CALTRANS EXPERIENCE WITH
RUBBERIZED ASPHALT CONCRETE

by

JACK L. VAN KIRK, P.E.
PAVEMENT RESEARCH ENGINEER

CALIFORNIA DEPARTMENT OF TRANSPORTATION
DIVISION OF NEW TECHNOLOGY, MATERIALS AND RESEARCH
5900 FOLSOM BOULEVARD
SACRAMENTO, CA 95819
(916) 739-2357

A PAPER PREPARED FOR PRESENTATION AT THE
TECHNOLOGY TRANSFER SESSION
"AN INTRODUCTION TO RUBBERIZED ASPHALT CONCRETE"
TOPEKA, KANSAS
JANUARY 23, 1991
CALTRANS EXPERIENCE WITH RUBBERIZED ASPHALT CONCRETE

by
Jack L. Van Kirk
Pavement Research Engineer

ABSTRACT

Caltrans has considerable experience with the use of rubber in dense graded asphalt concrete hot mix (DGAC). This experience began in 1978 and has continued to the present. The experience to date has indicated that the use of rubber in asphalt concrete can be cost-effective.

On the early projects, Caltrans compared equal thickness of rubberized asphalt concrete (RAC) to conventional DGAC. The RAC has outperformed the conventional mixes on these projects, but the question of cost-effectiveness is difficult to answer since most of the projects are still in service. In 1983, a project was constructed using reduced thickness RAC (as compared to the design thickness for the conventional DGAC). This project, which is still being evaluated, has shown that thinner sections of RAC can outperform thicker sections of conventional DGAC. But the question that remains is what reduction in thickness can be made and still provide the desired service (design) life.

Caltrans will continue to construction additional projects which will compare reduced thickness RAC to conventional DGAC. These projects are expected to provide field data in the near future to help determine what reduction in thickness is appropriate when using RAC. A gradual increase in the use of RAC is anticipated in the near future. However, if projects continue to indicate that RAC in reduced thickness will outperform conventional AC, then a more widespread usage will be expected.
INTRODUCTION

The California Department of Transportation (Caltrans) has been using rubber-modified asphalt concrete (RAC) for more than ten years. The first project using RAC was constructed in 1978 and since then Caltrans has had considerable experience with RAC. This experience has not only included field trials of RAC, but it has also included research in the laboratory (1). Caltrans has constructed more than 20 rehabilitation (overlay) projects using RAC overlays. These overlays have included various types of asphalt concrete (AC).

Overall Caltrans rehabilitation program has proved quite successful. However, in the snow regions where tire chains are used, the design life was not being achieved when using conventional DGAC, thereby resulting in increased maintenance costs. In 1978, in its quest to find a more durable mix for the snow region, Caltrans began experimenting with RAC mixes. Later laboratory research (1,2,3) indicated that RAC mixes were more abrasion resistant when compared to conventional DGAC. Field permeability testing (3) also showed that RAC mixes has extremely low permeabilities. It was felt that these low permeabilities would reduce the infiltration of water into the mat and therefore cut down on the freeze-thaw damage. The low permeabilities should also reduce oxidation and thereby lower the aging rate. Because of the success in the snow region, Caltrans began to broaden its use of RAC mixes.

BACKGROUND

On the RAC projects constructed by Caltrans prior to 1983, the RAC was compared to equal thicknesses of conventional DGAC. However, in 1983, a project was constructed (on Route 395 in northeastern California) using various overlay strategies including test sections of reduced thickness RAC (when compared to the conventional DGAC overlay design thickness). Also placed on the project were various thicknesses of conventional DGAC. This project, though not realized at the time, later became the turning point for Caltrans rehabilitation strategies involving RAC mixes. For awhile after 1983, Caltrans continued to construct and compare equal thicknesses of RAC and conventional DGAC on other projects, while reviewing and accumulating data on the Route 395 project. By 1987, it became evident that substantially thinner overlays of RAC, when compared to conventional DGAC, could provide a longer service life at a reduced cost. At this point in time, Caltrans strategy for RAC test section overlays changed. It was decided that all subsequent projects, if appropriate, would involve RAC overlays that were thinner than those required if conventional DGAC were used. These studies will continue until the necessary data are obtained to determine what reduction in overlay thickness is appropriate if RAC is used.
OVERLAY DESIGN

Caltrans uses a deflection-based design procedure for rehabilitation of flexible pavements. This procedure is also used for RAC overlays. On the early RAC projects, the RAC overlay design thickness was the same as that provided from the deflection study for conventional DGAC. Now Caltrans is experimenting with reduced thickness RAC overlays (as compared to the conventional AC design thickness). The design life normally used is ten years, and during this time only minor maintenance is expected.

A different approach is used for PCC pavement rehabilitation involving DGAC overlays. In order to try and obtain the desired ten-year design life, the early approach (prior to 1982) was to place a DGAC overlay 0.25 to 0.50 foot in thickness depending on the condition of the existing PCC pavement. However, the ten-year design life was not being achieved. After 1983, this strategy changed. PCC pavements are now cracked and seated, a leveling course of DGAC is placed, a pavement reinforcing fabric (PRF) is placed, and finally the pavement is overlayed with DGAC 0.25 thick placed in two lifts. This same approach is used for RAC overlays over PCC pavements. The RAC would replace the DGAC overlay over the PRF. In this particular case the RAC thickness may or may not be reduced.

MIX DESIGN

The Hveem mix design is used by Caltrans for all RAC mixes with a few minor changes. The mix and compaction temperature is increased to 300°F and Hveem stability requirement is waived. However, stability is still considered during mix design for DGAC mixes utilizing asphalt-rubber, with a lower value of around 20 being a target minimum. Void content and flushing on the surface of the fabricated briquettes are the primary concerns for mix design. The Caltrans 3/4 inch maximum, medium, Type B, grading is normally used for the dense graded RAC test sections. The binder content for open and dense graded RAC mixes is usually about 20% higher than that for the conventional DGAC mixes.

COST ANALYSIS

The cost per ton of RAC is about 40% to 50% over that of conventional DGAC. Most of the RAC projects constructed by Caltrans in the past have involved fairly low tonnages of RAC and, as a result, the cost has been relatively high. It is believed that as the use of RAC increases, a reduction in cost will be realized. However, even at the higher cost, RAC can be cost effective if reduced thicknesses (when compared to conventional DGAC) will provide the desired service life.
CONSTRUCTION

The construction of RAC overlays by Caltrans has been similar to that of conventional AC overlays, although there are a few important differences. First, these mixes must be placed at a higher temperature, preferably in a range between 300°F and 325°F. Raking should be completed before the mix temperature drops below 290°F. As the mix cools, it becomes stiffer and raking becomes very difficult. Breakdown rolling should be completed before the mix drops below 290°F. If the mix is compacted at 290°F or above, excellent relative compaction has usually been achieved quite easily. Values of 96% to 98% relative compaction (compared to a laboratory compacted briquette) are quite common.

TYPES OF RAC USED BY CALTRANS

Caltrans has constructed 21 rehabilitation projects using RAC overlays. These projects are listed in Table I. These projects have included rubber modified: dense graded asphalt concrete (DGAC), open graded asphalt concrete (OGAC), gap graded asphalt concrete (GGAC), and an Arizona-type, three-layer system. These overlays have been placed over flexible pavement (AC) as well as rigid pavement (PCC). On these projects six different types of RAC have been used: Devulcanized reclaimed rubber (Flomix or Ramflex) has been added to conventional DGAC mix; vulcanized reclaimed rubber has been added to a gap-graded aggregate and conventional asphalt (PlusRide - a patented mix), and vulcanized reclaimed rubber has been preblended with a conventional asphalt to form asphalt-rubber binder (Arm-R-Shield or Overflex - patented binders), which was then added to a dense graded, open graded or gap graded aggregate or the binder was used with a pre-coated chip as a stress absorbing membrane interlayer (SAMI) in an Arizona-type, three-layer system. SAMI's also have been used with other RAC mixes.

RAC LICENSE AND PATENT CHANGES

Over the years, there have been some major and minor changes concerning the ownership and use of the various RAC products. In the late 1970's, Flomix (produced and sold by U.S. Rubber Reclaiming, Inc.) was changed, reportedly in name only, to Ramflex. Ramflex was not only used as a dry rubber additive to conventional DGAC, but it was also reportedly used in the patented, asphalt-rubber binder, Arm-R-Shield, sold by Arizona Refining Company. In the middle 1980's, Caltrans was told that Arizona Refining did not use Ramflex and had not been using it since 1980, even though Arizona Refining had promoted their binder as being superior to Overflex, the patented asphalt-rubber binder sold by Crafco, because Arm-R-Shield utilized devulcanized rubber. There was concern at that time whether or not the formula had actually changed and whether the performance would also change. U.S. Rubber Reclaiming was sold a few years ago and Ramflex is no longer available.
TABLE I

RUBBERIZED ASPHALT CONCRETE PROJECTS PLACED IN CALIFORNIA

<table>
<thead>
<tr>
<th>PROJECT</th>
<th>CLIMATIC REGION</th>
<th>CONST. DATE</th>
<th>DISTRICT COUNTY ROUTE</th>
<th>POST MILE LIMITS</th>
<th>STRUCTURAL SECTION (FT)</th>
<th>AADT^2 (% TRUCKS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Meyers</td>
<td>S</td>
<td>1978</td>
<td>03-Ed-50</td>
<td>72.45/72.50</td>
<td>0.20 ARC</td>
<td>14,200 (3.1)</td>
</tr>
<tr>
<td>2. Strawberry</td>
<td>S</td>
<td>1980</td>
<td>03-ED-50</td>
<td>52.2/66.5</td>
<td>0.10 ARC/0.20 AC/PRF</td>
<td>10,000 (3.1)</td>
</tr>
<tr>
<td>3. Donner Summit</td>
<td>S</td>
<td>1980</td>
<td>03-Nav-80</td>
<td>5.16/5.59</td>
<td>0.20 ARC/0.40 AC</td>
<td>22,800 (9.0)</td>
</tr>
<tr>
<td>4. Donner Lake</td>
<td>S</td>
<td>1981</td>
<td>03-Nav-80</td>
<td>7.3/8.8</td>
<td>0.20 ARC/PRF/LEV</td>
<td>22,800 (9.0)</td>
</tr>
<tr>
<td>5. Boka</td>
<td>S</td>
<td>1982</td>
<td>03-Nav-80</td>
<td>23.8/24.8</td>
<td>0.10 &amp; 0.20 ARC/0.10 OGAC (R)</td>
<td>21,400 (16.1)</td>
</tr>
<tr>
<td>6. I-80/Ft 20 Jct.</td>
<td>S</td>
<td>1982</td>
<td>03-Nav-20</td>
<td>44.1/44.3</td>
<td>0.08 OGAC (R)</td>
<td>2,700 (8.0)</td>
</tr>
<tr>
<td>7. Ravendale</td>
<td>S</td>
<td>1983</td>
<td>02-Las-395</td>
<td>92.0/101.4</td>
<td>0.15 ARC &amp; Plus</td>
<td>1,100 (22.3)</td>
</tr>
<tr>
<td>8. Colfax</td>
<td>S</td>
<td>1984</td>
<td>03-Pla-80</td>
<td>35.0/36.9</td>
<td>0.15 ARC/PRF/LEV</td>
<td>24,500 (14.2)</td>
</tr>
<tr>
<td>9. Flouriston</td>
<td>S</td>
<td>1984</td>
<td>03-NEV-80</td>
<td>23.5/28.0</td>
<td>0.25 RAM/PRF/LEV</td>
<td>21,400 (15.1)</td>
</tr>
<tr>
<td>10. Monte Vista</td>
<td>S</td>
<td>1984</td>
<td>03-PLA-80</td>
<td>42.9/45.7</td>
<td>0.25 RAM/PRF/LEV</td>
<td>22,500 (14.2)</td>
</tr>
<tr>
<td>11. So. Lake Tahoe</td>
<td>S</td>
<td>1985</td>
<td>03-ED-89</td>
<td>8.9/10.0</td>
<td>0.17 ARC/PRF/LEV</td>
<td>18,000 (4.1)</td>
</tr>
<tr>
<td>12. Pittsburg</td>
<td>C</td>
<td>1985</td>
<td>04-CC-04</td>
<td>15.8/18.8</td>
<td>0.10 OGAC/SAMI(R)/0.10 OGAC</td>
<td>70,000 (5.0)</td>
</tr>
<tr>
<td>13. White Cloud</td>
<td>S</td>
<td>1986</td>
<td>03-NEV-20</td>
<td>28.3/29.2</td>
<td>0.10 Plus</td>
<td>3,000 (2.0)</td>
</tr>
<tr>
<td>14. Hayward</td>
<td>C</td>
<td>1986</td>
<td>04-Ala-80</td>
<td>13.7/15.0</td>
<td>0.08 OGAC (R)</td>
<td>170,000 (8.2)</td>
</tr>
<tr>
<td>15. Elkhorn RSR^4</td>
<td>V</td>
<td>1997</td>
<td>03-Sac-5</td>
<td>34.0</td>
<td>0.10 ARC</td>
<td>N/A</td>
</tr>
<tr>
<td>16. Ludlow</td>
<td>D</td>
<td>1987-88</td>
<td>06-Sbd-40</td>
<td>80.4/140.0</td>
<td>0.20 &amp; 0.30ARC &amp; Plus</td>
<td>7,000 (51.9)</td>
</tr>
<tr>
<td>17. Goldrun</td>
<td>S</td>
<td>1988</td>
<td>03-Pla-80</td>
<td>38.3/42.9</td>
<td>0.20 &amp; 0.30ARC &amp; Plus/PRF/LEV</td>
<td>24,500 (14.0)</td>
</tr>
<tr>
<td>18. San Francisco</td>
<td>C</td>
<td>1988</td>
<td>04-SF-101</td>
<td>0.0/3.0</td>
<td>0.08 OGAC (R)</td>
<td>190,000 (4.8)</td>
</tr>
<tr>
<td>19. Pit River Bridge</td>
<td>V</td>
<td>1989</td>
<td>02-Sha-5</td>
<td>28.1/29.9</td>
<td>0.10 ARC</td>
<td>13,000 (28.6)</td>
</tr>
<tr>
<td>20. Antler Undercrossing</td>
<td>V</td>
<td>1989</td>
<td>02-Sha-5</td>
<td>41.05</td>
<td>0.10 ARC</td>
<td>13,000 (28.6)</td>
</tr>
<tr>
<td>21. Chico</td>
<td>V</td>
<td>1990</td>
<td>02-But-32</td>
<td>18.58/18.71</td>
<td>0.10 AR-GAP</td>
<td>1500 (11.8)</td>
</tr>
</tbody>
</table>

Notes:

1. FLO = Flomix
ARC = Asphalt-Rubber Concrete
PRF = Pavement Reinforcing Fabric
LEV = Conventional DGAC Leveling Course
OGAC (R) = Open Graded Asphalt Concrete using Asphalt-Rubber Binder;
Plus = PlusRide
SAMI (R) = Stress Absorbing Membrane Interlayer using Asphalt-Rubber Binder.
RAM = Ramflex
AR-GAP = Asphalt Rubber Gap Graded


3. S = Snow Region - Tire Chains Used
C = Coastal Region
V = Valley Region
D = Desert Region

4. RSR = Roadside Rest.
In 1984, International Surfacing Inc. (ISI) came into existence under Crafco Inc. They (ISI) marketed strictly the Overflex binder. The next year, 1985, Arizona Refining was sold to Edginton Oil, who in turn sold the patents for Arm-R-Shield to Crafco. Crafco then owned all the patents for asphalt-rubber binder. This concerned Caltrans because of the elimination of competitive bidding. Crafco became aware that this created a problem for future asphalt-rubber usage so, in 1986, Crafco made arrangements with at least three other companies in the western United States to market the Arm-R-Shield binder. Manhole Adjusting Inc. (MA) was the company chosen to market this binder in California. Prior to 1988, their (MA) involvement was strictly with seal coats. For the last couple of years, MA has started using Arm-R-Shield in a new RAC mix. It is an asphalt-rubber hot mix using a gap grading for the aggregate (ARHM-GG). ISI is also presently marketing this type of mix.

In 1982 PlusRide Inc., who was licensed to sell PlusRide in the U.S.A., was sold to Pavetech Inc. (a group of investors) and the product was sold under the All Seasons Surfacing Company name. In recent years, Pavetech purchased the patent for PlusRide and has been marketing it under the Pavetech name.

With all the changes mentioned above, Caltrans has been concerned as to what effect these changes have had on the products themselves. The main concern today involves the difference in the two asphalt-rubber binders. In most of the early projects (Numbers 2, 3, 4, 5, 6, 7, 8 and 11 in Table I), the Arm-R-Shield binder was used. During this period, the Overflex binder was used strictly in seal coats. In 1985 this usage was reversed (in conjunction with the changes mentioned earlier). For the later projects (Numbers 12, 14, 15, 16, 17, 18, 19 and 20 in Table I) the Overflex binder was used. The first DGAC project using Overflex was not constructed until 1987; thus, our experience with this binder in DGAC covers only three years. It is not known whether the long-term experience will be the same using the Overflex binder in DGAC. As mentioned earlier, the most recent usage of Arm-R-Shield has been with the new mix ARHM-GG and this experience spans only three years. Overall, the patented binders have been produced for more than ten years; thus, the binders alone would not be considered experimental. It is the usage of the binders with different aggregate gradings (i.e., RAC mixes) that is considered experimental.

**EVALUATION OF RAC PROJECTS**

Caltrans experience with RAC far exceeds that of any other state in the United States. Even though this experience dates back twelve years, the evaluation of RAC mixes must be divided into two phases. The first phase would include the early projects where equal thicknesses of RAC and conventional DGAC were compared. This experience includes all the DGAC projects constructed up to 1987 with the exception of Ravendale Project (No. 7 in Table I). (The Ravendale Project started the second phase.) Based on the results obtained on the Ravendale Project after about three years, it
became evident that thinner structural sections of RAC could outperform thicker sections of conventional DGAC. All projects after 1986 involved reduced thicknesses of RAC (compared to the design thickness for the conventional DGAC mix).

All projects constructed by Caltrans were reviewed in October, 1990, and the project files also were reviewed. The Appendix contains observations for each type of RAC and specifically each project where it was used. A matrix showing the types of mixes used, number of projects, etc. is shown in Table II.

**TABLE II**

**RAC Matrix**

<table>
<thead>
<tr>
<th>Type of RAC</th>
<th>Flomix/Ramflex</th>
<th>Arm-R-Shield</th>
<th>Overflex</th>
<th>PlusRide</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Projects</td>
<td>3</td>
<td>9</td>
<td>8</td>
<td>4</td>
</tr>
<tr>
<td>Placed Over PCC</td>
<td>2</td>
<td>4</td>
<td>$4^2$</td>
<td>1</td>
</tr>
<tr>
<td>Placed Over AC</td>
<td>1</td>
<td>5</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Type of Dense Graded</td>
<td>3</td>
<td>7</td>
<td>5</td>
<td>N/A</td>
</tr>
<tr>
<td>(1, 9, 10)</td>
<td>(2, 3, 4, 5, 7, 8, 11)</td>
<td>(15, 16, 17, 19, 20)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Open Graded</td>
<td>0</td>
<td>1</td>
<td>$3^4$</td>
<td>N/A</td>
</tr>
<tr>
<td>(6)</td>
<td>(12, 14, 18)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mix of Gap Graded</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>(21)</td>
<td>(7, 13, 16, 17)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oldest Project</td>
<td>12 yrs</td>
<td>10 yrs</td>
<td>5 yrs</td>
<td>7 yrs</td>
</tr>
</tbody>
</table>

Notes: 1. RAC = Rubberized Asphalt Concrete.
   2. Includes 2 bridge decks.
   3. Numbers in ( ) represent projects listed in Table I.
   4. On Project 13 conventional OGAC was used over a SAMI(R) over conventional OGAC (Arizona-Type 3 Layer System).

There has been some laboratory analysis of mixes used on Caltrans projects, but this work has been limited. Caltrans is presently looking into possible laboratory tests which might be applicable for the evaluation of RAC mixes in a laboratory research effort.

**PERFORMANCE SUMMARY OF RAC (IN CALIFORNIA)**

*Flomix/Ramflex (DGAC)*: There have been three projects constructed using this rubber additive and the mix has not been considered cost-effective on any of these projects.
Arm-R-Shield (DGAC): There have been six projects constructed using equal thickness RAC and one using reduced thickness RAC of this type. Three have been considered not cost-effective, two cost-effective, and the other two are too new to determine cost-effectiveness. Even though the RAC outperformed the conventional DGAC on the two cost-effective projects, the benefits did not appear to override the initial higher cost of the RAC.

Arm-R-Shield (OGAC): There has been one project constructed using this OGAC(R). The use of OGAC(R) on this project indicate that it may be cost-effective because it allowed an OGAC mix to be used successfully in the snow country where conventional OGAC has not normally performed well. However, additional projects should be constructed in a freeze-thaw region.

Arm-R-Shield (GGAC): There has been one small project constructed using ARHM-GG and it is only a few months old. More laboratory research is necessary to provide a formal mix design for this type of mix and more field performance data, including long-term observations, are needed.

Overflex (DGAC): There have been five projects placed using this type of RAC. All these projects used reduced thickness RAC. The use of this mix has been considered cost effective on only one of the projects with the other four being too new to determine cost-effectiveness. On two of these projects, RAC has been used as a thin overlay strategy for bridge deck rehabilitation.

Overflex (OGAC): There have been two projects constructed using this OGAC(R). The thickness was reduced on these projects to help offset the initial cost. The use of OGAC(R) on both of these projects allowed an OGAC mix to be placed successfully in a climatic area where it normally could not be placed under current specifications. Also, it has been shown by experience in Arizona that OGAC(R) will perform as long or longer than conventional OGAC. Therefore, it appears that the use of OGAC(R) on these projects will be cost-effective.

Overflex (Three-Layer System): There has been one project constructed using an Arizona-type, three-layer system. The project is performing very well, but it is too early to determine if the use of this three-layer system is cost-effective.

PlusRide (GGAC): There have been four projects constructed using PlusRide RAC. Its use has been determined to be cost-effective on one project and it is too early to determine the cost-effectiveness on two other projects. The fourth project is not being considered in the evaluation of the PlusRide RAC because it was not properly designed.

**SUMMARY**

From our experience, it has been learned that when compared to conventional DGAC, RAC can tolerate higher deflections. The RAC has lower
permeabilities which in turn decreases oxidation and aging. These mixes have also proven to be more abrasion resistant in snow regions and, when distress does develop, it progresses at a much slower rate. All these desirable qualities that RAC mixes possess lead to decreased maintenance costs and ultimately to lower annual equivalent costs.

Overall, when RAC (DGAC) has been compared to an equal thickness of conventional DGAC, it has usually outperformed the DGAC by exhibiting less distress and requiring less maintenance. Unfortunately, these positive benefits have not always been enough to offset the 40-50% increase in cost over conventional mix. However, it has been shown on more than one project that reduced thickness RAC can outperform thicker conventional DGAC mixes. The question that arises is how does Caltrans determine the correct thickness or type of RAC to use on a particular project to obtain a certain design (service) life?

From the Ravendale experience, we have learned that a 50% reduction in overlay thickness can result in equivalent service life when using RAC. However, is this 50% reduction applicable to other climates as well? Can this 50% reduction be utilized at locations where thinner conventional DGAC thicknesses such as 0.40, 0.30 or 0.20 foot would be used? Will this 50% reduction hold true for overlays over PCC as well? Should a 30% reduction be used as a more conservative figure? What kind of reduction can be tolerated when using ARHM-GG? Will ARHM-GG outperform other types of RAC? There are many questions to be answered, but this will take time. Are we willing to make guesses routinely and hope to get our ten-year design life? If our guesses are wrong, it would be very costly. At this point in time, we are doing just that, guessing; but, these guesses are being made on selected experimental projects.

We need to move forward more quickly with the evaluation of RAC mixes. Based on our experience from the Ravendale project (No. 7 in Table 1), by using reduced thickness test sections we can hopefully obtain data more quickly. We will continue to work closely with the RAC industry on all projects which include RAC mixes. We need to construct a minimum of ten projects around the state as soon as possible to help expedite the evaluation of the various types of RAC mixes. Each project should contain the recommended design thickness and various reduced thicknesses of conventional DGAC. It also should contain at least two types of RAC and at least two thicknesses of each type of RAC. SAMI's should also be used on all RAC projects. The data obtained from projects of this nature and the data obtained from laboratory research should provide sufficient information to cut the evaluation period to approximately a five-year span. At that time, some type of recommendation for routine usage of RAC should be expected.
REFERENCE


DISCLAIMER

The contents of this paper do not necessarily reflect the official views or policies of either the Federal Highway Administration or the State of California. They reflect the views of the author, who is responsible for the facts and accuracy of the data presented herein. Also, neither the State of California nor the United States Government endorse products or manufacturers. Trade and manufacturers names are presented herein because they are considered essential to the objective of this paper.
APPENDIX

EVALUATION OF RAC PROJECTS

The project numbers listed below represent projects in Tables I and II.

Flomix/Ramflex (DGAC): Project 1 - This project is 12 years old. Both the RAC and the conventional DGAC control sections (equal thicknesses) have performed quite similar. They both exhibit the same type and degree of cracking. The use of Flomix on this project was not cost-effective. This project has been ready for major rehabilitation for the last few years.

Projects 9 and 10 - These two projects are six years old. Both of these projects exhibited distress in the form of transverse cracks (T-cracks), longitudinal cracks (L-cracks) and raveling within the first two years. The distress has increased since then with extensive maintenance required on these projects in the last two years. The conventional DGAC control sections (equal thickness) have performed better than the RAC and have required less maintenance. The use of Ramflex on these projects was not cost-effective.

Arm-R-Shield (DGAC): Project 2 - This project is ten years old. On this project a 0.30 foot overlay was placed over pavement reinforcing fabric (PRF) with the top 0.10 foot being RAC. There is considerable T-cracks, L-cracks and raveling existing on this project. There have been chip seals, slurry seals and some maintenance blankets placed. The conventional DGAC control section (0.30 foot thick) has performed quite well considering that the average life before major maintenance is required is usually four to six years in this region. The RAC section performed only slightly better over the years, requiring less maintenance in the early years. This project is ready for major rehabilitation. The use of RAC on this project was probably not cost-effective; however, this is difficult to determine because the control section was quite small and may not have been representative for the whole project.

Project 3 - This project is ten years old and the RAC used has performed extremely well. It is a truck climbing lane about one-half mile in length. It now exhibits extensive T-cracks, L-cracks and surface abrasion and is ready for major rehabilitation. A conventional AC overlay in this area (7000+ foot elevation with extensive chain wear during the winter) would normally require an overlay or replacement within five years. The RAC on this project required very little maintenance. The use of RAC on this project was cost-effective.

Project 4 - This project is nine years old. It is on a slight grade and is in the same area as Project 3. The control section was a conventional DGAC mix (equal thickness) with an asphalt content 0.4% above the normal optimum bitumen content (OBC). Both the RAC and "control" mixes have performed
very well on this project. They both now exhibit extensive T-cracks, L-cracks and surface abrasion with some raveling at the longitudinal joints at the lane lines. The rich "control" mix has required some patching and is now exhibiting some rutting. Both mixes have required very little maintenance overall with the majority of this being crack sealing. This project is still performing, but is getting very close to requiring major rehabilitation. The RAC has performed slightly better than the "control", but the use of RAC on this project probably was not cost-effective because the cost of the rich "control" mix was less than that of the RAC.

Project 5 - This project is eight years old. There were various test sections compared to a 0.35 foot conventional DGAC control section. The two RAC sections were 0.10 and 0.20 foot thick over a 0.10 foot thick conventional OGAC. All sections are now exhibiting T-cracks, L-cracks, and surface abrasion with some maintenance patches; but the 0.20 foot RAC over 0.10 OGAC(R) is showing less distress than all other sections. This project is ready for major rehabilitation. On this project the use of RAC does not appear to have been cost-effective.

Project 7 - This project is seven years old and was publicized nationally in a 1988 TRB paper. This was the first reduced thickness RAC project involving an overlay of AC pavement. On this project different thicknesses of RAC with and without a SAMI were compared to different thicknesses of conventional DGAC (0.18 to 0.52 foot actual thickness). The thin sections of DGAC all failed within the first two years. The 0.52 foot DGAC control section is now exhibiting intermittent to continuous T-cracks, L-cracks, block cracking, and surface abrasion. When most of the sections were placed on this project it was believed that there was a likelihood that a ten-year service life would not be achieved because of the thin sections used; however, the RAC sections have required little to no maintenance and are still performing today. The RAC sections are now exhibiting T-cracks, L-cracks, surface abrasion and some raveling. The use of RAC on this project is considered to have been cost-effective.

Project 8 - This project is six years old. There was no control section placed on this project. The RAC on this project developed T-cracks after only two years. The RAC now exhibits T-cracks every 15 to 50 feet, surface abrasion, and some raveled areas. A slurry seal was placed on the first 0.3 mile of the project after three years (1987). There has been very little maintenance required on the rest of the project. It is too early to determine the cost-effectiveness of RAC on this project.

Project 11 - This project is five years old. There was no control section placed on this project. The RAC on this project developed T-cracks after only two years. The RAC is now exhibiting intermittent T-cracks, some L-cracks, surface abrasion and some raveling. One 100-foot section (single lane width) has been replaced with conventional DGAC. This project will require some maintenance patching next year. It is too early to determine the cost-effectiveness of RAC on this project.
Arm-R-Shield (OGAC): Project 6 - This project is eight years old. Conventional OGAC is not used in the snow regions because of the freeze-thaw and tire chain action and a lack of resistance to snow plows. The OGAC(R) on this project now shows signs of surface abrasion and some portions have been removed by snow plows. The majority of the material removed by snow plows has taken place in the last two years (on the high side of the superelevation). This project is on a curve and a slight grade. These results indicate that OGAC(R) may be cost-effective in a freeze-thaw snow region over AC pavement. The use of OGAC(R) should be tried on additional projects in a freeze-thaw region.

Arm-R-Shield (GGAC): Project 21 - This project is only three months old. ARHM-GG was placed for the first time by Caltrans on this project. This project was funded under the SHRP Program. A standard mix design procedure for this type of RAC mix has not been formalized at this time. More laboratory research is necessary to formalize a procedure. The mix design decisions were made by MAI on this project, and the mix was placed without any major problems.

Overflex (DGAC): Project 15 - This project is three years old. The roadside rest (RSR) on this project was to be reconstructed around 1991 but the existing pavement was badly cracked. In the hopes of obtaining four years of surface life, a thin lift of RAC was used. The RAC is now showing signs of reflective cracking, but it appears that the thin RAC will accomplish its task of holding the underlying pavement intact until the time of reconstruction. Based on past experience, a conventional DGAC thin overlay would not have accomplished this. It appears at this time that the use of RAC will be cost-effective on this project.

Project 16 - This project is three years old. It is the first time RAC has been used in a desert climate by Caltrans. Two different thicknesses of RAC, one equal and one reduced thickness, were compared to two conventional DGAC control sections. Within one year, the reduced thickness RAC section and the control sections exhibited T-cracks and some L-cracks. Now the cracking is intermittent to continuous in these sections with some alligator cracking also existing. The distress in the equal thickness RAC section is very minor and consists of only one T-crack and one raveled area. Up to this point, the reduced thickness RAC section has performed equally to the control sections, and the equal RAC section has outperformed the control sections. However, it is not known at this time as to the reason(s) for the early cracking. (It will be investigated.) It appears that the conventional DGAC design was not appropriate. It is too early to determine if the RAC is cost-effective on this project.

Project 17 - This project is two years old. On this project two reduced thicknesses of RAC were compared to a conventional DGAC control section. T-cracks and some raveled areas appeared in the RAC sections within one year. The RAC sections are now exhibiting intermittent T-cracks and some
raveled areas throughout most of the project. The control section has only a few T-cracks. All sections are exhibiting surface abrasion due to the tire chain wear. The control section is also showing some flushing and bleeding in the wheel tracks. This control mix was probably overasphalted. This may be the reason for the small amount of T-cracks. The reduced thickness RAC (0.20 foot) was placed in two equal lifts (using 3/4 inch maximum aggregate). During compaction of these lifts, aggregate was broken on the surface. This is probably the reason for many of the severe raveled areas in this section. It is not known at this time why the T-cracks appeared so soon on this project and this will be investigated. It is too early to determine if RAC is cost-effective on this project.

Projects 19 and 20 - Both of these projects are bridge decks and are only one year old. A thin 0.10 foot lift of RAC was used to determine if it would provide a cost-effective bridge deck rehabilitation strategy. Within the first year each deck exhibited one small raveled spot which has been removed and replaced with conventional DGAC.

Overflex (OGAC): Projects 14 and 18 - These two projects are four and two years old respectively. Night construction is required in the San Francisco Bay area due to traffic volumes during the day, and temperature conditions at night restrict the placement of conventional OGAC in some locations. OGAC(R) can be mixed at a higher temperature and, therefore, placed at a lower ambient temperature. The thickness of the OGAC(R) was also reduced 20% to help offset the higher initial cost. By using OGAC(R) on these projects, it allowed the successful placement of an open graded mix in an area where it normally could not be placed. For this reason, the use of OGAC(R) on these projects is considered to be cost-effective.

Overflex (3-Layer System): Project 12 - This project is five years old and is the first time Caltrans has used an Arizona-type, three-layer system. At this time there is no distress on the project. It is performing quite well, but it is too early to determine its cost-effectiveness.

PlusRide (GGAC): Project 7 - This project was mentioned earlier under Overflex (DGAC). PlusRide was also placed in different thicknesses with and without a SAMI. The PlusRide sections exhibited some potholing after only a few years but have performed quite well compared to the thick conventional DGAC control section (0.52 foot thick). The PlusRide sections are exhibiting T-cracks, L-cracks, block cracks, some alligator cracks, surface abrasion and raveling. Some of the thicker PlusRide section (0.2 miles) required a maintenance overlay. The use of PlusRide on this project appears to have been cost-effective.

Project 13 - This project is four years old. On this project PlusRide was used in a 0.10 foot maintenance blanket and was compared to a conventional DGAC blanket of equal thickness. Unfortunately, there was no mix design provided by the PlusRide consultant and the mix was very likely underasphalted. A portion at the end of the PlusRide section raveled after
the first year and required an overlay of conventional DGAC. After two years a chip seal was placed on another portion of the PlusRide section. However, some of the remaining PlusRide section is still performing quite well, with less distress than the control. This project was placed at the same time that Pavetech had just purchased PlusRide Inc. and they would not provide any on-site assistance. Because this PlusRide mix was not designed properly, this project is not being considered for evaluation purposes (only for information).

Project 16 - This project is two years old. This project was mentioned earlier under Overflex (DGAC). PlusRide was also placed on this project in two different thicknesses, a reduced and equal thickness. The equal thickness section developed bleeding areas within the first year and they have become larger and more severe since then. The reduced thickness section has developed some small intermittent transverse humps in the surface and a few flushing spots in the wheel tracks but no cracking. As mentioned earlier, the control sections are exhibiting a considerable amount of cracking. It is too early to determine if PlusRide was cost-effective on this project.

Project 17 - This project is two years old. This project was mentioned earlier under Overflex (DGAC). The PlusRide was also placed on the project in two reduced thicknesses. The PlusRide sections are exhibiting very little surface abrasion, some flushing in the wheel tracks at a few locations, and a few potholes. This is the only distress noted at this time. Overall the PlusRide is performing very well, but it is too early to determine its cost-effectiveness.

RAC EXPERIENCE BY OTHERS

As mentioned earlier, the experience by others using RAC in general is very limited; however, this does not mean that there have not been any projects constructed elsewhere. More than 20 states have constructed at least one project using RAC. Unfortunately, the data on many of these projects are inconclusive regarding cost-effectiveness.

PlusRide has been used by a number of states with Alaska probably having the most experience. Because of Alaska’s positive experience with PlusRide, they recently presented a proposal to the FHWA to have it removed from the experimental category. The proposal was rejected by the FHWA because of insufficient backup data. The experience by other states has been mixed, some good and some bad.

More states are beginning to use asphalt-rubber in DGAC, but most of this experience is limited to one to three years. There are more than five states known to have projects that are in excess of three years, but there is no conclusive data available as to the cost-effectiveness of RAC based on our information.
ARHM-GG has been promoted quite heavily around the U.S.A. and especially in the southern California area in the past two years. There has been more than 20 projects constructed during this time, with most being only one year old. Experience to date has been very positive with this type of RAC. However, the oldest project, which dates back only three years, exhibited bleeding after one year. At this time, it is impossible to draw any long-term conclusions from the use of ARHM-GG since the experience with successful projects dates back only two years.

OGAC(R) has been used by a few states with Arizona having more than ten years experience. It has performed very well on a number of projects in different states based on our information.

Three-layer systems have also been used by Arizona and for more than ten years. They have been used very successfully in that state. In 1985, Arizona started using the three-layer system non-experimentally. Caltrans has additional three-layer test sections scheduled for construction at two locations in the fall of 1991.