AR 1000, 2000, 4000, 3000
0.96 FOR LIQUID GRADES RC, MC, SC, 70, 250, 800
* VALUE OF "Y" INCREASES BY: 0.49 WITH EACH 0.5% OF PAVING ASPHALT
0.52 WITH EACH 0.5% OF LIQUID ASPHALT

FIGURE 1

2

California Test 367
November 1984

TRANSPORTATION LABORATORY

ASPHALT CONCRETE MIX DESIGN

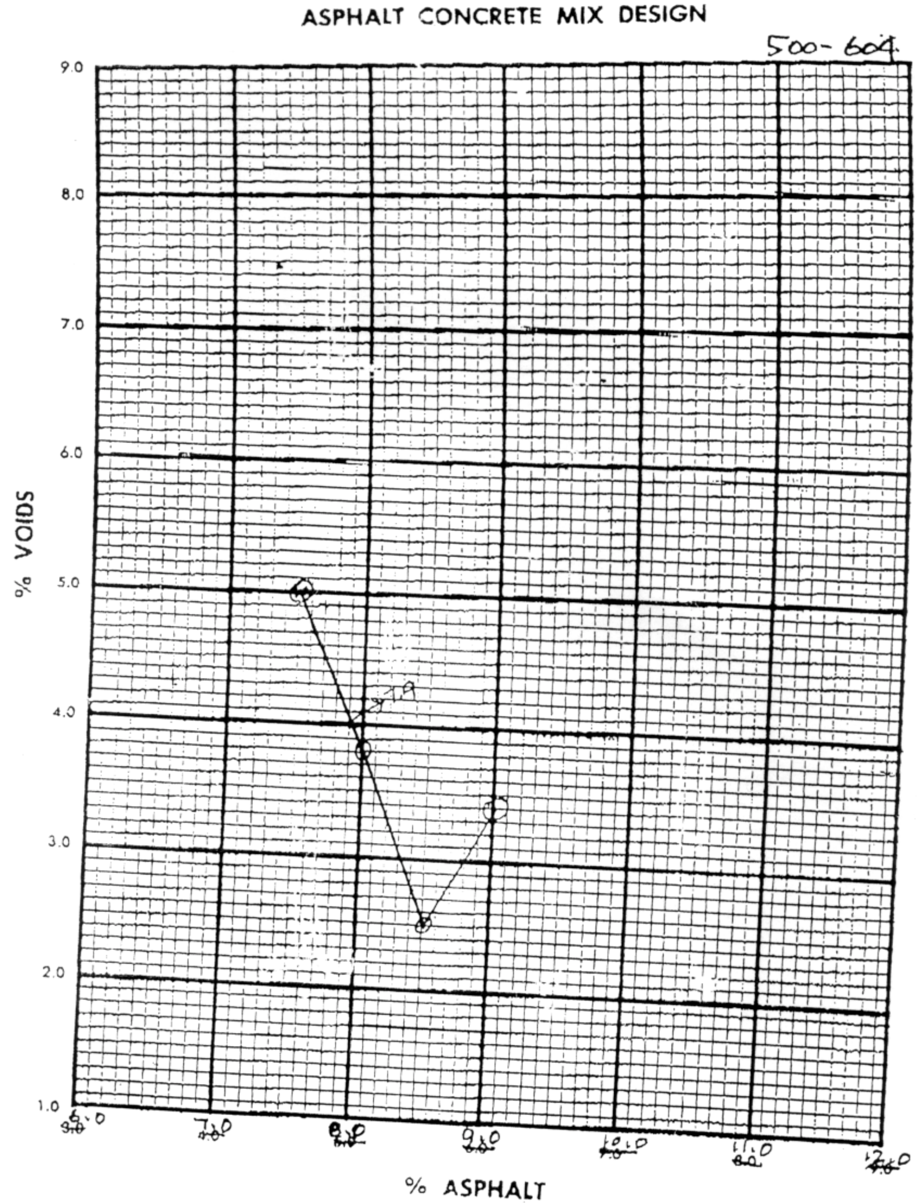


FIGURE 3

TRANSPORTATION LABORATORY
ASPHALT CONCRETE MIX DESIGN

TEST NO. 500-604

SOURCE Bauman Landscaping, 5 star Asphalt, UC Berkeley

ASPHALT GRADE Rubberized AC Binder

ABSORPTION N/A

SURFACE AREA N/A

SPECIFIC GRAVITY:

COARSE 2.62

FINE 2.76

AVERAGE 2.66

* RECOMMENDED RANGE 7.6 - 7.9

STEP 4 MAX. ASPHALT CONTENT WITH 4 OR MORE % VOIDS			7.9		OBC*
STEP 3 SPECIMENS MEETING MIN. STABILITY REQUIREMENT		7.5	8.0		
STEP 2 SPECIMENS WITH NO FLUSHING	7.5	8.0	8.5		
STEP 1 DESIGN SET	7.5	8.0	8.5	9.0	

RECOMMENDATION IS BASED ON THE GRADING CURVE SHOWN.

THIS IS NOT A VALID RECOMMENDATION IF THE MAXIMUM ASPHALT CONTENT USED IN THE DESIGN SET (STEP 1) IS FINALLY RECOMMENDED. IN THIS EVENT, ADDITIONAL SAMPLES MUST BE PREPARED WITH INCREASED ASPHALT CONTENT IN 0.5% INCREMENTS AND A NEW ANALYSIS MADE.

*Optimum Bitumen Content

* 4% voids controlled binder recommendation.

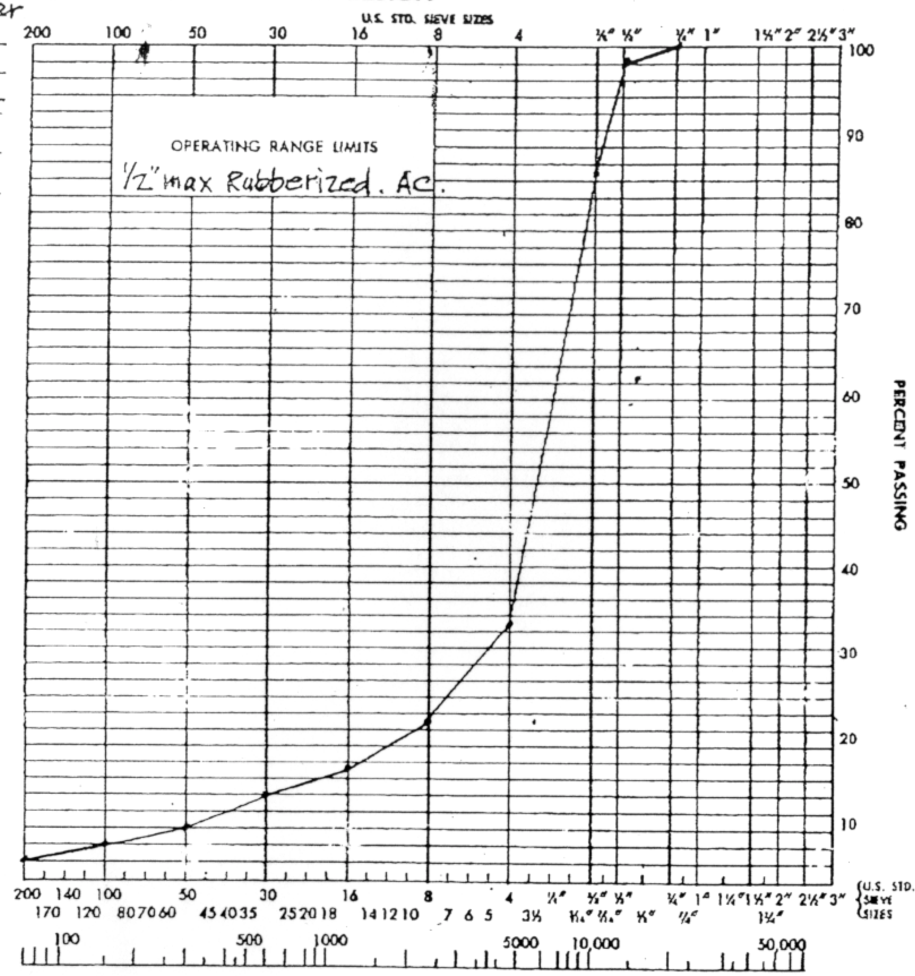


FIGURE 2

TL-3157 (Rev. 7-74)

Attention		From
John Harvey		ENGINEERING SERVICE CENTER TRANSPORTATION LABORATORY 5900 FOLSOM BOULEVARD SACRAMENTO, CA 95819-0128 TEL (916) 227-7305
Unit / Company UCB / RFS		Sender's Name Jeff Rush PAVEMENT BRANCH
		Date 12-10-97 / Total Pages (including cover sheet) 4
District / City		FAX # (area code) (916) 227-7242 / Calnet FAX # 8-498-7242
		Phone # (916) 227-7249 / Calnet #
Phone # (area code) (510) 231-9513	FAX # (area code) (510) 231-9589	Disposition of Original [ ] DESTROY [ ] RETURN [ ] CALL FOR PICK UP

John

Here's the Results from some testing that was done on the binder's used in the 1997 overlay's at RFS

DEC-10-1997 15:15 CALTRANS-ESC PAVEMENT 916 227 7242 P.02/04

?FS overlay

OF CALIFORNIA DEPARTMENT OF TRANSPORTATION

OSITY GRADED ASPHALT CEMENTS TESTS REPORT

(Rev. 6/92)

RECEIVED	TEST COMPLETED	CHECKED BY	DATE REPORTED	REPORTED BY	TEST NUMBER 971 1354 / TYPE
JUL 23 1997	12/1/97	R.R.	12/3/97	R. Rosse	Rubber

District Engineer
District Materials Engineer
Resident Engineer or Maintenance Superintendent
Headquarters Branch, Construction, or Maintenance

☐ Federal Aid Secondary Roads
☐ U.S. GOVERNMENT AGENCY
☐ M & R Files
☐ Cities, Counties, Other State Agencies

Tests	Test Method	Test Results	Out of Specs	Tested By
Residue from RTFC Procedure, AASHTO T240	AASHTO			
Absolute viscosity at 140°F, -30 cm Hg vacuum, ... Original Asphalt ______ P)	T202	P		
Kinematic viscosity at 275°F, centistokes	T201	cSt		
Penetration at 77° F, decimillimeters	T49	dmm		
Original Penetration at 77° F ... Final Penetration at 77° F ______ dmm)	T49	%		
Ductility at 77°F at 5 cm/minute, centimeters	T51	cm		
Original Asphalt				
Flash Point C.O.C.	T48	°F		
Solubility in Trichloroethylene	T44	%		
Specific Gravity 60°/60°F	T228			

SOURCE	CHARGE	EXPENDITURE AUTHORIZATION	SPECIAL DESIGNATION (Use when applicable.)	ACTIVITY OR OWE

REMARKS

ORIG $G^*/\sin\delta$ @ 82°C = 1.42 KPa

RTF $G^*/\sin\delta$ @ 82°C = 2.5 KPa

110°C PAV $G^* \cdot \sin\delta$ @ 31°C = 890 KPa

LIMITING STIFFNESS @ -28.6°C

∴ PG 82-28

TL-101 (REV. 6-78) STATE OF CALIFORNIA DEPARTMENT OF TRANSPORTATION

SAMPLE IDENTIFICATION CARD NO. C 240084

☐ PRELIMINARY TESTS
☐ PROCESS TESTS
☐ ACCEPTANCE TESTS
INDEPENDENT ASSURANCE TESTS
☐ DIST. LAB
☒ TRANS. LAB
☐ SPECIAL TESTS

SAMPLE SENT TO
☒ HDQTRS. LAB
☐ BRANCH LAB
☐ DIST. LAB

FIELD NO. ____
DIST. LAB NO. ____
LOT NO. ____
SHIPMENT NO. ____
P. O. OR REQ. NO. ____
AUTHORIZATION NO. ____

SAMPLE OF Asphalt Rubber binder

FOR USE IN ARHM - GG MIX

SAMPLE FROM FEED LINE

DEPTH Silvia Const

LOCATION OF SOURCE FIVE STAR @ Richmond

THIS SAMPLE IS SHIPPED IN 3 (NO. CONTAINERS) AND IS ONE OF A GROUP OF 3 SAMPLES REPRESENTING 200 (TONS, GALS., (LBS.) STA., ETC.)

OWNER OR MANUFACTURER SILVIA Const, Shel

TOTAL QUANTITY AVAILABLE ____ TEST RESULTS DESIRED ☐ NORMAL ☐ PRIORITY DATE NEEDED ____

REMARKS SAMPLED BY UNKNOWN

COVER ADDITIONAL INFORMATION WITH LETTER

DATE SAMPLED 3/26/97

BY DM TITLE TET

DIST., CO., RTE., P.M. Richmond Field STA BLDG 280, HVS Site

LIMITS ____

CONT. NO. 65-338-680300-3000?

FED. NO. ____

RES. ENGR. OR SUPT. ____

ADDRESS ____

CONTRACTOR GHILLOTTI, FIVE STAR, SILVIA Const

B22

P. 03/04 916 227 7242 CALTRANS-ESC PAVEMENT DEC-10-1997 15:16

…EPARTMENT OF TRANSPORTATION

…Y GRADED ASPHALT CEMENTS TESTS REPORT

…(Rev, 6/92)

RECEIVED	TEST COMPLETED	CHECKED BY	DATE REPORTED	REPORTED BY	TEST NUMBER
JUL 2 3 1997	12/2/97	RR	12/3/97	R. Reese	971 1353
					TYPE: AR 4000

District Engineer
District Materials Engineer
Resident Engineer or Maintenance Superintendent
Headquarters Branch, Construction, or Maintenance

☐ Federal Aid Secondary Roads
☐ U.S. GOVERNMENT AGENCY
☐ M & R Files
☐ Cities, Counties, Other State Agencies

Tests	Test Method	Test Results	Out of Specs	Tested By
Residue from RTFO Procedure, AASHTO T240	AASHTO			
…lute viscosity at 140°F, -30 cm Hg vacuum, …ises … n Original Asphalt ______ P)	T202	P		
…matic viscosity at 275°F, centistokes	T201	cSt		
…tration at 77° F, decimillimeters	T49	dmm		
…iginal Penetration at 77° F … iginal Penetration at 77° F ______ dmm)	T49	%		
…lity at 77°F at 5 cm/minute, centimeters	T51	cm		
…Original Asphalt				
…h Point C.O.C.	T48	°F		
…bility in Trichloroethylene	T44	%		
…ific Gravity 60°/60°F.	T220			

SOURCE	CHARGE	EXPENDITURE AUTHORIZATION	SPECIAL DESIGNATION (Use when applicable.)	ACTIV… OR OB…

…RKS

RTF @ 64C $G^* = 3{,}545$ Pa
$\delta = 86.8°$
$G^*/\sin\delta \sim 3.6$ kPa

100° PAV @ 25C $G^* = 4.8$ MPa
$\delta = 57°$
$G^*\sin\delta = 4.0$ MPa
LST = -21°C

BROOKFIELD THERMOSEL VISCOSITY SPINDLE 27
@ 100RPM
@ 120°C 0.70 Pa·s
@ 130°C 0.40 Pa·s
* @ 140°C 0.24 Pa·s
* @ 150°C 0.16 Pa·s
∴ PG 64-16

* OUT OF TORQUE SPECIFICATION

TL-101 (REV. 6-76)
STATE OF CALIFORNIA
DEPARTMENT OF TRANSPORTATION

SAMPLE IDENTIFICATION CARD NO. C240085

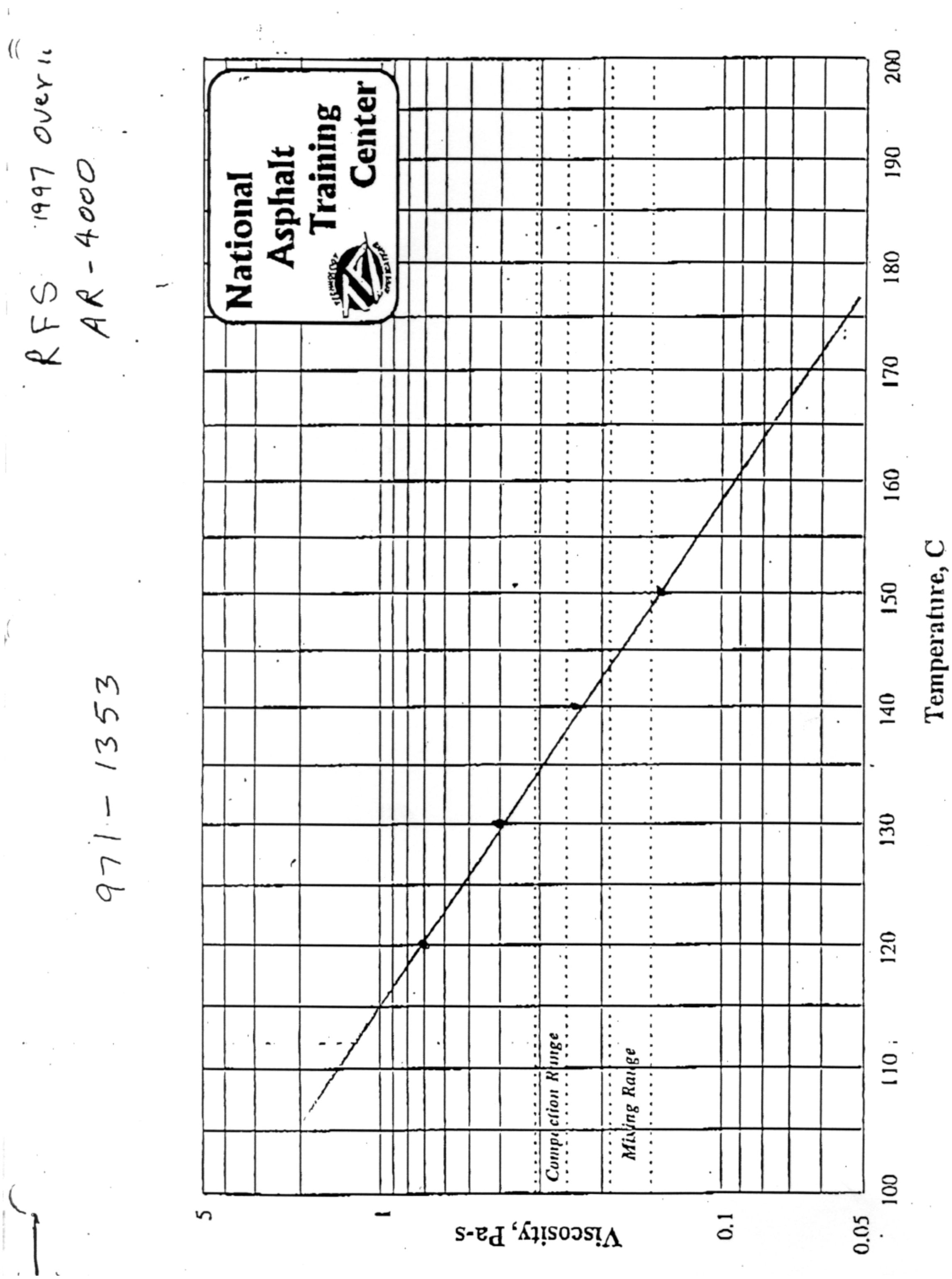
☐ PRELIMINARY TESTS
☑ PROCESS TESTS
☐ ACCEPTANCE TESTS
INDEPENDENT ASSURANCE TESTS
☐ DIST. LAB
☒ TRANS. LAB
☐ SPECIAL TESTS

SAMPLE SENT TO
☒ HDQTRS. LAB
☐ BRANCH LAB
☐ DIST. LAB

FIELD NO. ____
DIST. LAB NO. ____
LOT NO. ____
SHIPMENT NO. ____
P. O. OR REQ. NO. ____
AUTHORIZATION NO. ____

SAMPLE OF: AR 4000 BINDER
FOR USE IN: DGAC 1/2" or 3/4"
SAMPLE FROM: FEED LINE
DEPTH: ____
LOCATION OF SOURCE: FIVESTAR, Richmond HOT PLANT
THIS SAMPLE IS SHIPPED IN 2 (NO. CONTAINERS) AND IS ONE OF A GROUP OF 2 SAMPLES REPRESENTING ~~10 gal~~ (TONS, GALS., BBLS., STA., ETC.)
OWNER OR MANUFACTURER: HUNTWAY
TOTAL QUANTITY AVAILABLE: 10g TEST RESULTS DESIRED ☐ NORMAL ☐ PRIORITY DATE NEEDED ____
REMARKS: SAMPled by UNKNOWN

COVER ADDITIONAL INFORMATION WITH LETTER
DATE SAMPLED: 3/26/97
BY: DM TITLE: TCT
DIST., CO., RTE., P.M.: Richmond Field STA BLDG 280
LIMITS: HVS SITE
CONT. NO.: 65-338-680300-3xxx
FED. NO. ____
RES. ENGR. OR SUPT. ____
ADDRESS ____
CONTRACTOR: GHILLOTTI, FIVE STAR



National
Asphalt
Training
Center
Viscosity, Pa-s
Temperature, C
5
1
0.1
0.05
100
110
120
130
140
150
160
170
180
190
200
Compaction Range
Mixing Range
RFS 1997
AR-4000
971-1353

(Paras. 51 and 52 corrected.)
(Add applicable 39.XX SSPs that would apply to spreading, compacting and finishing rubberized asphalt concrete. Insert the applicable paragraphs at the locations indicated in the instructions. Edit appropriately to apply specifically to rubberized asphalt concrete.)
Use Contract Item Code No.
390140 RUBBERIZED ASPHALT CONCRETE (TYPE G) or
390199 RUBBERIZED ASPHALT CONCRETE (TYPE G)((Price Index.))

10-1.___ RUBBERIZED ASPHALT CONCRETE (TYPE G){ TC "10-1.___ RUBBERIZED ASPHALT CONCRETE (TYPE G)" \l 2 }.--Rubberized asphalt concrete (Type G) shall consist of furnishing and mixing gap graded aggregate and asphalt-rubber binder and spreading and compacting the mixture. Type G rubberized asphalt concrete shall conform to the requirements specified for Type A asphalt concrete in Section 39, "Asphalt Concrete," of the Standard Specifications and to these special provisions.

2
The last sentence of the first paragraph in Section 39-2.01, "Asphalts," of the Standard Specifications and the fifth, sixth, seventh and eighth paragraphs of Section 39-3.03, "Proportioning," of the Standard Specifications shall not apply to Type G rubberized asphalt concrete. The swell, moisture vapor susceptibility, and stabilometer value requirements in Section 39-2.02, "Aggregate," of the Standard Specifications shall not apply to Type G rubberized asphalt concrete.

3
The second paragraph in Section 39-3.05, "Asphalt Concrete and Asphalt Concrete Base Storage," of the Standard Specifications is amended to read:

3a
Storage silos shall be equipped with a surge-batcher sized to hold a minimum of 4,000 pounds of material. A surge-batcher consists of equipment placed at the top of the storage silo which catches the continuous delivery of the completed mix and changes it to individual batch delivery and prevents the segregation of product ingredients as the completed mix is placed into storage. The surge-batcher shall be center loading and shall be thermally insulated or heated or thermally insulated and heated to prevent material buildup. Rotary chutes shall not be used as surge-batchers.

3b
The surge-batcher shall be independent and distinct from conveyors or chutes used to collect or direct the completed mixture being discharged into storage silos and shall be the last device to handle the material before it enters the silo. Multiple storage silos shall be served by an individual surge-batcher for each silo. Material handling shall be free of oblique movement between the highest elevation (conveyor outfall) and subsequent placement in the silo. Discharge gates on surge-batchers shall be automatic in operation and shall discharge only after a minimum of 4,000 pounds of material has been collected and shall close before the last collected material leaves the device. Discharge gate design shall prevent the deflection of material during the opening and closing operation.

4
AIR MONITORING.--Samples of emissions from the rubberized asphalt concrete shall be collected by an industrial hygienist certified by the American Industrial Hygiene Association (AIHA). Laboratory analysis of samples collected shall be performed at an accredited laboratory.

The Contractor shall provide all labor, equipment, materials and tools to make specific tests and analyze results.

5

Air monitoring shall be conducted for at least seven consecutive hours of paving operation per day for 2 days. A record of wait-time, loads of rubberized asphalt concrete placed, ambient temperature, wind velocity and direction, and rubberized asphalt concrete temperatures shall be maintained. Temperatures of the rubberized asphalt concrete shall be determined at the windrow, paver hopper and mat.

6

An air monitoring area sample for rubberized asphalt concrete shall be collected from the paver, 3 feet above the auger, on the downwind side of the screed. Personal samples shall also be collected from the screed operator and the truck spotter (dump man). All samples shall be tested for the following contaminants:

Contaminant	Test Method	Area	Personal	Comments
Asphalt Fume	NIOSH 0500	2	2	None
CEP (cyclohexane extractable particulates)	OSHA 58	2	2	CEP's from asphalt fume sample (Save extract at lab)
Semi-volatile organics (poly-aromatic hydrocarbon PAH)	NIOSH 5515 or NIOSH 5506	2	0	Must identify predominant species (e.g. benzo-a-pyrene)
VOC (volatile organic compounds)	GC/MS	2	0	Collect onto single 100/50 mg Tenax tube. Previous monitoring has shown 8 to 400 $\mu g/m^3$ total VOC's
	Total	8	4	

Notes:
Breakthrough on sorbent tubes is not anticipated.
CEP's may be obtained by extracting the PVC filter used for gravimetric (asphalt fume) analysis.
Cyclohexane extractables should not be reported as coal tar pitch volatiles (CTPV) unless polyaromatic hydrocarbon data characterizes them as CTPV's (i.e., PAH's represent 10% of CEP results or greater).
NIOSH is the National Institute for Occupational Safety and Health.

7

A completed report shall be submitted to the Engineer within 90 days from the date air monitoring samples are completed. The Contractor shall permit the Engineer to interview paving operation employees during working hours on the job.

8
Air Monitoring will be paid for as extra work in accordance with Section 4-1.03D of the Standard Specifications.

9
GENERAL.--The Contractor shall furnish samples of aggregate to the Engineer in conformance with Section 39-3.03, "Proportioning," of the Standard Specifications.

10
The amount of asphalt-rubber binder to be mixed with the aggregate for Type G rubberized asphalt concrete will be determined by the Engineer using the samples of aggregates furnished by the Contractor in conformance with said Section 39-3.03 . The Engineer will determine the exact amount of asphalt-rubber binder to be mixed with the aggregate in accordance with California Test 367, except as follows:

10a
The specific gravity used in Section "B. Voids Content of Specimen" of California Test 367 will be determined using California Test 308, Method A.

10b
Section "C. Optimum Bitumen Content" of California Test 367 is revised to read:

10b1
1. Using Figure 2 record in Step 1 of the pyramid the asphalt-rubber binder content of the 4 specimens with the maximum asphalt-rubber binder content used in the square farthest to the right.

10b2
2. Plot asphalt-rubber binder content versus void content for each specimen on Form TL-306 (Figure 3), and connect adjacent points with straight lines.

10b3
(Para. 10b3, Determine void content percent based on the following table:

Traffic Index	Region: Mountain	Valley	Coastal	Desert
0-6	3.0	3.0	3.0	3.0
6-10	3.0*	4.0	4.0	4.0
>10	4.0	4.0	4.0	5.0

*** Note: Use 4.0% if summer ambient temperatures > 95° F.**

3. From Figure 3 select the theoretical asphalt-rubber binder content that has ___ percent voids. Record this amount in Step 4 of the pyramid.

10b3
4. Record the asphalt-rubber binder content in Step 4 as the Optimum Bitumen Content (OBC).

10b4
5. To establish a recommended range, use the Optimum Bitumen Content (OBC) as the high value and 0.3 percent less as the low value.

10c
Laboratory mixing and compaction shall be in accordance with California Test 304, except that the mixing temperature of the aggregate shall be between 300° F. and 325° F. The compaction temperature of the combined mixture shall be between 290° F. and 300° F.

11
The rubberized asphalt concrete mixture, composed of the aggregate proposed for use and the optimum amount of asphalt-rubber binder as determined by California Test 367 modified above, shall conform to the following quality requirements:

Test Parameter	California Test	Requirement
Percent Asphalt-Rubber Binder by Weight of Dry Aggregate, Percent	367	7.0-9.5
Stabilometer Value, Minimum	304 and 366	23
Voids in Mineral Aggregate, Percent, Minimum	See Note	18

Note: Voids in mineral aggregate test shall be determined as described in Asphalt Institute Mix Design Methods for Asphalt Concrete (MS-2).

12
The Contractor shall provide the Engineer a Material Safety Data Sheet (MSDS) for each of the constituent components of the asphalt-rubber binder, for the completed mixture of asphalt-rubber binder and for the Type G rubberized asphalt concrete.

13
PAVING ASPHALT.--The grade of paving asphalt to be used in the asphalt-rubber binder shall be AR-4000 and shall conform to Section 92, "Asphalts," of the Standard Specifications and these special provisions.

14
The Contractor shall submit to the Engineer any proposed changes to the specified grade at least 14 days prior to blending the asphalt-rubber binder. No change in grade of paving asphalt shall be made until approved in writing by the Engineer.

15
The paving asphalt for use in asphalt-rubber binder shall be modified with an asphalt modifier.

16
ASPHALT MODIFIER.--The asphalt modifier shall be a resinous. high flash point, aromatic hydrocarbon compound conforming to the following requirements:

ASPHALT MODIFIER

Test Parameter	ASTM Designation	Requirement
Viscosity, cSt, at 100° F.	D 445	1600 - 3900
Flash Point, COC, ° F.	D 92	405 min.
Molecular Analysis:		
Asphaltenes, percent by weight	D 2007	0.1 max.
Aromatics, percent by weight	D 2007	55 min.

17
The asphalt modifier shall be added at the production site where the asphalt-rubber binder is blended and reacted. Asphalt modifier shall be added to the paving asphalt at an amount of 2.5 to 6.0 percent by weight of the paving asphalt based on the recommendation of the asphalt-rubber binder supplier. The exact amount will be determined by the Engineer. The paving asphalt shall be at a temperature of not less than 350° F. nor more than 400° F. when the asphalt modifier is added.

18
CRUMB RUBBER MODIFIER (CRM).--Crumb rubber modifier (CRM) shall consist of a combination of scrap tire CRM and high natural CRM. The scrap tire CRM shall consist of ground or granulated rubber derived from any combination of passenger tires, truck tires or tire buffings. The high natural CRM shall consist of ground or granulated rubber derived from materials that utilize high natural rubber sources.

19
Steel and fiber separation may be accomplished by any method. Cryogenic separation, if utilized, shall be performed separately from and prior to grinding or granulating.

20
All CRM shall be ground or granulated at ambient temperature. Cryogenically produced CRM particles which can pass through the grinder or granulator without being ground or granulated respectively, shall not be used.

21
CRM shall not contain more than 0.01-percent by weight of CRM of wire and all other contaminants, except fabric. Fabric shall not exceed 0.05-percent by weight of CRM. A certificate of compliance certifying these percentages shall be furnished to the Engineer in accordance with Section 6-1.07, "Certificates of Compliance," of the Standard Specifications.

22
The length of any individual CRM particle shall not exceed 3/16 inch.

23
The CRM shall be sufficiently dry so as to be free flowing and not produce foaming when combined with the blended paving asphalt and asphalt modifier mixture. Calcium carbonate or talc may be added at a maximum amount of 3 percent by weight of CRM to prevent CRM particles from sticking together. The CRM shall have a specific gravity between 1.1 and 1.2 as determined by ASTM Designation: D 297. CRM material shall conform to the following requirements as determined by ASTM Designation: D 297:

SCRAP TIRE CRUMB RUBBER MODIFIER

Test Parameter	Percent	
	Min.	Max.
Acetone Extract	6.0	16.0
Ash Content	—	8.0
Carbon Black Content	28.0	38.0
Rubber Hydrocarbon	42.0	65.0
Natural Rubber Content	16.0	39.0

HIGH NATURAL CRUMB RUBBER MODIFIER

	Percent	
Test Parameter	Min.	Max.
Acetone Extract	4.0	10.0
Rubber Hydrocarbon	50.0	—
Natural Rubber content	40.0	—

24

The CRM for asphalt-rubber binder shall conform to the gradations specified below when tested in accordance with ASTM Designation: C 136 amended as follows:

24a

To a 100.0 gram sample of CRM, add 5.0 grams of talc. Mix the CRM and talc for a minimum of one minute by shaking by hand in a sealed one-pint size jar. Continue shaking or open the jar and stir until particle agglomerates and clumps are broken and the talc is uniformly mixed. After sieving the combined material for 10 minutes, sum the total weight of the contents of each sieve, and the pan, and subtract 100. The remainder is to be subtracted from the bottom pan contents. This is the adjusted bottom pan contents, accounting for talc used.

CRM GRADATIONS

Sieve Size	Scrap Tire CRM Percent Passing	High Natural CRM Percent Passing
No. 8	100	100
No. 10	98-100	100
No. 16	60-75	95-100
No. 30	2-15	35-85
No. 50	0-2	10-30
No. 100	0-1	0-4
No. 200	0	0-1

25

ASPHALT-RUBBER BINDER.--Asphalt-rubber binder shall consist of a mixture of paving asphalt, asphalt modifier and crumb rubber modifier (CRM).

26

At least two weeks before its intended use, the Contractor shall furnish to the Engineer 4 one-quart cans filled with the asphalt-rubber binder proposed for use on the project.

27
The method and equipment for combining paving asphalt, asphalt modifier and CRM shall be so designed and accessible that the Engineer can readily determine the percentages by weight for each material being incorporated into the mixture.

28
The proportions of the materials, by weight, shall be 79 percent ± 1 percent combined paving asphalt and asphalt modifier, and 21 percent ± 1 percent CRM. The CRM shall be combined at the production site and shall contain 75 percent ± 2 percent scrap tire CRM and 25 percent ± 2 percent high natural CRM, by weight.

29
The paving asphalt and asphalt modifier shall be combined into a blended mixture that is chemically compatible with the crumb rubber modifier.

30
The blended paving asphalt and asphalt modifier mixture, and the CRM shall be combined and mixed together at the production site in a blender unit to produce a homogeneous mixture.

31
The temperature of the blended paving asphalt and asphalt modifier mixture shall be between 375° F. and 425° F. when the CRM is added. The combined materials shall be reacted for a minimum of 45 minutes after incorporation of all the CRM. The asphalt-rubber binder shall be maintained at a temperature between 385° F. and 415° F. during the reaction period. The temperature shall not be higher than 10° F. below the actual flash point of the asphalt-rubber binder.

32
After reacting, the blended asphalt-rubber binder shall conform to the following requirements:

BLENDED ASPHALT-RUBBER BINDER

Test Parameter	ASTM Test Method	Requirement Min.	Max.
Cone Penetration @ 77° F., 1/10 mm	D217	25	70
Resilience @ 77° F., Percent rebound	D3407	18	—
Field Softening Point, ° F.	D36	125	165
Viscosity @ 375° F., Centipoise	See Note	1,900	3,500

NOTE: The viscosity test shall be conducted with a hand held Haake Viscometer Model VT-02 with Rotor 1, 24 mm depth x 53 mm height, or equivalent, as determined by the Engineer. The viscometer shall be calibrated to a Brookfield viscometer tested in accordance with ASTM Designation: D 2196 to ± 100 centipoise and the calibration shall be certified by a certificate of compliance. The certificate of compliance shall be furnished to the Engineer in accordance with Section 6-1.07, "Certificates of Compliance," of the Standard Specifications.

33
The Contractor shall provide a Haake Viscometer, or equivalent, at the production site during the combining of asphalt-rubber binder materials. The Contractor shall take viscosity readings of asphalt-rubber binder from samples taken from the feed line connecting the storage and reaction tank and the asphalt concrete plant. Readings shall be taken at least every hour with no less than one reading for each batch of asphalt-rubber binder. The Contractor shall log these results including time and asphalt-rubber binder temperature, and a copy of the log shall be submitted to the Engineer on a daily basis. As determined by the Engineer, the Contractor shall either notify the Engineer at least 15 minutes prior to each test or provide the Engineer a schedule of testing times.

34

The reacted asphalt-rubber binder shall be maintained at a temperature of 400° F. ± 15° F.

35

If any of the material in a batch of asphalt-rubber binder is not used within four hours after the 45 minute reaction period, heating of the material shall be discontinued. Any time the asphalt-rubber binder cools below 385° F. and is then reheated, it shall be considered a reheat cycle. The total number of reheat cycles shall not exceed 2. The material shall be uniformly reheated to a temperature of 400° F. ± 15° F. prior to use. Additional scrap tire CRM may be added to the reheated binder and reacted for a minimum of 45 minutes. The cumulative amount of additional scrap tire CRM shall not exceed 10 percent of the total binder weight. Reheated asphalt-rubber binder shall conform to the requirements for blended asphalt-rubber binder.

36

EQUIPMENT.--The Contractor shall utilize the following equipment for production of asphalt-rubber binder:

36a

1. An asphalt heating tank equipped to heat and maintain the blended paving asphalt and asphalt modifier mixture at the necessary temperature before blending with the CRM. This unit shall be equipped with a thermostatic heat control device and a temperature reading device;

36b

2. A mechanical blender for proper proportioning and homogeneous mixing of the blended paving asphalt and asphalt modifier, and the CRM. This unit shall have both an asphalt totalizing meter calibrated in gallons or liters and a flow rate meter calibrated in gallons per minute or liters per minute; and

36c

3. An asphalt-rubber binder storage tank equipped with a heating system furnished with a temperature reading device to maintain the proper temperature of the asphalt-rubber binder and an internal mixing unit capable of maintaining a homogeneous mixture of blended paving asphalt, asphalt modifier and CRM.

37

All equipment shall be approved by the Engineer prior to use.

38

(Para. 9 of SSP 39.06 to be inserted after Para. 38 if applicable.)

AGGREGATE.--The aggregate for Type G rubberized asphalt concrete shall conform to the following grading and shall meet the quality requirements specified for Type A asphalt concrete in Section 39-2.02, "Aggregate," of the Standard Specifications, except the loss at 500 revolutions from the Los Angeles Rattler, California Test 211, shall be 40 percent maximum. The definition of a crushed particle in California Test 205 Section D, is amended to read: "Any particle having two or more fresh mechanically fractured faces shall be considered a crushed particle".

39

(Add SSP 39.18 after table if applicable.)

The symbol "X" in the following table is the gradation which the Contractor proposes to furnish for the specific sieve.

Aggregate Grading Requirements
Percentage Passing
1/2" maximum

Sieve Size	Limits of Proposed Gradation	Operating Range	Contract Compliance
3/4"		100	100
1/2"		90-100	90-100
3/8"	83-87	X±5	X±7
No. 4	33-37	X±5	X±7
No. 8	18-22	X±4	X±5
No. 30	8-12	X±4	X±5
No. 200		3-7	0-8

40

(Para. 40. Do not use when lift thickness is less than 0.15 of a foot. Include only when approved in writing by the Pavement Consulting Services Branch of the Office of Materials Engineering Testing Services. When included delete Paras. 39 and 41.)
(Add SSP 39.18 after table if applicable.)

The symbol "X" in the following table is the gradation which the Contractor proposes to furnish for the specific sieve.

Aggregate Grading Requirements
Percentage Passing
3/4" maximum

Sieve Size	Limits of Proposed Gradation	Operating Range	Contract Compliance
1"		100	100
3/4"		95-100	90-100
1/2"	83-87	X±5	X±7
3/8"	65-70	X±5	X±7
No. 4	33-37	X±5	X±7
No. 8	18-22	X±4	X±5
No. 30	8-12	X±4	X±5
No. 200		3-7	0-8

41

(Para. 41. Include when lift thicknesses are 0.08-foot or less. When included delete Paras. 39 and 40.)

The symbol "X" in the following table is the gradation which the Contractor proposes to furnish for the specific sieve.

Aggregate Grading Requirements
Percentage Passing
3/8 inch maximum

Sieve Size	Limits of Proposed Gradation	Operating Range	Contract Compliance
1/2"		100	100
3/8"		78-92	78-92
No. 4	33-37	X±5	X±7
No. 8	18-22	X±4	X±5
No. 30	8-12	X±4	X±5
No. 200		3-7	0-8

42

(Paras. 1, 4 and 6 of SSP 39.06 to be inserted after Para. 42 when applicable.)

CONSTRUCTION.--When batch type asphalt concrete plants are used to produce Type G rubberized asphalt concrete, the asphalt-rubber binder and mineral aggregate shall be proportioned by weight.

43

When continuous mixing type asphalt concrete plants are used to produce Type G rubberized asphalt concrete, the asphalt-rubber binder shall be proportioned by an asphalt meter of the mass flow, coriolis effect type. The meter shall be calibrated in accordance with California Test 109.

44

The temperature of the aggregate shall not be greater than 325° F. at the time the asphalt-rubber binder is added.

45

Type G rubberized asphalt concrete shall be placed only when the atmospheric and pavement surface temperatures are above 50° F.

46

(SSPs 39.08, 39.09 & 39.12 to be inserted after Para. 45 as applicable .)
(Add SSP 39.03 for compaction requirements for Type G Rubberized Asphalt Concrete. If the rubberized asphalt concrete is to be placed in layers of less than 0.15', SSP 39.03 shall not be used and changes to Standard Specifications are needed and approval by the Pavement Consulting Services Branch of the Office of Materials Engineering testing Services is required.)

Type G rubberized asphalt concrete shall be spread at a temperature of not less than 285° F. nor more than 325° F., measured in the mat directly behind the paving machine.

Pneumatic tired rollers shall not be used to compact Type G rubberized asphalt concrete. 47

(Para. 48. Include when SSP 39.03 is not included.) 48

Alternative compacting equipment as specified in Section 39-6.03, "Compacting," of the Standard Specifications shall be used to compact the Type G rubberized asphalt concrete .

Traffic shall not be allowed on the Type G rubberized asphalt concrete until final rolling operations have been completed and sand has been applied to the surface. 49

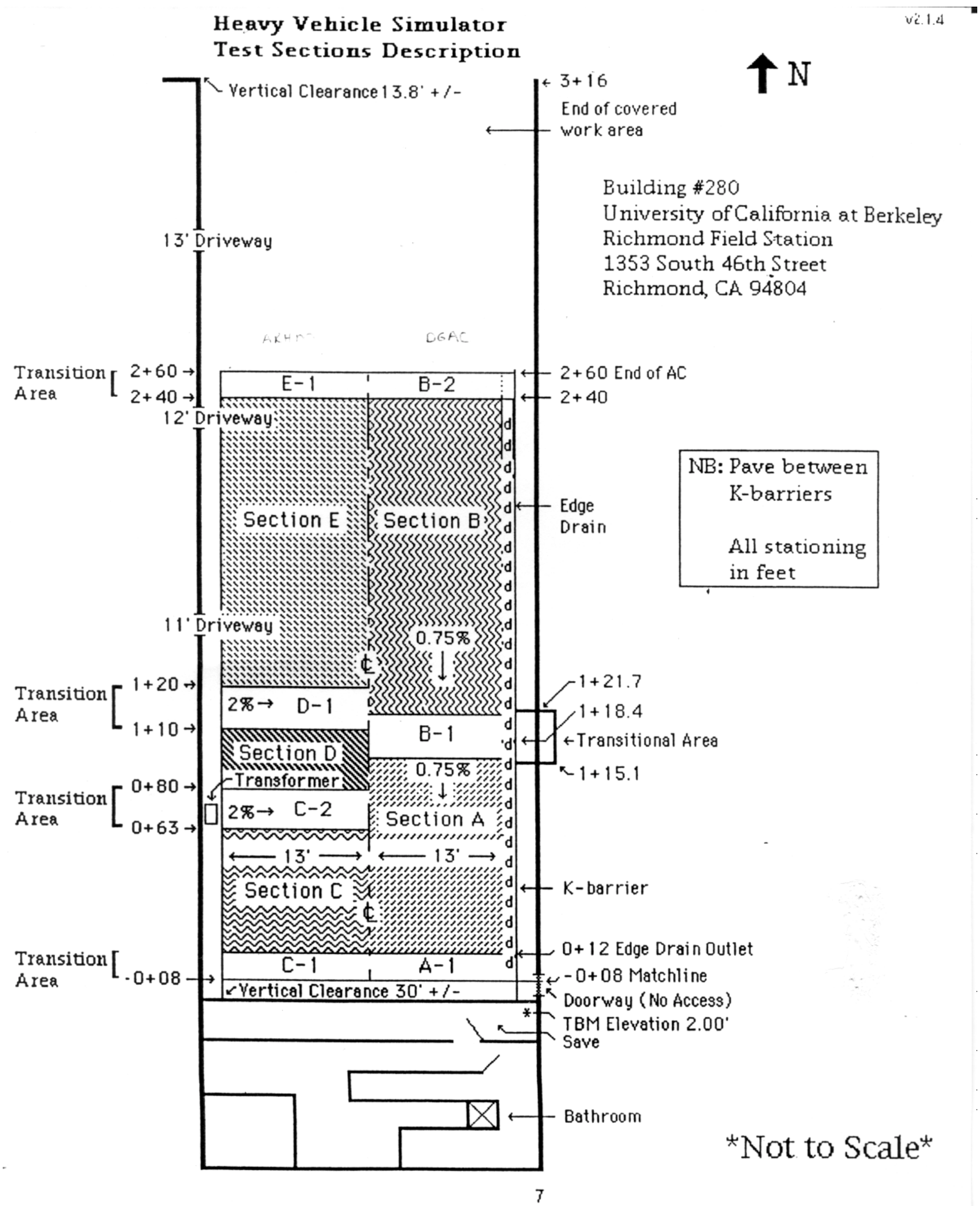
(Paras. 7 and 8 of SSP 39.06 to be inserted after Para. 50 when applicable.) 50

Sand shall be spread on the surface of Type G rubberized asphalt concrete at a rate of 1 to 2 pounds per square yard. The exact rate will be determined by the Engineer. When ordered by the Engineer excess sand shall be removed from the pavement surface by sweeping. Sand shall be free from clay or organic material. Sand shall conform to the fine aggregate grading requirements in Section 90-3.03, "Fine Aggregate Grading," of the Standard Specifications.

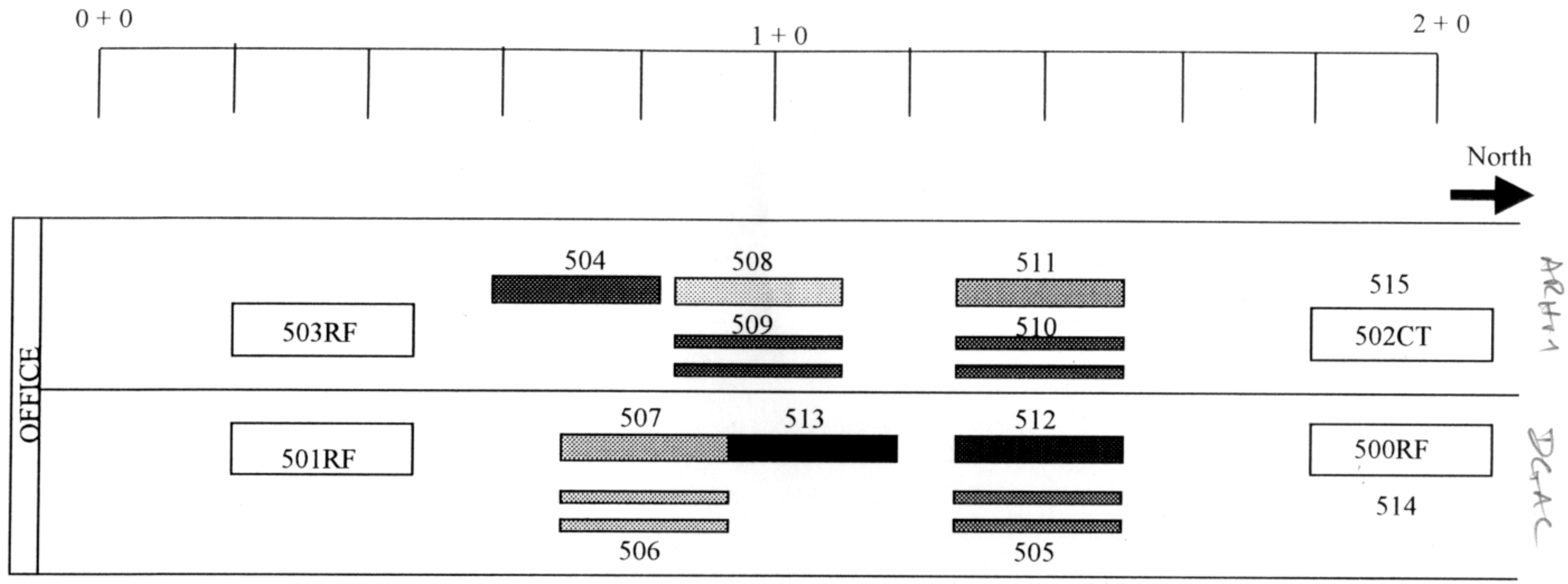
MEASUREMENT AND PAYMENT.--Rubberized asphalt concrete (Type G) will be measured and paid for by the ton in the same manner specified for asphalt concrete in Section 39-8, "Measurement and Payment," of the Standard Specifications. 51

Full compensation for furnishing, spreading and sweeping sand cover and for any delay or inconvenience to the Contractor's operations arising from air monitoring sampling of rubberized asphalt concrete operations shall be considered as included in the contract price paid per ton for rubberized asphalt concrete (Type G) and no separate payment will be made therefor. 52

APPENDIX C: SITE LAYOUT


v2.1.4
Heavy Vehicle Simulator
Test Sections Description
Vertical Clearance 13.8' +/-
3+16
End of covered work area
N
Building #280
University of California at Berkeley
Richmond Field Station
1353 South 46th Street
Richmond, CA 94804
13' Driveway
Transition Area
2+60
2+40
E-1
B-2
2+60 End of AC
2+40
12' Driveway
NB: Pave between K-barriers
All stationing in feet
Section E
Section B
Edge Drain
11' Driveway
0.75%
Transition Area
1+20
1+10
2%→ D-1
B-1
1+21.7
1+18.4
Transitional Area
1+15.1
Section D
Transformer
0.75%
Transition Area
0+80
0+63
2%→ C-2
Section A
13'
13'
Section C
K-barrier
0+12 Edge Drain Outlet
Transition Area
-0+08
C-1
A-1
-0+08 Matchline
Vertical Clearance 30' +/-
Doorway (No Access)
TBM Elevation 2.00'
Save
Bathroom
Not to Scale
7

Section A-1	-0+08 - 0+12	Matchline from existing to .25’ of 19mm (3/4”) DGAC
Section A	0+12 - 1+15.1	.25’ of 19mm (3/4”) DGAC
Section B-1	1+15.1 - 1+18.4	Transition Area .25’ DGAC to .20’ DGAC
Section B	1+18.4 - 2+40	.20’ DGAC
Section B-2	2+40 - 2+60	.20’ to match existing
Section C-1	-0+08 - 0+12	Matchline from existing to .12’ of 12.5mm (1/2”) ARHM
Section C	0+12 - 0+63	.12’ of 12.5mm (1/2”) ARHM
Section C-2	0+63 - 0+80	Transition .12’ to .20’
Section D	0+80 - 1+10	.20’ of 12.5mm (1/2”) ARHM
Section D-1	1+10 - 1+20	Transition .20’ to .12’
Section E	1+20 - 2+40	.12’ of 12.5mm (1/2”) ARHM
Section E-1	2+40 - 2+60	.12’ of 12.5mm (1/2”) ARHM to match existing



0 + 0
1 + 0
2 + 0
North
OFFICE
504
508
509
511
510
503RF
515
502CT
ARH1
DGAC
507
513
512
501RF
500RF
514
506
505

sections

APPENDIX D: VIBRATORY ROLLER QUALIFICATION LISTS FOR CALIFORNIA TEST METHOD 113

VIBRATORY ROLLER QUALIFICATION LIST
and QUALIFYING CONDITIONS

The following vibratory rollers have been evaluated in accordance with California Test Method 113

January 1995

Item No.	BRAND	MODEL NO.	FREQUENCY	AMPTITUDE	SPEED	BREAKDOWN COVERAGES*	DRUM LENGTH (INCHES)	OPERATING WEIGHT (TONS)	DATE TESTED
28	Ingersoll-Rand	DA-30S	2800	0.015"	2.75,	3	40	3.5	Apr-84
29	Ingersoll-Rand	DA-40	2800	0.026" (High)	3	3	60	7.7	Oct-82
30	Ingersoll-Rand	DA-48	2500	0.040" (Position 8)	2.5	3	66	10	Oct-83
31	Ingersoll-Rand	DA-50	2400	0.026"	2.5	2	75	12	Jun-78
32	Ingersoll-Rand	DD-90, 91	2500	0.033" (Position 5)	3.25	2	66	10	Nov-93
34	Ingersoll-Rand	DD-110	2450	#4	3.5	2	78	11.7	Oct-92
35	Ingersoll-Rand	DD-145	2200	0.023" (Medium)	3	2	84	16	Oct-88
36	Koehring-Bomag	BW-140AD	2800	0.024"	2.5	2	56	6.6	Jul-80
37	Koehring-Bomag	BW-160AD & 161AD	2300	0.028"	2.5	2	65	9	Jul-80
38	Pettibone	C-33	3200	0.015"	2	3	49.5	3.8	Jun-81
39	Pettibone	C-44	2400	0.0353"	4	3	68	10.9	Jun-81
40	Raygo	2-66 (1)	2300	0.030"	2.5	2	66	11.4	Jun-77
41	Raygo	2-84 (1)	2300	Low	2.5	2	84	13.9	May-76
42	Raygo	5604-A	3000	0.018" (High)	2	3	56	7.8	Nov-81
43	Raygo	6604	2300	Low	2.5	3	66	11.8	Jun-80
44	Raygo	7204	2300	Low	2.75	3	72	12.5	Jun-80
45	Rexnord	SP-1100	2000	0.039"	3	2	80	12.8	Nov-79
46	Rexworks	1000	2200	Position 3.5	2.25	2	66	10.9	Jul-86
47	Sakai	SW-70C	3100	0.02"	2.5	3	57	7.7	Jun-85
48	Sakai	SW-100	2400	High	2.5	4	77	12.7	Jul-88
49	Sakai	SW-40	3200	0.016" (Position 1)	0.75	3	51	10	Jul-93
50	Tampo	RS-166A	2200	Low	3	2	66	10	Dec-73
51	Tampo	RS-188A	2200	0.023" (Medium)	3	2	84	16	Jun-77
52	Tampo	RS-288A	1750	Medium	3	2	84	18.5	May-77

Qualifying operating conditions are for breakdown rolling only. If used for final rolling, such rolling shall be performed with the vibrating units off.

(1) Qualified when drums are in line or when they are extended to maximum width

(2) When drums are in line

(3) When drums are extended

VIBRATORY ROLLER QUALIFICATION LIST
and QUALIFYING CONDITIONS

The following vibratory rollers have been evaluated in accordance with California Test Method 113

January 1995

Item No.	BRAND	MODEL NO.	FREQUENCY	AMPTITUDE	SPEED	BREAKDOWN COVERAGES*	DRUM LENGTH (INCHES)	OPERATING WEIGHT (TONS)	DATE TESTED
28	Ingersoll-Rand	DA-30S	2800	0.015"	2.75,	3	40	3.5	Apr-84
29	Ingersoll-Rand	DA-40	2800	0.026" (High)	3	3	60	7.7	Oct-82
30	Ingersoll-Rand	DA-48	2500	0.040" (Position 8)	2.5	3	66	10	Oct-83
31	Ingersoll-Rand	DA-50	2400	0.026"	2.5	2	75	12	Jun-78
32	Ingersoll-Rand	DD-90, 91	2500	0.033" (Position 5)	3.25	2	66	10	Nov-93
34	Ingersoll-Rand	DD-110	2450	#4	3.5	2	78	11.7	Oct-92
35	Ingersoll-Rand	DD-145	2200	0.023" (Medium)	3	2	84	16	Oct-88
36	Koehring-Bomag	BW-140AD	2800	0.024"	2.5	2	56	6.6	Jul-80
37	Koehring-Bomag	BW-160AD & 161AD	2300	0.028"	2.5	2	65	9	Jul-80
38	Pettibone	C-33	3200	0.015"	2	3	49.5	3.8	Jun-81
39	Pettibone	C-44	2400	0.0353"	4	3	68	10.9	Jun-81
40	Raygo	2-66 (1)	2300	0.030"	2.5	2	66	11.4	Jun-77
41	Raygo	2-84 (1)	2300	Low	2.5	2	84	13.9	May-76
42	Raygo	5604-A	3000	0.018" (High)	2	3	56	7.8	Nov-81
43	Raygo	6604	2300	Low	2.5	3	66	11.8	Jun-80
44	Raygo	7204	2300	Low	2.75	3	72	12.5	Jun-80
45	Rexnord	SP-1100	2000	0.039"	3	2	80	12.8	Nov-79
46	Rexworks	1000	2200	Position 3.5	2.25	2	66	10.9	Jul-86
47	Sakai	SW-70C	3100	0.02"	2.5	3	57	7.7	Jun-85
48	Sakai	SW-100	2400	High	2.5	4	77	12.7	Jul-88
49	Sakai	SW-40	3200	0.016" (Position 1)	0.75	3	51	10	Jul-93
50	Tampo	RS-166A	2200	Low	3	2	66	10	Dec-73
51	Tampo	RS-188A	2200	0.023" (Medium)	3	2	84	16	Jun-77
52	Tampo	RS-288A	1750	Medium	3	2	84	18.5	May-77

Qualifying operating conditions are for breakdown rolling only. If used for final rolling, such rolling shall be performed with the vibrating units off.

(1) Qualified when drums are in line or when they are extended to maximum width

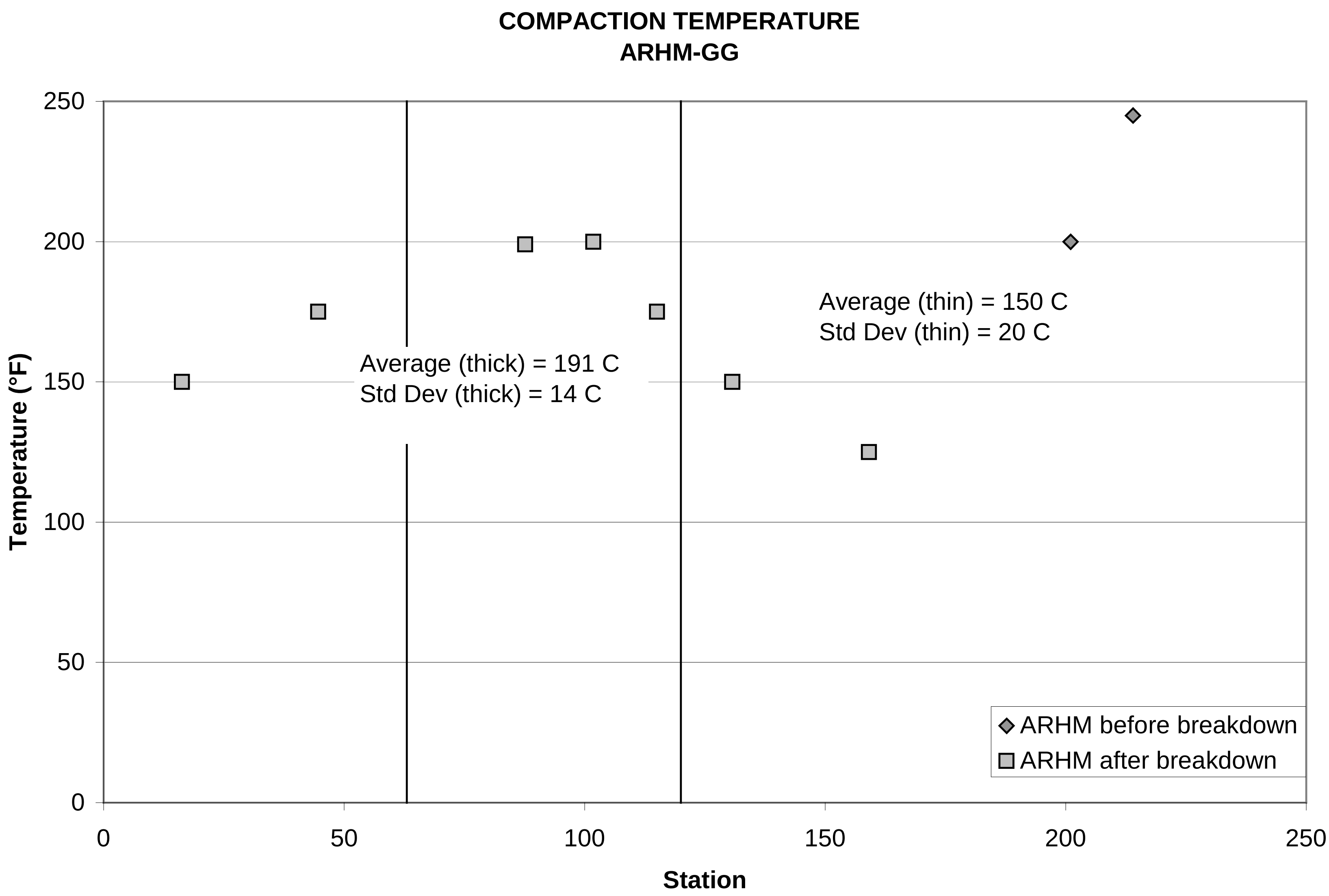
(2) When drums are in line

(3) When drums are extended

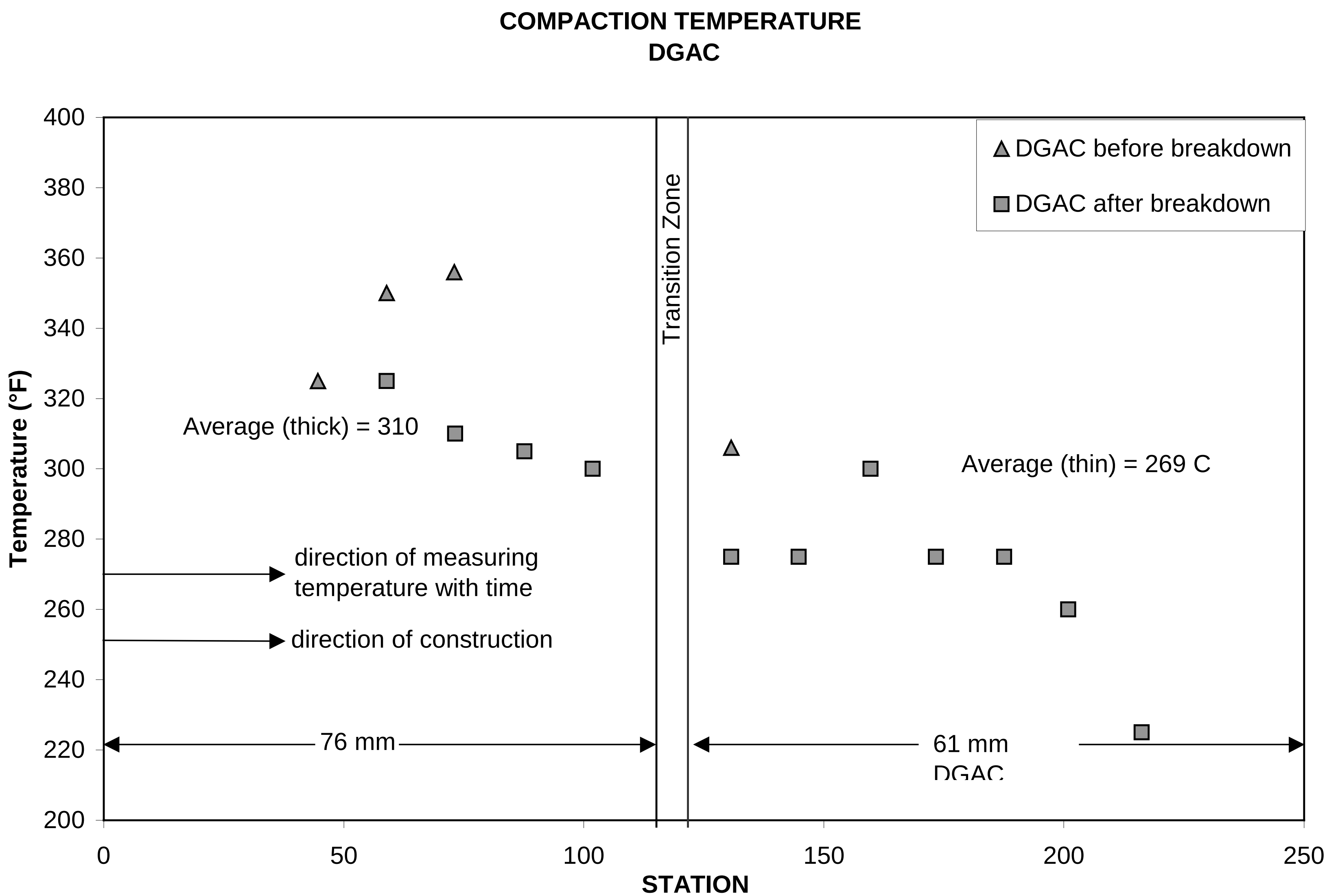
APPENDIX E: COMPACTION TEMPERATURES

Appendix E, Table 1 Compaction Temperatures for Goal 3 Overlays

STATION	TIME	ROLLER TEMPERATURE #1	ROLLER TEMPERATURE #2
ASPHALT RUBBER HOT MIX: BEFORE BREAKDOWN			
2 + 1.0	1:20	200 ºF	
2 + 14.0	1:18	245 ºF	
ASPHALT RUBBER HOT MIX: AFTER BREAKDOWN			
0 + 16.30	1:30	150 ºF	100 ºF
0 + 44.60	1:38	175 ºF	110 ºF
0 + 87.65	1:43	199 ºF	175 ºF
1 + 1.85	1:46	200 ºF	120 ºF
1 + 15.10	1:50	175 ºF	160 ºF
1 + 30.70	1:55	150 ºF	100 ºF
1 + 59.15	1:58	125 ºF	100 ºF
DENSE GRADED ASPHALT CONCRETE: BEFORE BREAKDOWN			
0 + 73	2:28	356 ºF	325 ºF
0 + 58.9	2:30	350 ºF	325 ºF
0 + 44.6	2:33	325 ºF	320 ºF
1 + 30.7	2:46	306 ºF	256 ºF
DENSE GRADED ASPHALT CONCRETE: AFTER BREAKDOWN			
0 + 58.9	2:37	325 ºF	300 ºF
0+ 73.25	2:40	310 ºF	275 ºF
0 + 87.65	2:42	305 ºF	275 ºF
1 + 1.85	2:44	300 ºF	280 ºF
1 + 30.7	2:59	275 ºF	250 ºF
1 + 44.75	3:01	275 ºF	265 ºF
1 + 59.75	3:03	300 ºF	280 ºF
1 + 73.35	3:05	275 ºF	250 ºF
1 + 87.6	3:14	275 ºF	260 ºF
2 + 0.9	3:16	260 ºF	250 ºF
2 + 16.2	3:18	225 ºF	225 ºF



Appendix E, Figure 1. Goal 3 overlay ARHM-GG compaction temperature measured during construction.



Appendix E, Figure 2. Goal 3 overlay DGAC compaction temperature measured during construction.

APPENDIX F: NUCLEAR DENSITY GAGE DATA

NUCLEAR DENSITY GAGE DATA ON DGAC			
DISTANCE		**IN-PLACE**	**AVERAGE AIR**
LONGITUDINAL	**TRANSVERSE**	**WET DENSITY**	**VOIDS**
0 + 34 '	6.5 '	2.333	6.5%
1 + 01.85 ;	5.5 '	2.369	5.1%
1 + 77 '	5.5 '	2.313	7.4%
1 + 55 '	10.0 '	2.336	6.4%
1 + 33 '	2.5 '	2.318	7.2%
0 + 28 '	9.5 '	2.342	6.2%
0 + 39 '	9.5 '	2.305	7.7%
0 + 65 '	3.5 '	2.391	4.3%
0 + 90 '	7.0 '	2.358	5.6%
1 + 25 '	5.5 '	2.288	8.4%
1 + 33 '	7.0 '	2.293	8.2%
1 + 50 '	5.0 '	2.324	6.9%
1 + 90 '	9.5 '	2.289	8.3%
2 + 04 '	10.0 '	2.31	7.5%
0 + 66 '	11.0 '	2.304	7.7%
Average		2.325	6.9
Standard Deviation		0.03	1.2
Minimum		2.288	4.3
Maximum		2.391	8.4
Maximum Specific Gravity = 2.497			

APPENDIX G: AIR VOID DATA FROM SITE CORES

CAL / APT GOAL 3 HVS Site Cores

Specimen heights are measured at four locations for the different asphalt layers

After cores are cut down to 50 mm specimens for testing, the lifts are identified as follows

O (or OV) - The Overlay, either DGAC or ARHM-GG

T (or TL) - The Top Lift of Goal 1 Construction

B (or BL) - The Bottom Lift of Goal 1 Construction

Section	**Point**	**Lift**	**AVwp**	**AVnp**	**RiceMaxSpG**	**WA**	**WAWP**	**WWWP**	**WW**	**SpGwp**	**SpGnp**
G3-DG	1	OV	6.4469	5.526293	2.543	2143	2145	1242	1251	2.379055	2.402466
G3-DG	2	OV	7.0346	5.61456	2.543	2165	2167	1249	1263	2.364111	2.400222
G3-DG	3	OV	6.7240	5.710665	2.543	2158	2160	1248	1258	2.372008	2.397778
G3-DG	4	OV	6.5626	5.872001	2.543	2195	2197	1271	1278	2.376113	2.393675
G3-DG	5	OV	6.3390	5.526834	2.543	2155	2157	1250	1258	2.3818	2.402453
G3-DG	6	OV	5.2507	4.337279	2.543	2187	2190	1279	1288	2.409475	2.432703
G3-DG	7	OV	5.7362	5.142657	2.543	2171	2174	1265	1271	2.397129	2.412222
G3-DG	8	OV	6.0570	5.255851	2.543	2166	2169	1259	1267	2.388971	2.409344
G3-DG	9	OV	7.3086	5.693266	2.543	2156	2159	1241	1257	2.357143	2.39822
G3-DG	10	OV	6.5399	5.41191	2.543	2148	2150	1244	1255	2.37669	2.405375
G3-DG	11	OV	5.7649	4.94966	2.543	2173	2175	1266	1274	2.396398	2.41713
G3-DG	12	OV	5.5016	4.587523	2.543	2174	2177	1269	1278	2.403095	2.426339
G3-DG	13	OV	5.4169	4.806963	2.543	2169	2171	1267	1273	2.405249	2.420759
G3-DG	14	OV	6.3338	4.688682	2.543	2162	2165	1254	1270	2.381932	2.423767
G3-DG	15	OV	6.3721	5.033865	2.543	2159	2161	1252	1265	2.380958	2.414989
G3-DG	16	OV	5.7748	5.059626	2.543	2156	2158	1256	1263	2.396147	2.414334
G3-DG	17	OV	7.0426	6.001303	2.543	2039	2043	1176	1186	2.363906	2.390387
G3-DG	18	OV	6.4731	5.709917	2.543	1959	1962	1135	1142	2.378389	2.397797
G3-DG	19	OV	7.0851	6.036718	2.543	2000	2005	1153	1163	2.362825	2.389486
G3-DG	20	OV	7.1803	6.228259	2.543	2015	2018	1161	1170	2.360406	2.384615
G3-DG	21	OV	7.6531	5.777322	2.543	2202	2205	1264	1283	2.348383	2.396083
G3-DG	25	OV	9.0396	6.257532	2.543	2217	2222	1258	1287	2.313123	2.383871
G3-DG	26	OV	10.8355	6.622958	2.543	2111	2120	1179	1222	2.267454	2.374578
G3-DG	27	OV	7.8378	5.674405	2.543	2214	2217	1269	1291	2.343684	2.3987
G3-DG	28	OV	7.3946	6.16424	2.543	2255	2259	1297	1310	2.354955	2.386243
G3-DG	29	OV	8.3976	5.925769	2.543	2177	2181	1242	1267	2.32945	2.392308
G3-DG	30	OV	6.5620	5.290967	2.543	2223	2227	1287	1300	2.376128	2.408451
G3-DG	31	OV	7.7337	5.640546	2.543	2186	2189	1254	1275	2.346333	2.399561
G3-DG	32	OV	8.0773	5.8654	2.543	2255	2258	1290	1313	2.337595	2.393843
G3-DG	33	OV	7.9894	5.511662	2.543	2201	2204	1260	1285	2.33983	2.402838
G3-DG	34	OV	6.8695	5.513461	2.543	2237	2241	1292	1306	2.36831	2.402793
G3-DG	35	OV	8.3802	5.155647	2.543	2231	2235	1273	1306	2.329891	2.411892
G3-DG	36	OV	9.1271	5.799028	2.543	2144	2146	1216	1249	2.310898	2.395531
G3-DG	37	OV	7.8344	6.018196	2.543	2237	2242	1282	1301	2.343772	2.389957
G3-DG	38	OV	6.6098	5.167953	2.543	2291	2294	1326	1341	2.374914	2.411579
G3-DG	39	OV	8.7645	5.666973	2.543	2159	2163	1228	1259	2.320119	2.398889
G3-DG	40	OV	7.7745	5.83584	2.543	2215	2220	1270	1290	2.345294	2.394595
G3-DG	41	OV	7.1275	5.640451	2.543	2198	2201	1267	1282	2.361748	2.399563

G3-DG	42	OV	8.5218	5.823378	2.543	2165	2168	1234	1261	2.326289	2.394912
G3-DG	43	OV	8.5247	5.736379	2.543	2167	2171	1235	1263	2.326217	2.397124
G3-DG	44	OV	8.8368	5.596799	2.543	2139	2142	1216	1248	2.31828	2.400673
	AVERAGES		7.2	7.2		Min	5.3			Number of Cores	
	St Dev		1.2	1.2		Max	10.8			41	
G3-DG	5	BL	3.0585	2.349886	2.513	2238	2241	1319	1326	2.436139	2.453947
G3-DG	15	BL	3.0958	2.698362	2.513	2186	2189	1288	1292	2.435202	2.44519
G3-DG	7	BL	3.2670	2.762618	2.513	2187	2190	1287	1292	2.4309	2.443575
G3-DG	2	BL	3.2994	2.476488	2.513	2240	2242	1318	1326	2.430087	2.450766
G3-DG	8	BL	3.3744	2.871141	2.513	2187	2190	1286	1291	2.428201	2.440848
G3-DG	6	BL	3.4299	2.723183	2.513	2227	2230	1309	1316	2.426807	2.444566
G3-DG	14	BL	3.4380	2.822533	2.513	2171	2174	1276	1282	2.426602	2.44207
G3-DG	10	BL	3.5270	2.912056	2.513	2169	2172	1274	1280	2.424367	2.43982
G3-DG	9	BL	3.6141	3.207233	2.513	2177	2179	1278	1282	2.422178	2.432402
G3-DG	4	BL	3.6649	2.854225	2.513	2224	2227	1305	1313	2.4209	2.441273
G3-DG	1	BL	3.7070	2.979423	2.513	2187	2189	1283	1290	2.419843	2.438127
G3-DG	3	BL	3.9928	2.969119	2.513	2236	2238	1309	1319	2.41266	2.438386
G3-DG	17	BL	4.1657	3.284694	2.513	2027	2030	1185	1193	2.408317	2.430456
G3-DG	13	BL	4.1697	3.238585	2.513	2169	2172	1268	1277	2.408216	2.431614
G3-DG	18	BL	4.3176	4.128425	2.513	2031	2034	1186	1188	2.404499	2.409253
G3-DG	11	BL	4.4088	3.270849	2.513	2178	2181	1271	1282	2.402206	2.430804
G3-DG	19	BL	4.4301	3.932922	2.513	2011	2017	1173	1178	2.401672	2.414166
G3-DG	16	BL	4.4908	3.232498	2.513	2174	2176	1268	1280	2.400147	2.431767
G3-DG	12	BL	4.7747	3.941574	2.513	2146	2148	1249	1257	2.393012	2.413948
G3-DG	20	BL	4.9217	3.977577	2.513	1998	2005	1161	1170	2.389317	2.413043
	AVERAGES		3.9	3.9		Min	3.1			Number of Cores	
	Std. Dev.		0.6	0.6		Max	4.9			20	
G3-DG	13	TL	4.8593	4.256257	2.513	2151	2154	1251	1257	2.390886	2.40604
G3-DG	4	TL	4.9398	4.130904	2.513	2202	2204	1280	1288	2.388862	2.40919
G3-DG	12	TL	5.0020	4.291176	2.513	2143	2146	1245	1252	2.3873	2.405163
G3-DG	10	TL	5.0416	4.345279	2.513	2149	2153	1248	1255	2.386305	2.403803
G3-DG	1	TL	5.1755	4.682732	2.513	2151	2154	1248	1253	2.382939	2.395323
G3-DG	6	TL	5.3468	4.523324	2.513	2145	2147	1243	1251	2.378635	2.399329
G3-DG	9	TL	5.3685	4.238163	2.513	2149	2152	1245	1256	2.378089	2.406495
G3-DG	11	TL	5.6211	4.612347	2.513	2143	2147	1239	1249	2.371741	2.397092
G3-DG	5	TL	5.6540	4.532108	2.513	2152	2155	1244	1255	2.370914	2.399108
G3-DG	3	TL	5.6592	4.637634	2.513	2164	2166	1251	1261	2.370785	2.396456
G3-DG	2	TL	5.7303	4.708377	2.513	2160	2162	1248	1258	2.368998	2.394678
G3-DG	16	TL	5.7324	4.487695	2.513	2141	2143	1237	1249	2.368945	2.400224
G3-DG	15	TL	5.8206	4.90658	2.513	2134	2137	1232	1241	2.366728	2.389698
G3-DG	41	TL	5.8447	5.978275	2.513	2221	2224	1282	1281	2.366122	2.362766
G3-DG	14	TL	5.8809	4.862019	2.513	2135	2138	1232	1242	2.365214	2.390817
G3-DG dropped	30	TL	5.9984	4.907827	2.513	2220	2222	1280	1291	2.362261	2.389666
G3-DG	36	TL	6.0332	5.262688	2.513	2226	2229	1283	1291	2.361386	2.380749
G3-DG	8	TL	6.0608	4.621529	2.513	2138	2141	1232	1246	2.360692	2.396861
G3-DG	7	TL	6.0731	4.737788	2.513	2133	2136	1229	1242	2.360384	2.393939
G3-DG	40	TL	6.1415	5.36856	2.513	2214	2217	1275	1283	2.358665	2.378088
G3-DG	33	TL	6.2281	5.448931	2.513	2224	2226	1280	1288	2.356487	2.376068
G3-DG	39	TL	6.2414	5.164833	2.513	2214	2217	1274	1285	2.356155	2.383208

G3-DG	44	TL	6.2837	5.207667	2.513	2213	2216	1273	1284	2.35509	2.382131
G3-DG	42	TL	6.3534	5.072457	2.513	2209	2212	1270	1283	2.353338	2.385529
G3-DG	21	TL	6.3795	5.293336	2.513	2211	2213	1271	1282	2.352684	2.379978
G3-DG	29	TL	6.4287	5.252559	2.513	2231	2233	1282	1294	2.351446	2.381003
G3-DG	26	TL	6.4553	5.486113	2.513	2216	2219	1273	1283	2.350778	2.375134
G3-DG	43	TL	6.4553	5.283076	2.513	2216	2219	1273	1285	2.350778	2.380236
G3-DG	34	TL	6.5290	5.464902	2.513	2226	2229	1278	1289	2.348927	2.375667
G3-DG	31	TL	6.6694	5.406417	2.513	2225	2228	1276	1289	2.345397	2.377137
G3-DG	19	TL	6.6738	5.485444	2.513	1969	1973	1129	1140	2.345289	2.375151
G3-DG	38	TL	6.6955	5.730841	2.513	2215	2218	1270	1280	2.344742	2.368984
G3-DG	18	TL	6.7135	5.550802	2.513	1989	1994	1140	1151	2.34429	2.373508
G3-DG	27	TL	6.9028	5.625014	2.513	2208	2210	1264	1277	2.339534	2.371643
G3-DG	20	TL	6.9041	5.921898	2.513	1967	1969	1126	1135	2.3395	2.364183
G3-DG	17	TL	7.0040	5.710804	2.513	1988	1991	1137	1149	2.336991	2.369487
G3-DG	37	TL	7.0191	5.459491	2.513	2219	2222	1269	1285	2.336609	2.375803
G3-DG	25	TL	7.1479	5.389494	2.513	2204	2208	1259	1277	2.333373	2.377562
G3-DG	28	TL	11.4348	5.486113	2.513	2216	2219	1220	1283	2.225644	2.375134
	AVERAGES		6.2	4.7		Min	4.9			Number of Cores	
	Std. Dev.		1.1	1.3		Max	11.4			39	