Performance of Rubberized Asphalt Concrete Open Graded High Binder Content (RAC-O-HB) Surface Mixes in California

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PROJECT SUMMARY PAGE	**Technical Report: CP2-105-2007**
Title: Performance of Rubberized Asphalt Concrete Open Graded High Binder Content (RAC-O-HB) Surface Mixes in California	
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Abstract:

The California Department of Transportation constructed six experimental sections using a rubberized asphalt concrete open graded with a high binder content (RAC-O-HB) as the surface layer. This was placed over two types of Portland cement concrete (PCC) and four hot mix asphalt (HMA) existing pavement structures. The PCC projects received either partial traditional concrete repairs or cracking and seating prior to placement of the RAC-O-HB. The existing HMA surfaces were resurfaced without repair. Traffic levels ranged from 300,000 to 3 million annual equivalent single 18,000 pound axle loads. The RAC-O-HB surface treatment is placed as a 1-inch, non-structural surface treatment.

Pavement condition surveys from 5 to 7 years after placement showed that the RAC-O-HB surface treatments were generally in excellent condition. In areas with visible distresses, the cracks were very fine reflective cracks. One of the projects was placed at cooler than desirable nighttime temperatures and with a lower than optimum binder content. This project showed a tendency for the reflective cracks to be slightly wider and more raveled around the edges. Regardless of the severity level of the cracks, all surface treatments exhibited exceptionally good bonds with the pre-treatment surface. Noise measurements indicated both an initial and sustained noise reduction of about 5 dB for the RAC-O-HB compared to either old HMA or PCC surfaces.

Keywords:
RAC-O-HB, Rubberized Asphalt, Open Grade, RHMA-O-HB

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DISCLAIMER

The contents of this report reflect the views of the authors who are responsible for the facts and accuracy of the data presented herein. The contents do no necessarily reflect the official views or polices of the State of California or the Federal Highway Administration

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INTRODUCTION

Asphalt rubber is a blend of asphalt cement, reclaimed and ground tire rubber, and additives such as extender oils. Various types of asphalt rubber mixes including gap graded and open graded friction courses are used in the state of California. Thinner types of maintenance and rehabilitative mixes are used for noise reduction and improved resistance to reflective cracking over distressed flexible and rigid pavements (Carlson, no date; Caltrans 2003).

Open graded mixes, unlike the gap graded mixes, are not considered a structural component of the pavement. Open graded mixes are designed to provide a freely draining driving surface that rapidly removes water away from the tire-pavement interface. They are also used to restore or improve surface friction in dry conditions, accentuate visibility of pavement markings, and minimize reflective cracking from older, distressed pavement surfaces. Open graded surface courses are placed in thin lifts of 1- to 1.2 inches; rubberized asphalt binder can be used instead of paving grade asphalt with this gradation. In California, the increase in binder content in the open graded mixes is 20% more than for open graded mixes constructed with unmodified asphalts (Caltrans 2003).

Caltrans is currently evaluating potential additional benefits of using a higher binder content, similar to those used by the Arizona Department of Transportation (Carlson, no date), with RAC-O mixes. The 5 to 7 year performance of Caltrans high binder mixes, designated RAC-O-HB for rubberized asphalt concrete open graded mixes with a high binder content, are the focus of the case studies summarized in this paper.

OBJECTIVES and SCOPE

The objective of this report is to summarize individual RAC-O-HB project durability and noise reduction performance for seven projects on five California roadways as reported by George Way on behalf of the California Pavement Preservation Center to the California Department of Transportation (2007). Projects varied by the type of existing surface (HMA and PCC), traffic level (300,000 to 3,000,000 annual ESALs), and environmental conditions (desert to mountainous) (Figure 1).

MATERIALS

Aggregates

Table 1 shows a typical set of aggregate properties for the RAC-O-HB mixes used for in these case studies. The aggregates are high quality with low LA abrasion values, high specific gravities (implying low water absorption capacities), and 100% crushed (Caltrans 2003; Way 2006 and 2007. The gradation is predominately 2-sized, with 63% of the 4.75 mm size and 27% of a 2.36 mm size (Figure 2).

The 100% crushed faces requirement for all of the aggregates used in these mixes provides the high quality, wear resistant, angular shape needed for skid resistance and aggregate interlock for shear (rutting) resistance

RAC-O-HB Project Locations

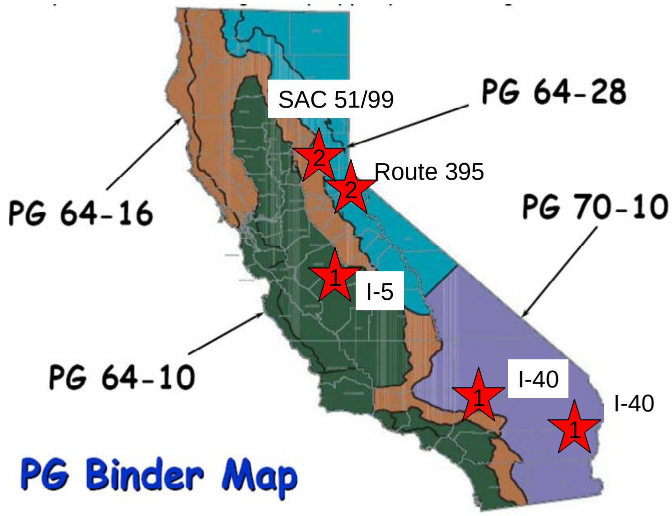

Figure 1. Location and general climatic conditions for RAC-O-HB projects.

Table 1. Typical aggregate properties (RAC-O-HB) (Way 2007).

Test	Coarse Aggregate	Fine Aggregate	Combined
Specific Gravity	2.75	2.71	
Crushed Particles	100%	100%	
LA Abrasion, 100, %	4		
LA Abrasion, 500, %	17		
Sieve Size, mm			Percent Passing, %
19			100
17.5			100
12.5			100
9.5			98
4.75			35
2.38			8
1.18			6
0.6			5
0.3			3
0.15			2
0.075			1

Shaded areas indicate no data available.

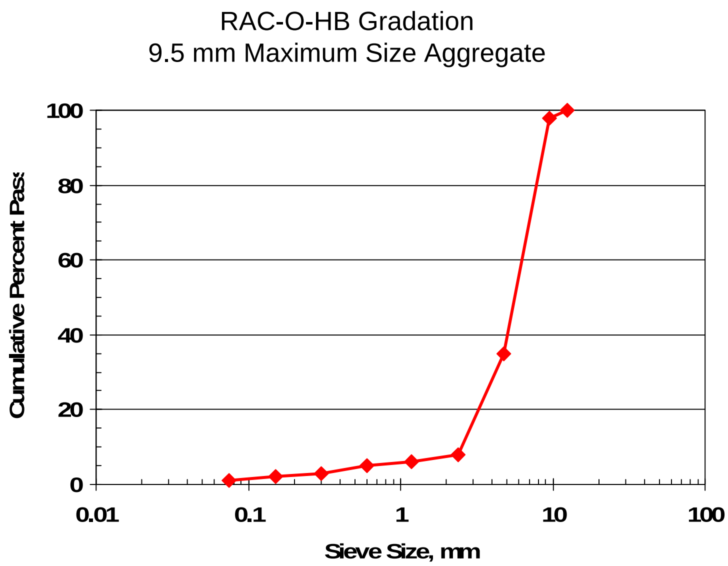

Figure 2. Typical aggregate gradation for RAC-O-HB (after Way 2007).

Rubberized Asphalt Binder

Rubberized asphalt binder as specified by Caltrans (2003) is comprised of 80% conventional paving grade AR-4000 and 20% (+/- 2%) of a 25:75 blend of high natural rubber (isoprene; truck tires) and scrap tire rubber (synthetic rubber; passenger tire rubber). The truck tire rubber is finely ground to a particle size between 1.18 and 0.30 mm (No. 16 and No. 50). The passenger tire rubber has a slightly coarser gradation which is typically between 2.00 and 0.60 mm (No 10 and No. 30). Extender oils are used as additive to improve the blending and interactions between the rubber particles and the base asphalt. Table 2 shows the properties evaluated for rubberized asphalt (Type II) and the specification limits for each.

This modified asphalt produces a binder that retains a high resistance to permanent deformation (rutting) at warm temperature while the base asphalt properties provide the ductility needed for resistance to thermal and reflective cracking. This combination of desirable materials properties is responsible for the improved crack resistant, durable, long wearing surface course.

Table 2. Asphalt rubber binder requirements (Caltrans 2003).

Test	Specification Limits at 45 minutes
Viscosity, cP Haake at 190C	1,500 to 4,000
Resilience at 5C (% Rebound)	18 minimum
Ring and Ball Softening Point, C	52 to 74 (15 to 165F)
Cone Penetration at 25C	25 to 70

RAC-O-HB Mix Design

The basis for the Caltrans RAC-O-HB mix design is the California Test 368 Standard Method for Determining Optimum Bitumen Content for Open Graded Asphalt Concrete (Caltrans 2007-1). This test method statically compacted discs of asphalt-coated aggregate, then uses a draindown test to select the highest binder content with a draindown of no more than 4 grams. The approximate binder ratio (ABR) is used to estimate the binder content used for preparing samples. The ABR is calculated as the centrifuge kerosene equivalent (K_c) times 1.5 plus 4.0. The K_c value, which was 1.4 for these projects, is determined according to the California Test 303 Standard test for Centrifuge Kerosene Equivalent and Approximate Bitumen Ratio (Caltrans 2007-2). Figure 1 shows how the optimum binder content is determined for open graded mixes using a conventional paving grade binder. The optimum rubberized binder content for open graded mixes is then defined as the optimum content times 1.2 (i.e., a 20% increase for rubberized binders). Based on other state's experiences and recommendations from industry, Caltrans selected the optimum binder for the high binder content RAC-O-HB mixes as 1.65 times the optimum binder content for open graded mixes using conventional AR4000 paving grade binder. Industry also recommended that this value be set at a minimum of 8.5%. It is important to note that California describes the optimum binder content as a percent of the dry weight of aggregate rather than the total weight of mix.

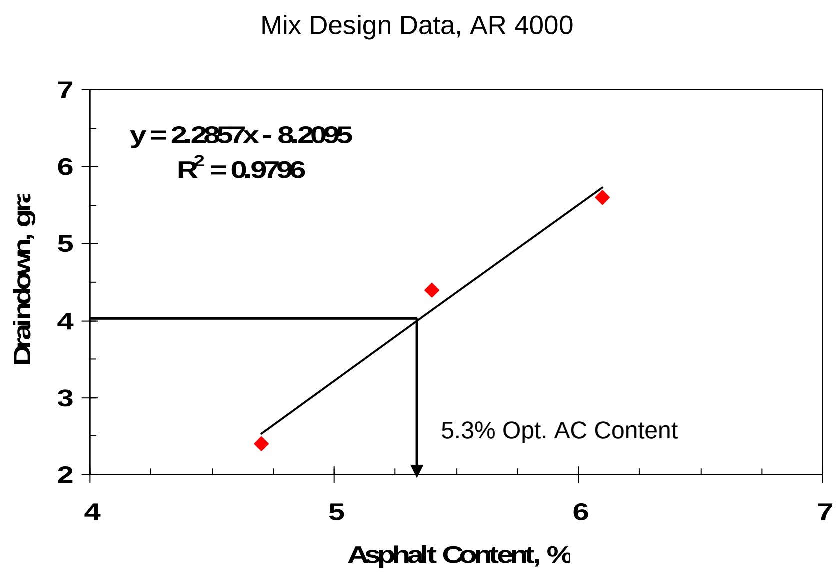

Figure 3. Selecting optimum binder content for open graded mix (K_c is 1.4).

PROJECT PERFORMANCE

Project Descriptions

The ***SAC 50/99*** project was constructed in 1999 in District 3 from posted miles (PM) 21.6 to 24.6, in Sacramento California. This project was designed to reconstruct the Route 99 median and add a high occupancy vehicle (HOV) lane in both the north and south bound directions as well as convert the number 1 lanes in both directions on Route 51 to HOV lanes. The pre-treatment existing pavement condition was a cracked and seated old PCC pavement. While some repair work was completed to repair spalling, longitudinal and transverse cracking, and slab replacement prior to placing the RAC-O-HB; the high traffic volumes and need for construction speed limited the actual amount of repairs that could be completed prior to resurfacing. This resulted in the RAC-O-HB being placed over the old, unrepaired PCC pavement in some locations.

The ***FRE I-5*** project was constructed in 2000 in District 6 on I-5 PM 0.0 to 38.0, which is 70 miles north of Bakersfield, California. This is a valley farming area (500 ft elevation) with summer highs around 100^{o}F, with winter lows down to 32^{o}F, annual rainfall 5.7 inches, two-way annual average daily traffic (AADT) of 33,500 with 8,899 trucks in the mix. This traffic level was used to estimate the annual equivalent 18,000 lb single axle loads (ESALs) of 2,748,000. The pre-treatment surface was a cracked and seated PCC pavement.

The ***MONO 395*** project was constructed 2000 in District 9 on Route 395 from PM 76.0 to 84.5 near Bridgeport, California. This is a mountainous area (6,250 elevation) with summer highs of 80^{o}F and winter lows of around 10^{o}F and an annual rainfall around 9 inches. The two-way traffic has an AADT of about 6,400 with a low number of trucks (1,062) in the mix. The estimated annual ESALs are 297,000. The 1-in RAC-O-HB treatment was placed on existing distressed HMA pavement. Predominate distresses in the existing pavements were thermal cracking with some alligator cracking in the wheel paths.

The two sections of the ***SBD 40*** project were constructed in District 8 in 2002: 1) I-40 from PM 3.0 to15.0 near Barstow, California, and 2) I-40 PM 73.4 to 89 about 50 miles east of Ludlow. Both sections can be described by the same environmental and traffic conditions. The area is considered a desert area at an elevation of 1,900 ft, with summer highs well over 100^{o}F and winter lows around 32^{o}F with an annual rainfall around 4.3 inches. The AADT two-way is 14, 900 with 6,333 trucks, which results in estimated annual ESALs of 1,892,000. The 1-in RAC-O-HB treatment was placed over old HMA with minor distress levels.

Surface Condition

Table 4 summarizes the projects evaluated, the year of RAC-O-HB construction, binder contents extracted from construction records, condition of existing pavement prior to treatment, and surface condition at the time of the follow up survey (Way 2006 and 2007).

SAC 50/99

The project work was started on April 1, 1998. The production and the paving of the RAC-O-HB mix were completed during a night time paving operation between July 19, 1999 and August 3, 1999. Due to various difficulties, only the southbound lane PCC pavement was complete; repairs on the northbound lane was less thoroughly repaired. The minimum air temperature of 65^{o}F

(18^{o}C) was difficult to meet; paving temperatures were closer to 55^{o}F (13^{o}C) during most of the paving. The binder content was also lower than the preferred target of 8.5% (Table 4). The construction records indicate intermittent difficulties with pick-up on the mat by rubber tires and difficulty in hand-working the mix. Construction records indicate the following observations were made:

- The binder content was consistently too low due to a field engineering change in the mix design. There was some debate on whether the final mix represented a RAC-O-HB as a result of the low binder content.
- Longitudinal joints were not aligned with the striping, leaving a construction joint in a wheel path.
- The contractor was instructed to pave the full width of the lane each night. It was felt that a better paving job would have been accomplished by paving each lane in its entity, with one full lane being completed each night.
- Pick-up would have been less of a problem if sanding the new surface had been required.

The overall performance, even with all of the less-than-optimum paving conditions, produced a surface treatment that is providing good to fair performance. In areas where the reflective cracks in the surface mix are starting to ravel, the areas of distresses are limited and the mix is well bonded with the original PCC surface (Figure 4).

Table 3. Project locations, length, year constructed, pre-RAC-O-HB condition, and performance after 5 or more years (after Way 2006 and 2007).

Project	PM	Lane Miles	Date Const.	% Binder	Pre-Overlay Surface	RAC-O-HB Condition in 2007
SAC 99	21.6-24.6	3	1999	7.0-8.2	* PCC with variable distresses * South bound lane PCC repaired * North bound lane PCC partially repaired	• Reflective cracking at PCC joints and old PCC slab cracks, both with moderate raveling along edges of cracks • Very limited loss of surface material along cracks
FRE I-5	0-38	165	2000	8.5-10.0	HMA over a crack and seat PCC with some rutting and cracking in HMA surface Plain jointed unreinforced PCC	• Estimated PCI 84 North bound and 90 South bound • Limited and narrow reflective cracking from shattered slabs • Occasional punch out of shattered slab section with pumping • No more than 1/8 in ruts
MONO 395	76.0-84.5	8.5	2000	8.7-10.0	HMA with some thermal cracking	• Estimated PCI 74 to 88 • Low level thermal cracking
SBD 40	3-15	112	2002	8.5-10.0	HMA with some minor distress	• Estimated PCI 85 to 91
SBD 40	73.4-89.5	112	2002	8.5-10.0	HMA with some minor distress	• **PM 80 to 89:** Estimated PCI 83 to 91 with some raveling and low level transverse cracking; limited low level longitudinal cracking • **PM 76.5 to 80**: Estimated PCI 61 to 73 with frequent low to moderate transverse cracking, mostly sealed; localized areas of alligator cracking and rut depths around ½ to 1 inch

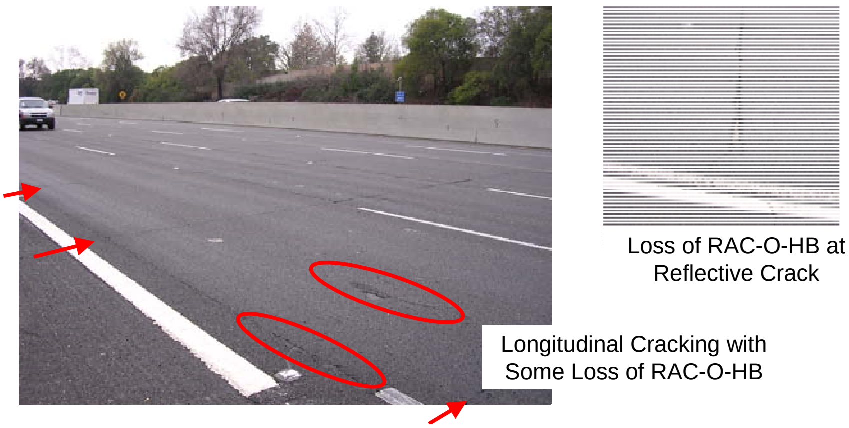

Figure 4. Typical condition of SAC 50/99 project after 7 years.

FRE-5 Project

The condition of this RAC-O-HB was rated as good. The condition survey indicated a smooth ride (subjective), a low severity of cracks when present, and occasional indications of distresses in the old PCC. There were very limited problems with the PCC; these distresses were limited to isolated punch outs accompanied by evidence of pumping of fines (Figure 5).

In an effort by the reviewers to quantify the performance, the Pavement Condition Index (PCI) number was estimated using the procedure detailed in the American Society for Testing and Materials (ASTM) Standard Test Method for Airport Pavement Condition Index Surveys. The presence, extent and severity of individual distresses are used to calculate a statistically determine rating of pavement condition from 100 (Best) to 0 (worst). The PCI was estimated by the reviewers as 84 for the north bound lanes and 90 for the south bound lanes. Both estimates reflect the good to very good condition of this project. The differences between the two directions likely reflect differences in the original condition of the pre-treatment pavement; however this can not be confirmed at this time.

FRE-5
RAC-O-HB Over Crack and Seat PCC
Estimated 2,748,000 Annual ESALs

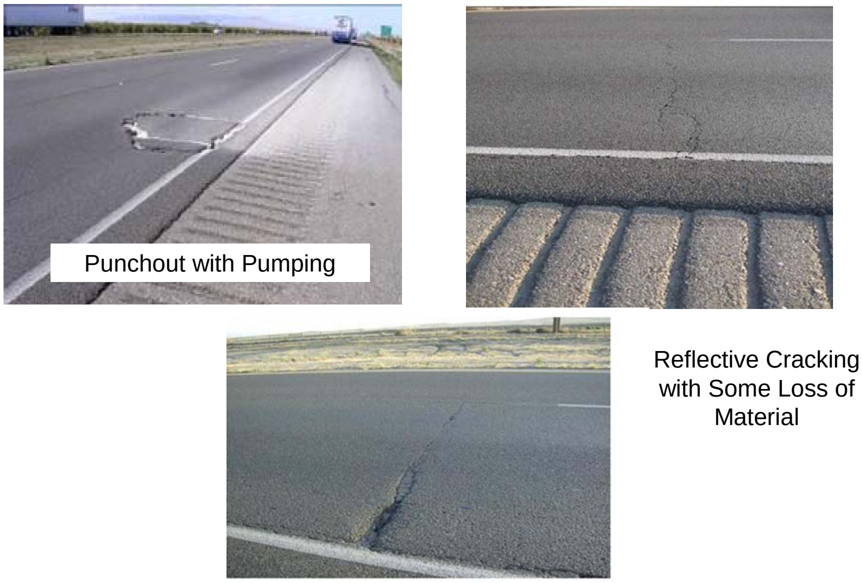

Figure 5. Typical condition of FRE-5 after 7 years.

MONO 395 Project

Transverse cracking consistently observed at spacing of between 25 and 50 feet. This type of cracking distress is environmentally related and is due to either long term thermal cycling or large single drops in temperature. It is likely that the cracking in the RAC-O-HB is a reflection of cracking patterns in the old HMA surface. Some of the transverse cracks had been sealed to limit water intrusion into the underlying layers (Figure 6).

Alligator cracking, a traffic load-related distress, is only seen in limited areas of the project. These limited areas also exhibited some loss of material (raveling). Rutting was usually less than 1/8 in; in some cases rutting was as much as 3/8 inch.

The reviewers noted that the ride was good, with some occasional noticeable bumps at the transverse cracks. The PCI for this project was estimated between 74 and 88. In general, this RAC-O-HB is in good shape for a 7 year old surface treatment.

Mono 395 PM 76 – 84.5
RAC-O-HB Over Distressed HMA
Estimated 297,000 Annual ESAL's

Figure 6. Typical condition of Mono 395 after 7 years.

SBD-40 Project PM 3 to 15

Only limited pre-treatment information was available for these projects (Table 4). After 5 years of heavy traffic, the RAC-O-HB was in very good condition. There were only a few fine longitudinal cracks in the wheel paths, limited alligator cracking of a low severity, and little to no rutting. There was some evidence of pumping of fines in the areas of alligator cracking (Figure 7).

The PCI estimates of 85 to 91 support the conclusion that these sections are in very good to excellent condition.

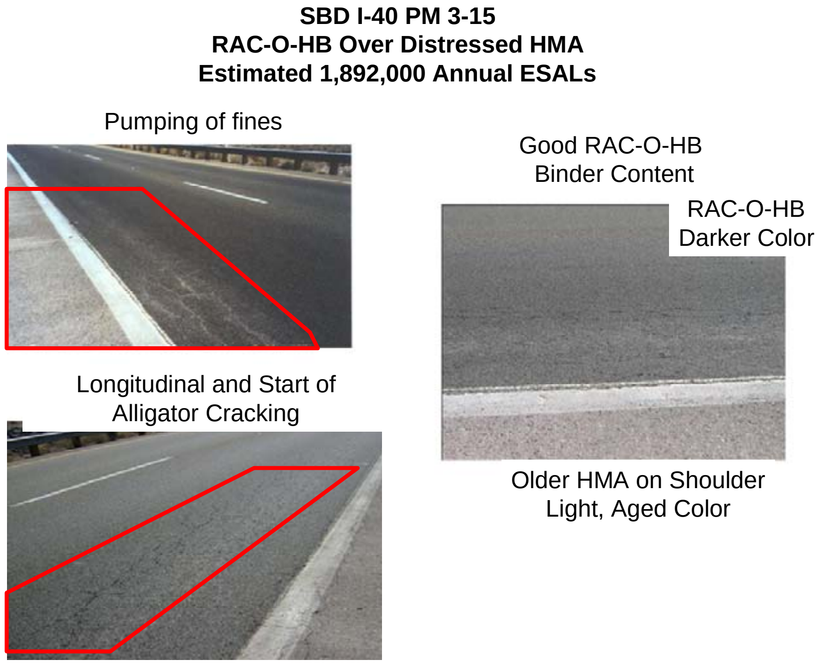

Figure 7. Typical condition of SBD-40 PM 3-15 after 5 years.

SBD 40 PM 73.4 – 89.5

A bridge reconstruction repair job between PM 78.5 and 80 divide this one project into two sections, each with different current pavement conditions. From PM 73.4 to about PM 80, the RAC-O-HB is in good condition with only a few longitudinal cracks in the wheel paths, limited alligator cracking, and some wear and weather related raveling (Figure 8). The estimated PCI were between 83 and 90.

The section of the project from PM 80 to 89.5 showed sealed transverse cracks from low to moderate severity for more than half of the section. In one area, there was a limited section of severe alligator cracking with ½ to 1 in ruts (Figure 8). The estimated PCI for this side of the bridge were much lower: 61 to 73.

The significant difference between the pavement condition on either side of the bridge suggests that there may be different geological or original construction differences (e.g., cut versus fill). These results highlight the need to assess the load carrying capability and structural condition of the existing roadway prior to selecting a surface treatment.

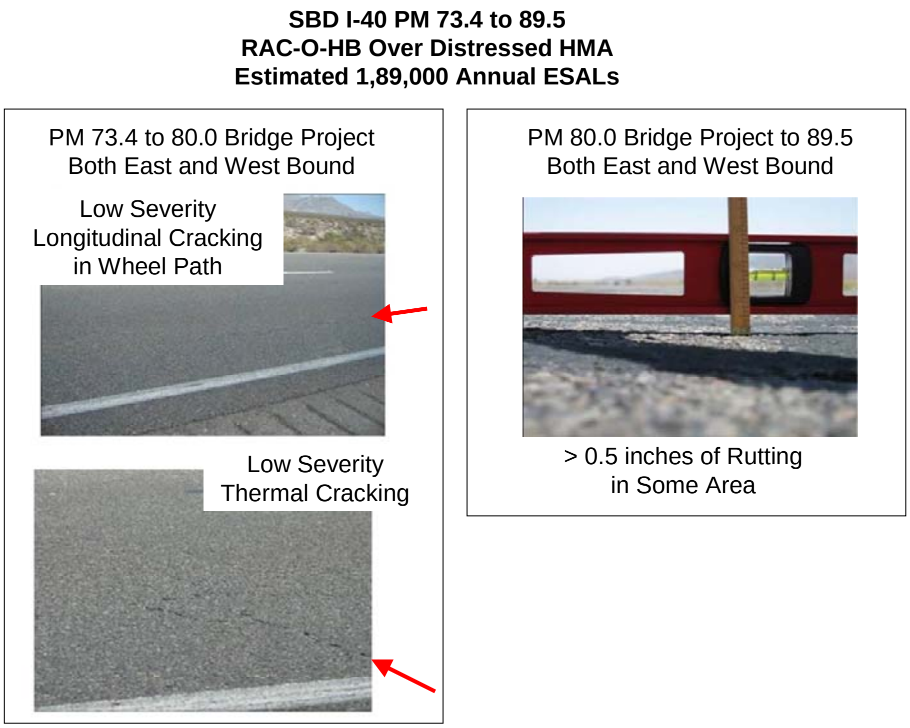

Figure 8. Typical condition of SBD-40 PM 73.4-89 after 5 years.

Noise Reduction

A 1999 report by Sacramento County and Bollard & Brennen, Inc. documents several California asphalt rubber open graded mix studies between 1991 and 1993. This research was conducted using the pass-by Federal Highway Administration Highway Traffic Noise Prediction Model, which rigorously evaluated noise before (old HMA) and after resurfacing with new HMA and with an asphalt rubber open grade mix. There was an initial reduction in noise of 2dB with the new conventional HMA. After 4 years, the HMA surface had returned to the pre-surfacing dB level, resulting in no net reduction in the noise level. However, the asphalt rubber open grade surface initially reduced the noise level by 6 dB, and retained the reduction in noise level at about 5dB 6 years after construction.

The noise testing for the RAC-O-HB projects was conducted with a hand held noise measurement device from inside of a Lexus, with the windows closed and the air conditioner on low. This type of testing can be considered a variation of the close proximity (CPX) type of testing with the acoustical chamber being the interior of the car. This provides a relative comparison of occupant-perceived sound levels as the car travels over different pavement surfaces.

The noise levels for the projects are shown in Table 3. Nearby pavements with old HMA and Portland cement concrete surfaces were also tested when possible. The average dB level of the old HMA and the PCC surfaces tested were similar (71.5 and 70.2 dB, respectively) and 66.9 dB after 5 to 7 years of service for the RAC-O-HB (Figure 10). Because the dB scale is a logarithmic scale, a 3 dB reduction in the noise level is considered significant. For these projects, the RAC-O-HB treatment produces pavement surfaces with almost 5 dB reduction in noise compared to conventional HMA. The level of noise reduction achieved with the RAC-O-HB mixes is consistent with previously reported values.

Table 4. Estimated noise levels inside car.

Route	Direction	PM	Surface Type	Average dB
395	North Bound	76-84.5	HMA (Old)	66.6
I-5	North Bound	78-80	HMA (Old)	74.5
I-5	North Bound	85-87	HMA (Old)	69.6
I-5	North Bound	20-22	HMA (Old)	72.7
I-40	West Bound	19-20	HMA (Old)	72.2
I-40	East Bound	17-18	HMA (Old)	73.6
			Average	***71.5***
			Std. Dev	***2.9***
I-5	North Bound	69-71	PCC	73.1
I-40	West Bound	69-73.4	PCC	68.6
I-40	East Bound	69-73.4	PCC	69.0
			Average	***70.2***
			Std. Dev	***2.0***
395	North Bound		RAC-O-HB	69.7
I-5	North Bound	3-11	RAC-O-HB	69.3
I-5	South Bound	29-36	RAC-O-HB	67.2
I-5	South Bound	11.5-16.5	RAC-O-HB	68.0
I-40	West Bound	3-15	RAC-O-HB	67.9
I-40	West Bound	81-89	RAC-O-HB	65.6
I-40	West Bound	78-81	RAC-O-HB	67.6
I-40	West Bound	73.4-78	RAC-O-HB	67.4
I-40	East Bound	3-4	RAC-O-HB	64.9
I-40	East Bound	5-10	RAC-O-HB	66.1
I-40	East Bound	10-15	RAC-O-HB	66.9
I-40	East Bound	73.4-75	RAC-O-HB	68.2
I-40	East Bound	76.5-79.5	RAC-O-HB	66.9
I-40	East Bound	81-82	RAC-O-HB	65.4
I-40	East Bound	83-86.5	RAC-O-HB	68.7
			Average	***66.9***
			Std. Dev	***1.4***
SAC 50, 99	No Data Available			

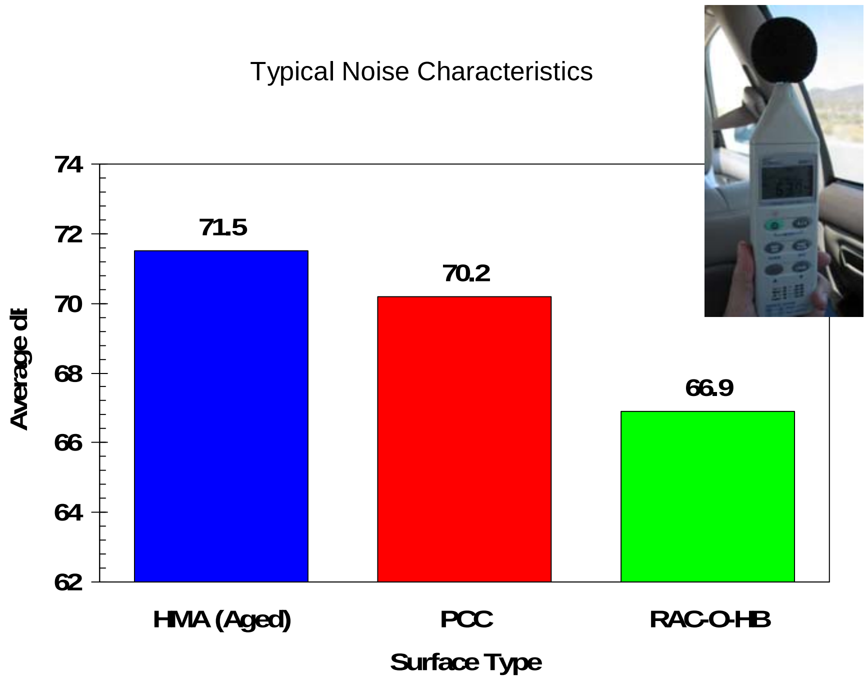

Figure 9. Estimates of noise levels inside car on various surfaces (photo from Way 2007).

CONCLUSIONS

These California case studies evaluating RAC-O-HB surface treatments, which is a rubberized asphalt concrete open graded mix with a high binder content of at least 8.5% (by dry weight of aggregate), placed in a 1 inch surface course. The following conclusions can be drawn from these studies:

- The high binder content and rubberized modification of the binder bonds very well with a wide range of existing pavement surfaces such as older distressed HMA, distressed PCC, and PCC that has been cracked and seated.
- The reflective cracking, while expected with such a thin surface treatment, is typically of a low severity, which is a function of the fine and narrow width of any visible cracks.
- RAC-O-HB surfaces, when placed using the minimum recommended binder content, can be expected to perform well, even at high traffic levels (3M annual ESALs), for at least 7 years without needing any other maintenance activities.
- When the rubberized binder content is below the recommended 8.5%, the surface treatment is less wear- and crack-resistant.

Best Practices

The following key points need to be considered for future evaluations and for achieving maximum service life:

- Preparation of existing PCC pavements such as slab repair or replacement, crack sealing, and spall repairs will influence the life of the treatment. For example, weak areas in a crack and seat PCC project can result in punch outs. While the

RAC-O-HB will still be firmly bound to the PCC, the punch out will still have to be repaired.

- Treatment joints need to be aligned with new lane lines to prevent placing joints in wheel paths. This high wear in a potentially low density or thermally segregated area can result in accelerated loss of the treatment surface.
- Assurances that the minimum recommended binder content of 8.5% (dry weight of aggregate) is achievable are needed at the mix design phase. Adjusting the gradation to provide more room for higher binder content at the design stage is more desirable than a lowering of the binder content based on visual inspection during construction. This is especially important if it is a night time job when visual inspections are difficult. Since night time paving is usually on high traffic volume roadways, attention to the mix design prior to paving is critical.
- Mix designs and optimum binder content should be verified using project materials immediately prior to placement.
- Material properties for all components (e.g., crumb rubber materials, rubberized asphalt, aggregates) should be submitted to a central data collection point so that construction material histories can be evaluated during future pavement condition surveys of experimental materials. Rubber tired vehicles should be limited on still-warm RAC-O-HB surfaces to avoid pick-up and damage to the new surface.
- Tight controls are needed on temperatures: air temperature, pavement temperature, and mix delivery temperature.
- Include the existing pavement (pre-treatment) distress survey information in the construction records for future comparisons.

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