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Establish Criteria for Rehabilitation of California Pavements

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Brian D. Murray

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16. ABSTRACT

Roadway condition records of various pavement treatments such as sand seals, screening seals, thin asphalt concrete blankets and structural overlays were evaluated to determine the treatments service lives. Roadways included in the study were those receiving the treatments during the periods 1965 to 1975. Service life for asphalt concrete pavements were generally based on the extent of alligator type cracking while for the small number of overlays over Portland cement concrete, reflective cracking was the criteria.

17. KEYWORDS

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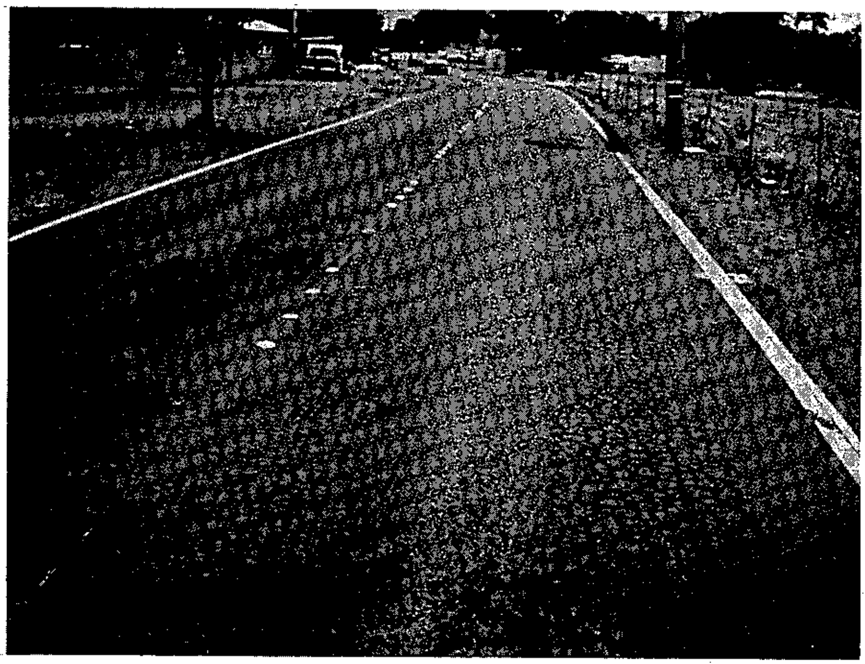
ESTABLISH CRITERIA FOR REHABILITATION OF CALIFORNIA PAVEMENTS



FINAL REPORT

FEB 1979

Caltrans
CALIFORNIA DEPARTMENT OF TRANSPORTATION

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STATE OF CALIFORNIA
DEPARTMENT OF TRANSPORTATION
DIVISION OF CONSTRUCTION
OFFICE OF TRANSPORTATION LABORATORY

February 1979

FHWA No. D-4-96
TL No. 633502

Mr. C. E. Forbes
Chief Engineer

Dear Sir:

I have approved and now submit for your information this final research project report titled:

ESTABLISH CRITERIA FOR REHABILITATION
OF CALIFORNIA PAVEMENTS

Study made by .... Roadbed & Concrete Branch

Under the Supervision of .... D. L. Spellman

Principal Investigator .... J. A. Matthews

Co-Investigator .... B. D. Murray

Report Prepared by .... B. D. Murray

Very truly yours,

Neal Andersen

NEAL ANDERSEN
Chief, Office of Transportation Laboratory

Attachment

BDM:cj

ACKNOLWEDGEMENTS

This study, titled "Establish Criteria for Rehabilitation of California Pavements", was conducted by the Office of Transportation Laboratory, Division of Construction of the California Department of Transportation. Credit is shared with the personnel involved with developing the Pavement Management System who provided some direction and guidance for this work. These include: Ray Wilson, Charles Bartell, and Karl W. Kampe.

Appreciation is also expressed to Fred L. Boucher and the District Maintenance personnel for providing the pavement evaluation data and the information relative to that roadway maintenance which has been performed.

The research work reported herein was accomplished under Highway Planning and Research Project D-4-96 in cooperation with the U.S. Department of Transportation, Federal Highway Administration.

CONVERSION FACTORS

English to Metric System (SI) of Measurement

Quanity	English unit	Multiply by	To get metric equivalent
Length	inches (in)or(")	25.40 .02540	millimetres (mm) metres (m)
	feet (ft)or(')	.3048	metres (m)
	miles (mi)	1.609	kilometres (km)
Area	square inches (in^2) square feet (ft^2) acres	6.432×10^{-4} .09290 .4047	square metres (m^2) square metres (m^2) hectares (ha)
Volume	gallons (gal) cubic feet (ft^3) cubic yards (yd^3)	3.785 .02832 .7646	litres (l) cubic metres (m^3) cubic metres (m^3)
Volume/Time			
(Flow)	cubic feet per second (ft^3/s)	28.317	litres per second (l/s)
	gallons per minute (gal/min)	.06309	litres per second (l/s)
Mass	pounds (lb)	.4536	kilograms (kg)
Velocity	miles per hour(mph) feet per second(fps)	.4470 .3048	metres per second (m/s) metres per second (m/s)
Acceleration	feet per second squared (ft/s^2)	.3048	metres per second squared (m/s^2)
	acceleration due to force of gravity(G)	9.807	metres per second squared (m/s^2)
Weight Density	pounds per cubic (lb/ft^3)	16.02	kilograms per cubic metre (kg/m^2)
Force	pounds (lbs) kips (1000 lbs)	4.448 4.448	newtons(N) newtons (N)
Thermal Energy	British thermal unit (BTU)	1055	joules (J)
Mechanical Energy	foot-pounds(ft-lb) foot-kips (ft-k)	1.356 1.356	joules (J) joules (J)
Bending Moment or Torque	inch-pounds(ft-lbs) foot-pounds(ft-lbs)	.1130 1.356	newton-metres (Nm) newton-metres (Nm)
Pressure	pounds per square inch (psi) pounds per square foot (psf)	6895 47.88	pascals (Pa) pascals (Pa)
Stress Intensity	kips per square inch square root inch (ksi $\sqrt{in}$)	1.0988	mega pascals $\sqrt{metre}$ (MPa $\sqrt{m}$)
	pounds per square inch square root inch (psi $\sqrt{in}$)	1.0988	kilo pascals $\sqrt{metre}$ (KPa $\sqrt{m}$)
Plane Angle	degrees (°)	0.0175	radians (rad)
Temperature	degrees fahrenheit (F)	$\frac{tF - 32}{1.8} = tC$	degrees celsius (°C)

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INTRODUCTION

The California Department of Transportation is currently responsible for maintaining 45,000 lane miles of highway pavements. All of this pavement is wearing out at varying rates. The overall objective behind this work was to develop performance criteria for pavement maintenance strategies.

One part of this objective was to determine service life of various strategies now available. These include sand seals, screening seals, thin AC blankets and structural overlays.

Another purpose of this study was to match defects with appropriate remedies. This involved taking into consideration the average service life and functions of each remedy.

Finally, the various methods used in the past to determine structural overlay thicknesses were reviewed and evaluated. These included three formalized methods: deflection analysis, gravel equivalent, reflection cracking control and one informal method that might be categorized as "subjective determination".

Cost effective maintenance strategies can be developed by combining the performance criteria with current construction costs.

GENERAL CONCLUSIONS

1. By careful evaluation of "present roadbed conditions" a choice of maintenance strategies can be made that will improve the cost-effectiveness of maintenance and rehabilitation programs.

2. The design method based on deflection measurements is the best of the four methods commonly used to "design" overlays for asphalt concrete pavements (i.e., Deflection analysis, gravel equivalent, reflection cracking control, and subjective).

3. Load associated "alligator" cracking can be used as a visual indicator of the structural condition of a roadway.

4. The condition of the existing pavement has a significant effect on the expected service life of a particular treatment. There is an optimum time for applying many of the repair strategies.

RECOMMENDATIONS

When planning for rehabilitation, repair or reconstruction of pavements, the information shown in Table 1 should be used to assist in selecting the strategy. Table 1, in effect, summarizes some of the most important findings of this study.

The California Overlay Design Method based on deflection measurements should be used to design structural overlays on asphalt concrete pavements where vertical grade controls do not exist.

TABLE 1

SURFACE TREATMENT EFFECTIVENESS

Function	Product: Binder Modifiers	Emulsion Seals	Screening Seals	Open Graded AC	1" AC Blanket	Thick AC Overlays
Reduce Hydroplaning	0	0	2	3	0 to 1	0 to 1
Improve Skid Resistance	0	0	2	3	1 to 2	1 to 2
Seal Dried Out Pavements	2	1	2	2	2	2
Retard Fine Raveling or Correct Fine & Coarse Raveling	3*	3*	3	3	3	3
Heal Cracks or Correct Cracked Conditions	0	0	0	1	1	3
Improve Ride Quality	0	0	0	1	2	3
Improve Structural Strength	0	0	0	0	1	3

Key

0 - No benefit or unsuitable considering objectives or condition to be corrected.

1 - Slight benefit only.

2 - Moderate benefit.

3 - Major benefit.

*Retard fine ravelling only

SPECIFIC FINDINGS

1. Structural overlays of asphalt concrete pavements designed and constructed in accordance with the "Deflection Analysis Design Method" (Test Method No. Calif. 356) have a mean service life of 129 months with an estimated standard deviation of 13.6 months.

2. Structural overlays designed and constructed using the California "Gravel Equivalent Method" have a mean service life of 100 months with an estimated standard deviation of 24.5 months.

3. Structural overlays designed and constructed using subjective judgement, have a mean service life of 94 months with an estimated standard deviation of nearly 23 months.

4. Thin blanket asphalt concrete overlays in California have an average service life of 30 months to a reoccurence of load associated alligator cracking and/or patching extending over 10% of the area. The geographic/topographic effect on service life of a thin blanket is minimal due to their short service life.

5. A coarse or medium screening seal is a short-term strategy for sealing cracks or for preventing intrusion of surface water. The mean service life is 16 months with an estimated standard deviation of 11 months.

6. Screening seals are effective in improving skid resistance, retarding raveling and sealing a dried-out mix. The optimum time for placement is at the earliest appearance of the above defects.

7. Sand seals are a short-term solution for sealing permeable pavement or cracks to prevent intrusion of surface water. The mean service life is 13.5 months with an estimated standard deviation of 8.5 months.

8. Reclamite (and other binder modifiers) should be used primarily to retard raveling and to add additional binder to dried out pavements to seal off the surface from moisture. The optimum placement time is at the earliest signs of raveling.

9. Reclamite and Petroset or similar products should not be used routinely as a construction seal. A well-constructed asphalt pavement built with specification material and proper asphalt content would not ordinarily need a surface treatment as a construction seal. There are numerous instances where bleeding has occurred through construction seals, particularly in the summer months following construction which indicates a construction seal was not needed.

10. Asphalt emulsions used as surface seals can be effective in adding additional binder to a dried out pavement having insufficient binder. As in the case of binder modifiers, not all pavement surfaces will accept the emulsion. The binder which is admitted, may penetrate at a slow rate possibly creating a temporary low skid resistance condition.

11. On the average, ten year service life with limited reflective cracking can be obtained from a 0.35 foot thick asphalt concrete overlay on a portland cement concrete pavement.

IMPLEMENTATION

As the performance criteria were developed, they were immediately implemented into California's Pavement Management System which was simultaneously being developed. The performance criteria were developed using pavement condition information obtained from past biennial pavement evaluation surveys. The experience gained in utilizing this pavement condition information was fed back, along with information from the Pavement Management Group, into modifying the type of information recorded in future biennial pavement evaluation surveys.

The results of this project have now been incorporated into the California Pavement Management System (Division of Maintenance), Part IV, Strategies and Performance.

GENERAL DISCUSSION

Pavements do not "wear out" all at once. Maintenance is often constrained by insufficient money available. Traffic and weather affect pavements unpredictably. For all these reasons, a precise measure of service life, as determined by the time between construction and subsequent repairs, cannot be clearly established.

To meet this problem, failure criteria was adopted. In general, failure was defined by the amount and type of cracking. "Service life" was defined as the length of time between construction and failure. The definition of failure for each strategy of pavement repair is described as each strategy is discussed.

For the purposes of this work the following "strategies" were evaluated.

1. Thin blankets - overlays of dense graded asphalt concrete, 0.08 foot in thickness, for general maintenance over alligator cracked pavements.

2. Thin blankets - overlays 0.04 foot to 0.10 foot thick, used for preventative maintenance.

    a) Dense graded
    b) Open graded

3. Asphalt concrete overlays 0.15 foot or thicker.

4. Coarse and medium screening seals.

5. Sand seals.

6. Fog seals

   a) Emulsions
   b) Softening agents
   c) Binder modifiers in general

The performance obtained from each of these "strategies" was determined by reviewing records, making some on-site pavement surveys, and by discussing with maintenance and construction personnel appropriate failure criteria.

The biennial pavement evaluation surveys extending back to 1969 and other data dating back to 1964 provided the information to develop performance criteria. The overlay information came primarily from construction contract files supplemented by maintenance records. Another source of information was the results and recommendations from deflection studies conducted during this period. Annual traffic data was used to calculate the Traffic Index. Pavement condition information came from surveys and the "Pavement Evaluation System" which included data on cracking, patching and ride scores. Other data included environmental and geographic factors of temperature, rainfall, and terrain.

With this information, an attempt was made to develop equations to predict service life. Such factors as geographic/topographic, width of initial and final crack, traffic index, A.D.T., maintenance work, ride score, alligator cracking and patching were considered (see PROCEDURE AND DETAILED DISCUSSION). However, in the final analysis, a simple relation between the strategy selected and past service life experience was considered more meaningful.

Strategy 1. Thin Blanket Overlays (.08') Dense Graded General Maintenance

In this category, over 4,500 lane miles of one inch blankets placed from 1970 to 1974 were used to develop expected service life. The failure condition for this strategy is defined as follows:

> Load associated alligator cracking or patching extending over 10% of the area is defined as the end of service life for all surface treatments and thin blankets placed on AC pavements.

California experience indicated the average service life of a one-inch blanket is approximately thirty months with a 99.7% probability of being in the range of 0 to 75 months. The service life does, however, vary with geographic/topographic (GT) areas. The desert areas exhibited an average twenty-five month service life and the Northern Coast an average thirty-four months. The distribution of the service lives in relation to the geographic/topographic areas is given in Figure 2.

Strategy 2. Thin Blanket Overlays (0.04'/0.10') Preventive Maintenance

Dense Graded Blankets

The vast majority of blankets in this category were placed sometime after alligator cracking developed. Only 43 of 576 could truly be categorized as preventive in that there was no alligator cracking when the overlays were constructed. Further, only with three of them could there be a conclusive statement regarding the efficacy of the preventive measure.

Based on this minimum amount of data, this type of blanket does not appear to be an effective strategy in retarding alligator cracking. It would appear to be more cost effective to wait until cracking appears before overlaying the pavement.

Open Graded Blankets

Fourteen sections were used to determine the effectiveness of the open-graded blankets in retarding alligator cracking. Ten of the fourteen sections indicated that the open-graded blanket had no effect in retarding alligator cracking. One of the fourteen retarded the alligator cracking for a short period, but cracking equalled that in the adjacent control section within two years after its appearance in the control section. The remaining three sections have either retarded or disguised the alligator cracking from eight months to two years past its occurrence in the control sections, as of the 1978 biennial pavement evaluation. The conclusion can be made that the open-graded blanket does not retard alligator cracking, but then neither was it intended nor expected to do so.

The thin blankets, whether open-graded or dense-graded, provide no significant structural enhancement to an uncracked flexible pavement. They, in themselves, provide an uncracked surface only as long as they remain flexible and self healing. They do improve aesthetics, correct surface raveling, surface bleeding, poor skid resistance, and poor ride quality due to minor bumps, and they may also retard the oxidation of the underlying asphalt layers. Thus, when properly used, have an important role in pavement management.

Strategy 3. Asphalt Concrete Overlays (0.15' or thicker)

Overlays Over AC Pavement

The service life for this strategy could be based on either average alligator crack width criteria or extent of alligator cracking. The failure criteria for the crack width service life was the occurrence of 1/8" or wider alligator cracks. By definition, the failure criteria or end of service life for the extent of alligator cracking was reached when 30% of the area exhibits a combination of load associated alligator cracking and patching. This criteria was arbitrarily selected by the Pavement Management Team who directly implemented the results of this work.

The service life based on the width of alligator cracking was limited to contract placed overlays built between 1969 and 1974. This yielded less than 500 lane miles of pavement overlays on which to base service life. A statistical treatment of the data indicated the statewide average service lives from the time of overlay placed over 1/4" wide alligator cracks until the occurrence of 1/8" wide alligator cracks in the new overlays are:

0.15' thick - 55 months
0.20' thick - 63 months
0.25' thick - 62 months

It would immediately appear that there was little-to-no advantage in placing thicker overlays to increase service lives. However, it is probable that the thicknesses placed were in some proportion to the level of roadway distress prior to the overlays placement. Thus, since initial conditions were likely dissimilar, the length of service lives versus thickness cannot be compared directly. If, in fact, the roadways receiving the thicker overlays had wider cracks than those covered with thinner overlays, and if the "present" condition affects service life, then we might expect nearly equal service life from variable overlay thicknesses.

The service life based on extent of alligator cracking utilized a larger data base consisting of all overlays 0.15' or thicker placed by contract during the period 1964 to 1974. These overlays were grouped according to their method of design:

Deflection Analysis
Gravel Equivalent
Subjective Judgement
Reflective Cracking

Analyses were made in an attempt to determine service lives corresponding to the method of design.

Deflection Analysis

Eight projects whose design was based on an analysis of pavement deflections yielded an average service life of 129 months and an estimated standard deviation of 13.6 months. This exceeds the earlier estimates of ten years;

however, this increase might be explained in that the ten year life estimate was based on a service life during which a minimum of maintenance was performed versus the present definition based on 30% extent of distress. The distribution is shown in Figure 3.

Gravel Equivalent

Sixteen locations reportedly designed using the gravel equivalent method were analyzed. This method requires the engineer to make an initiutive assessment of in-place pavement conditions and assign a gravel factor to the existing AC pavement. Then an overlay is designed based on the future traffic and gravel equivalent of the in-place roadway. Analysis of these projects gave a service life of 100 months with an estimated standard deviation of 24.5 months. This distribution is also shown in Figure 3. The wide distribution in the service life reflects the difficulty of intuitively assigning an appropriate gravel factor to the in-place distressed AC surface.

Subjective Judgement

Thirty-six projects covering 250 lane miles of pavement were constructed, essentially using subjective judgement to determine overlay thickness. The average service life was found to be ninety-four months with an estimated standard deviation of 22.9 months. The distribution is presented in Figure 3. The bulk of this large deviation can be attributed to the non-rational overlay thickness selection procedure. Generally the decisions were based on either intuitive judgements of what had worked else-where on roads that appeared similarly distressed, or on how much money was available. Neither approach is considered good practice from an engineering viewpoint. The outward appearance of a roadway condition does not always indicate the actual supportive capabilities of the existing structural section, nor does the amount of available money relate to a given service life.

Reflective Cracking

California utilizes a deflection based overlay design method (Test No. 356) which also considers reflection cracking potential. For purposes of this study, our reflection cracking control design was considered as a separate method to study its effectiveness.

Fourteen projects were examined where the thickness of overlay was designed to control reflective cracking. However, the data, for various reasons, was inadequate to develop a valid service life.

Of the four methods of design, the deflection analysis appears to give the most rational and consistent results as evidenced by the range in service lives of the various methods and the estimated standard deviations.

Overlays Over PCC Pavement

Unlike AC pavement overlay failures, PCC overlay failures do not show up as alligator cracking. Instead, service life is defined as that point in time when five transverse cracks per 100 feet have reflected through the overlay.

Twenty-four overlays placed during the period 1965 to 1969 were analyzed. The average service life was eighty-eight months with an estimated standard deviation of 27.7 months (See Figure 4). When service life is plotted against overlay thickness (Figure 5), the two are directly proportional. The graph indicates a ten year service life would generally be obtained from a 0.35' thick AC pavement.

Strategy 4. <u>Coarse and Medium Screening Seals</u>

The failure criteria for these seals is similar to thin blanket overlays, i.e., a return to 10% alligator cracking. These seals, covering 800 miles, were evaluated as two groups. The first group included only seals placed over pavements with 1 to 15% alligator cracking and the other group included only seals placed over pavements with greater than 15% alligator cracking.

Those seals placed over the 1-15% alligator cracked pavements had an average service life of 17.3 months with an estimated standard deviation of 12.9 months. Those placed over the more severely alligator cracked pavements yielded an average service life of 14.9 months with an estimated standard deviation of 9.4 months. A comparison of the groups indicated there was no significant difference in their service lives and that the initial extent of alligator cracking had little effect on their return to a 10% extent alligator cracking. Therefore, the data was combined and an average service life of 16.2 months with an estimated standard deviation of 11.3 months was obtained. The three distributions are presented in Figure 6. This indicates that placement of a coarse and medium screening seal to seal cracks and prevent surface intrusion of water is a short-term strategy.

This "strategy" might be considered for those situations when we need to "hold the pavement through the winter months" and no other remedial strategy is available on short notice. It should at least be recognized that a coarse or medium screening seal strategy cannot be expected to serve the purpose of crack sealing for longer than about one year (not through more than one winter).

In addition to crack sealing, a good use of seals has been their use to eliminate raveling conditions, increase skid resistance, prevent intrusion of surface water, and delineate lanes. Table 2 indicates effectiveness of such seals to retard raveling and cracking (also asphalt hardening) at several locations.

The seal placement is as much an art as it is a science. When the seals are placed on new pavement, construction is quite critical. There is a risk for screening embedment to occur because of the "open" characteristics and softness of the surface before it is opened to traffic. Traffic action tends to knead the chips into the new pavement surface.

In the event that temperature control and emulsion setting time is different than planned, or if the screenings have a dirty or dust coated surface, there is a big risk of screening "whip off". The opening of the roadway to traffic "prematurely", before chips are "bound" to the old surface will particularly cause "chip" whip off. This can result in "slick" wheelpaths and car windshield and paint damage if the maximum size screenings are larger than 3/8 inch.

Strategy 5. Sand Seals

The sand seal performance was evaluated in the same manner as that used for the coarser screening seals, that is, "How long did they seal the cracks?" The sand seals were evaluated in two groups, those placed over pavements with 1% to 15% alligator cracking, and those placed over pavements with greater than 15% alligator cracking. Those seals placed over the 1-15% cracking had an average service life of 14.2 months with an estimated standard deviation of 10.1 months. Those placed over the more severely alligator cracked pavements had an average service life of 12.7 months with an estimated standard deviation of 6.4 months. A comparison of the groups indicated there was no significant difference in their service lives and that the initial extent of alligator cracking had little effect on their return to a 10% extent alligator cracking condition. Therefore, the data was combined and an average service life of 13.5 months with an estimated standard deviation of 8.5 months was obtained. The three distributions are presented in Figure 7. This indicates that placement of a sand seal to seal cracks or when used on permeable pavements to prevent surface intrusion of water is a short-term strategy.

Strategy 6. Fog Seals

Research work performed by this department relative to emulsion seals, binder modifiers, and softening agents was evaluated as preventive maintenance strategies. A summarization of the results of this evaluation is as follows:

Emulsion Seals

As indicated by Table 3, mixed results have been obtained with the use of emulsion seals when placed to retard raveling. Emulsion seals have been used successfully for this purpose because they add additional binder to a dry pavement surface.

Emulsions were not found successful in retarding asphalt hardening within the top 1/2 inch of the pavement. It appears that emulsions tend to "lay" on the pavement surface, more so than binder modifiers, and are not always absorbed into the mat as are binder modifiers. The emulsion seals in this study were not found effective in retarding crack development in AC pavements.

Softening Agents

Reclamite was found quite successful in retarding the raveling of fine aggregates from the pavement surface. This was true whether Reclamite was placed for preventive maintenance or for corrective treatment after raveling had started.

The asphalt hardening properties of only the top 1/4 inch to 1/2 inch of pavement were significantly affected by Reclamite treatment. This was determined by microviscosity testing of recovered asphalt from 1/4 inch slices of pavement cores taken from the test installation. It is believed that the softer asphalt in the top layer of pavement may possibly be of benefit to the pavement from a crack retarding standpoint. Further, the increased binder content in the upper portion of the pavement may resist the spalling of and cracking which does occur. Also the increased binder content should tend to seal off the pavement surface to moisture intrusion from rainfall. However, in seven of eight installations available for this study, as shown in Table 4, there was no significant difference in cracking when test sections were compared to control sections after 4 to 9 years of service. Table 6 shows results of effectiveness of Reclamite treatment on roadways where distress had already started.

Rather than form firm conclusions at this time, it is believed that there is sufficient reason to take a closer look at all binder modifiers and seal coat treatments with respect to potential crack retarding properties.

Petroset is also a binder modifier which has been utilized as a softening and rubberizing agent. Reclamite and Petroset tend to exhibit temporary crack healing properties in the warm weather months, particularly in the wheel path areas of the pavement surface. However, during colder weather these cracks tend to "reopen", thus admitting moisture at a time when it is most likely to rain.

Binder Modifiers in General

The effectiveness of binder modifiers were studied under a separate research project entitled "Binder Modifier Agents for Construction and Maintenance Seals", now nearing completion. Projects 6 and 7 listed in Table 4 and all projects listed in Table 6 show product names and location of test installations with results to date. All of the binder modifiers studied gave somewhat similar results. Raveling is retarded but cracking has not started in either the control or treated sections. Asphalt hardening properties are not affected to any significant extent below the top 1/2 inch of the pavement.

When binder modifiers are used, there is always a risk of reducing the skid resistance of the pavement surface for an interim period. Therefore permeability tests, or better yet, 100 ft - 200 ft test section, should actually be tried initially to determine if the pavement surface will absorb the material before extensive applications are undertaken.

BACKGROUND

This background is offered for those readers interested in the details of how the study evolved. Some of the earlier information is repeated for continuity.

The maintenance and rehabilitation of California's highway network of 45,000 lane miles is an expensive resource consuming operation. Highway maintenance is defined as a program to preserve a system of roadways and their elements to meet their design service life in a safe and usable condition by repairs and restoration.

Highway rehabilitation is defined as a rebuilding and/or improving a system of roadways and their elements by resurfacing, restoration, and reconstruction. The purpose is to extend service life to meet both future traffic load requirements and projected standards of design and operational characteristics. This is generally performed when a segment or element is considered to be not economically maintainable in a safe or usable condition, or extensive damage has been caused by storms, earthquakes, ship collison, etc. The development of quantitative methods to determine the proper maintenance or rehabilitation strategy, its optimum time of application and its expected service life is of utmost importance. The overall objective of this work was to develop performance criteria that address maintenance and rehabilitation problems.

The development of performance criteria requires information relative to expected service relative to the strategy selected. Numerous estimates exist regarding the length and effectiveness of various repair strategies; however, prior to this work California had performed little compilation of data to support these opinions. Most of the work to date had consisted of studying individual test sections where a new placement procedure or material had been used. There was little systematic follow-up of routine operations to determine their effectiveness.

The objectives and direction of this research work were modified a number of times to permit a direct implementation of the results into a concurrently developing Pavement Maintenance Management System. Early in 1973 the research proposal for this work was prepared with the sole objective of "establishing criteria for determining when to overlay existing flexible pavements (structural overlays) for long term economic benefits". This proposal was based on a methodology that required annual pavement deflection surveys on selected test sections. In June 1974 an amended workplan was prepared. The initial objective was retained, however, the methodology to attain it was modified and two additional objectives were incorporated into the workplan. These additional objectives were:

1. To establish predictive criteria for determining the optimum time to rehabilitate a pavement with a thin blanket (one inch of asphalt concrete).

2. To determine the effects of a thin blanket on maintenance costs.

In July 1975 the Office of Maintenance had begun an effort to develop an implementable Pavement Management System to "more effectively manage and coordinate the functions of performing preventive maintenance, remedial maintenance, major remedial maintenance, resurfacing, rehabilitation and reconstruction of rigid and flexible highways....".

These developments required a revision in two of the Work Plan objectives and in May 1976 a final amended version was submitted to FHWA. Both project objectives that were revised involved changes in the Thin Blanket Program that has been in use in California for many years. The ability to "predict" future optimum placement times for repaving a roadway with a one-inch thick AC blanket was no longer necessary. The new objective was: "Establish criteria for determining the optimum time to apply preventive maintenance strategies and determine the expected performance life for each strategy". This expanded the scope to include seal coats in addition to AC overlays 0.10 ft or less in thickness.

The objective of the previous work plan to determine the effect of a thin blanket on maintenance costs was found to be an impossible task. One reason was that Maintenance cost records are not now available on a post-mile by post-mile basis. Instead, the maintenance cost information was recorded on a maintenance foreman's county, route and cost center. It was a rare incident when a thin blanket overlay was placed through a foreman's entire county-route. In order to maximize the benefit from a thin blanket, maintenance forces perform digout type repairs and seal cracks prior to the overlay. This would affect the results in two ways (1) by causing higher than "routine maintenance costs" for this section of roadway, and (2) by giving the thin blanket a longer serviceability period than it would have if the structural condition of the roadway were not improved before blanketing. For these reasons this objective was eliminated from the work plan.

The remaining objective in this revised work plan was to establish criteria for determining the optimum time to apply resurfacing strategies and determine the expected service life for each strategy.

PROCEDURE AND DETAILED DISCUSSION

The first phase of this project to fulfill the objectives in the 1976 work plan was to segregate the maintenance strategies and select projects on which these strategies had been used. The following maintenance strategies were evaluated:

1. Thin Blankets - dense graded .08 foot thick AC blanket for general maintenance over alligator cracked pavements.

2. Thin Blankets - dense graded and open graded .04 foot to .10 foot thick for preventive maintenance over pavements without alligator cracking.

3. Asphalt concrete overlays 0.15 foot or thicker.

4. Coarse and medium screening seals.

5. Sand seals

6. Fog seals
   a) Emulsions
   b) Softening agents
   c) Binder modifier in general

The biennial pavement evaluation surveys only extended back to 1969; therefore, initially only overlays placed from 1969 forward were utilized in developing the performance criteria. Ninety-four monthly issues of the "Statement of Going Contracts" published by the California Department of Transportation, dating from

December 1968 to September 1976 inclusive, were reviewed to obtain a list of all widening and surfacing jobs performed by contract. An additional source of information was inquiries sent to each of the eleven District Maintenance Departments. Some overlays were included in the responses, but generally they yielded only information relative to seals, rejuvenators, "grader blankets", and patches. The records of maintenance and repairs as to their exact locations and when performed were only approximate for most maintenance territories. This information was useful, however, in determining what recorded maintenance work had been performed on pavements which had been overlaid by contract or maintenance. A final source of information was the deflection investigation files to locate any additional overlays not identified during the search of the "Statement of Going Contracts".

Following the selection of the projects the strategy details and pavement conditions were determined. The microfilm index of "as builts" was searched for each contract and the required information extracted. The ten year Traffic Index (T.I.) for each overlaid section was also calculated based on one year equivalent axle loads compiled annually by the Office of Traffic. Pavement distress information was obtained from the "Pavement Evaluation System", relative to the severity and extent of alligator cracking, extent and condition of patching, and the ride score. The information had been presented in a weighted form with a single value representing both severity and extent. These single weighted values were found to be completely unworkable during earlier attempts to develop performance criteria. The reason was that the single value was the product of different weighted condition factors, and often represented a variety of pavement distress conditions. However, the individual condition ratings for severity and extent of cracking, although not presented in the computer output for the pavement evaluation system, were stored in computer files. A computer program was prepared, a file search performed, and the individual condition ratings were obtained and used in developing the performance criteria.

Strategy 1: Thin Blanket Overlays (.08') Dense Graded General Maintenance

Over 4,500 lane miles of nominal 0.08' blankets placed from 1970 to 1974 were used to develop both a thin blanket performance model and the service life. The model was based on width of alligator cracking and failure was defined as the point where crack width clearly exceeded 1/8 inch. The variables considered in developing this model were geographic factors, tropgraphic factors, traffic index, average daily traffic, width of alligator cracks, maintenance work, ride score and time. Many different methods of analysis were attempted; however, only those used as a basis in arriving at this performance model will be reported in detail.

One variable on which the performance model was developed is the geographic/topographic/climatic (GTC) areas of the State. Initially ten GTC areas were established by combining three sources of information. Thes sources were the twenty-four climatological areas for plant types, published in Sunset Garden Book, the nine geographic/topographic (GT) areas delineated in March 1974 by the Maintenance Branch (Planning), and the asphalt durability studies performed by the Transportation Laboratory.

Based on these ten GTC areas the overlay service life for each area had a large standard deviation of approximately 15-20% of the mean. It was felt that this variance might be reduced by modifying the GTC area boundaries.

Therefore, two different approaches were tried. First, to possibly establish new boundaries, the state was divided into a grid system of approximately 200 areas. Attempts at correlation with service life did not prove viable and this strategy was discontinued. Second, the overlaid road sections were segregated into groups according to the length of their service lives. The range of service lives established for any one group was five months.

Individual map transparencies of California were prepared for each service life group, on which were marked the locations of the particular group's overlaid roadway sections. These transparencies were overlaid in various groupings in an attempt to either delineate new GTC boundaries, or verify earlier area boundaries. The findings from this procedure and the aforementioned procedures indicated that the nine geographic/topographic (GT) areas of the state established by the Maintenance Branch would be as satisfactory as any other boundary groupings. These areas are shown in Figure 1. Using these boundaries, the performance model would utilize a pre-existing system of geographic/topographic areas. A final analysis of the service life data indicated that the mean overlay life was approximately equal within many of the areas. Different climatic conditions and materials exist in each area; however, the combined effects sometimes yielded the same service lives. The equality of the service life in many of the nine areas permitted their consolidation into four service life areas (GTA) reflecting geographic and topographic influences. These four areas are as follows:

Maintenance Branch Areas		Adopted GTA(Areas)
1,5,6	=	1
3,7	=	2
9	=	3
2,4,8	=	4

(See Figure 1)

Next, the effect of the level of traffic on the service life was examined. Linear regression analyses were performed and no correlation was found to exist either between the traffic index or average daily traffic and overlay service lives for a large number of roads. Traffic levels are directly related to overlay service life for any single road; however, these relationships do not exist for a large grouping of roads. This might be explained in that the roads were generally constructed with structural sections in proportion to their traffic levels. Thus, the support for the overlay is generally proportional to that required for the given traffic loading. As such, traffic index and average daily traffic have no value in a performance model without the inclusion of information relative to the structural section. The use of these two variables would increase the confidence of the performance model; however, the available structural section data is obsolete. For these reasons the traffic levels were not included in the performance model as a variable.

The width of alligator cracks prior to the placement of an overlay was found to have a significant effect on overlay service life relative to reflection cracking. The time period, in months, from the occurrence of the original alligator hairline condition until a pavement is overlaid, for purposes of this discussion, will be called the "wait period". During this wait period, the severity of the original hairline alligator cracking progresses, which directly affects the service life of any overlay placed over it. The wait period when multiplied by the factor 1.15 equals the loss in service life of an overlay when compared with that of an overlay placed immediately following the occurrence of hairline cracking.

In order to develop the performance model it was necessary to determine when an overlay developed 1/8" wide alligator cracks. The listing of maintenance work was reviewed to determine if any work had been performed which could obscure or negate the biennial roadway evaluation ratings for any given test section. The biennial ride scores were also reviewed as any significant change in ride score generally indicated that something had been done to the roadway. When it appeared that possibly some work had been performed, or a question related to the pavement ratings developed, the section was eliminated from further consideration.

All of the selected sections were reviewed to statistically develop <u>average</u> rates of deterioration. These deterioration rates are not directly applicable to any one road, but are applicable to a group of roads. It was found that 1/8" alligator cracking occurs on the average twelve months following the occurrence of hairline alligator cracking. Within another eight months the 1/8" wide alligator cracking progresses into 1/4" wide alligator cracks. Within another four months the alligator cracking is considered as >1/4" cracking.

Based on these average deterioration rates, the actual conditions of selected sections observed during the biennial evaluation ratings were extrapolated to that point in time at which 1/8" wide alligator cracking had occurred or would be expected to occur following the overlay. For this performance model this extrapolated point in time was considered as the end of overlay service life.

The alligator cracking condition just prior to placement of the overlay was determined in a similar manner. The condition rather than the time was extrapolated, as the time from the prior biennial evaluation to the overlay placement is known. The projects were then grouped according to the alligator crack width at the time of overlay placement.

A linear regression analysis was performed on each alligator crack width group for each geographic/topographic area. The two variables regressed were the number of months of overlay performance life, and the "wait" period in months plus the months of overlay service life. This yielded the mean service lives with and without the wait period. The slope of the regression line was utilized in determining the effect on total service life due to the "wait" period.

The information was then all combined into a single equation into which the variables can be substituted and an overall service life can be calculated. This equation and terminology are as follows:

$$SL = \frac{GTA_f}{70}(60 - 1.15\ WP) + (FC_f - IC_f)$$

SL = service life (months)

GTA_f = Geographic/Topographic area factor (weighted as follows:)

GT Area	GTA_f
1,5.6	70
3,7	60
9	55
2,4,8	50

WP = Wait Period (Months)(Time between when hairline cracking occurs and when the overlay is placed.)

FC_f = Final alligator width condition factor (end of overlay life)

IC_f = Initial alligator width condition factor (at time of rating)

Alligator Crack Width	FC_f or IC_f (weighted as follows:)
Hairline	0
1/8"	12
1/4"	20
>1/4"	24

Fox River Bend

Association

Fox River Bend

The development of this performance model verified that alligator crack width had a significant impact on the service life of an overlay when using crack width as the failure criteria.

The service life based on extent of alligator cracking required a different failure criteria. The failure condition for this is defined as follows:

> Load-associated alligator cracking or patching extending over 10% of the area was defined as the end of service life for all surface treatments and thin blankets placed on AC pavements.

In order to develop this service life it was necessary to determine when the thin blanket developed 10% extent alligator cracks or patching. The extent of alligator cracking and patching was obtained from the same information sources as used for the crack width performance model. The nine geographic/topographic areas shown in Figure 1 were utilized in grouping and analyzing the data. The data was assumed to be normally distributed and a mean life and standard deviation was calculated for each group. The data from the nine geographic/topographic areas was combined into a single group to represent a statewide average service life. The mean service life and standard deviation for this statewide group and the other nine geographic/topographic groupings are given in Figure 2.

Although the performance model work outlined above has usefulness, California has elected to use performance criteria based on the strategy selected and its past service life experience.

Strategy 2. Thin Blanket Overlays (0.04'/0.10') Preventive Maintenance

Dense Graded Blankets

Of the five hundred and seventy-six thin blankets placed on California roadways from 1970 to 1974 only forty-three were placed over pavements with prior biennial condition ratings indicating no alligator cracking. Seventeen of these thin blankets had adjacent roadway sections that were also evaluated as having no alligator cracking which could be used as a comparison or control sections.

An in-depth investigation of these seventeen overlaid sections and their adjacent sections was performed. Information was researched relative to their structural sections and any maintenance or contract work performed on the overlaid or control sections. This information included work performed both before and after the placement of the thin blanket. The biennial pavement ratings for 1978 were also reviewed to obtain the latest pavement condition ratings. It was determined by analysis that fourteen of the seventeen sections were not usable as to develop a service life. The typical reasons were that: (1) Generally the control sections either had different structural sections or (2) work had been performed on the control sections just prior to or following the overlay, or (3) neither control section nor thin blanket section had yet exhibited any alligator cracking.

The remaining three sections indicated variable results. The 04-SCr-17 test section indicated there was no retardation of alligator cracking from the thin blankets. The 03-Sut-99 thin blanket placed in June 1973 exhibited 3%

alligator cracking in the 1978 biennial pavement evaluation whereas its adjacent control exhibited 1 to 15% alligator cracking in 1976 and received a thin blanket in 1977. This indicates possibly a 24 month delay in the development of alligator cracking. The third project, 02-Las-36, indicated that the thin blanket lasted twenty-nine months longer than the control before exhibiting alligator cracking.

Since a thin blanket, on the average, lasts thirty months when placed over alligator cracked pavements, it appears there is no economical advantage to placing a thin blanket over pavement to retard alligator cracking since the additional life gained over the adjacent control sections is less than thirty months (perhaps considerably less).

Open Graded AC-Blankets

One hundred and fifty-six open-graded asphalt concrete blankets placed on California state roadways during the years 1970 to 1974 inclusive were investigated to determine their effect on retarding the development of alligator cracking. They ranged in thickness from .04 to .10 foot. The biennial pavement evaluation ratings were reviewed to determine the pavement condition prior to placing the open-graded overlay.

Sixty roadway sections were rated as having no alligator cracking at the time of the biennial evaluation survey which sometimes preceded the placement of the open-graded blanket by as much as two years. These sixty sections were examined further and thirty-eight were found to have adjacent sections which were also simultaneously rated as having no alligator cracking.

These thirty-eight overlaid sections and their adjacent sections were investigated in detail. The biennial roadway evaluation ratings up to 1978 were obtained to determine roadway conditions. Next, structural section data and any ensuing maintenance and contract work on each of the roadways was compiled. All of this information was analyzed for each roadway section. Fourteen sections were found to have structural sections somewhat comparable to the adjacent sections which could be used as control. These fourteen sections were used to determine the effectiveness of the open-graded blanket in retarding alligator cracking. The time extent of alligator cracking in each of the fourteen control sections was directly compared with that in each of the fourteen overlaid sections. This comparison showed that ten sections had no effect in retarding alligator cracking. The remaining four projects yielded mixed results.

Strategy 3. <u>Asphalt Concrete Overlays (0.15' or thicker)</u>

An attempt was made to develop six service lives for the thick AC overlay strategy. These were segregated as follows:

1. Overlays over AC (0.15' to 0.25' thick) based on alligator crack width failure criteria.

2. Overlays over AC (0.15' or thicker) designed by Deflection Analysis. End of service life based on area of load associated alligator cracking.

3. Overlays over AC (0.15' or thicker) designed by the Gravel Equivalent Method. End of service life based on area of load associated alligator cracking.

4. Overlays over AC (0.15' or thicker) designed subjectively, stage construction, etc. End of service life based on area of load associated alligator cracking.

5. Overlays over AC (0.15' or thicker) designed based on reflective cracking criteria. End of service life based on area of load assocated alligator cracking.

6. Overlays over PCC (0.15' or thicker) designed based on reflective cracking. End of service life based on number of reflective cracks.

Overlays Over AC Pavement

The service life based on the width of alligator cracking was developed first. It was limited to contract-placed overlays built between 1969 and 1974. This yielded less than 500 lane miles of pavement overlays on which to develop the service life. The end of service life or failure criteria was again defined as the occurrence of alligator cracks larger than 1/8 inch in width.

This service life presented the problem of determining what had been the original roadway alligator crack width at the time of overlay placement. A review of those overlays placed after initiation of the biennial rating system indicated that on the average, the thick overlays were placed over 1/4 inch wide alligator cracks. For purposes of developing the service life the assumption was made that those roads on which thick overlays were placed prior to the initial biennial rating had 1/4 inch wide alligator cracking. Since we were dealing with averages, this assumption is believed to be valid for determining the average service life.

The next step, to determine length of service, was hampered by the fact that many of the overlaid sections did not show any distress at the time of the last biennial pavement evaluation survey. For those roadways which did show distress, the service lives were calculated in the same manner as that used for the thin blanket crack width model. Next, the following statistical analysis was performed to determine a projected average service life for the distressed and non-distressed overlays. The overlays were assembled into single sample groups for each 0.05' increment of thickness. For analysis purposes a service life distribution for each group of thick overlays was assumed. This distribution, equivalent to that found for the thin blankets, is normal with a single standard deviation of 15% of the total mean. Based on the service lives of those distressed roads within the sample, the percentage of the total sample they comprised, and the assumed distribution, an average total service life was calculated for each 0.05' thickness group.

The service life based on the extent of alligator cracking utilized a data base twice the size of that used for the crack width service life. This data base included all overlays 0.15' or thicker placed over AC pavement by contract during the period 1964 to 1974 on California highways. The failure criteria for determining service life based on extent of cracking was arbitrarily reached when 30% of the area exhibits a combination of load associated alligator cracking and patching.

The service life based on extent of alligator cracking presented a similar problem to that of the service life based on crack width in that the roadway condition prior to the overlay was not known. This lack of information on the initial surface conditions prior to overlay prevented the examination of its impact of variable thickness on the service life of the various overlays. However, it is felt that the roadway condition must have been severely distressed to warrant the thick overlay. Therefore the assumption was made that for thicker overlays placed over AC pavements, the alligator and patching condition prior to overlay probably equalled or exceeded 30% in extent. Thus, for the same reason previously given it is believed that since we are dealing with "averages", the results are reasonable and valid. Also, the thicker overlays are intended to provide the additional structural support believed necessary to provide a long service life despite the initial pavement condition.

The next step was to determine the service life for each overlay. The service life was determined arbitrarily for those overlayed roadways which had not yet exhibited the 30% distress level at the last biennial pavement but did exhibit some alligator cracking or patching. This was done by adding 24 months to their life at the time of their last biennial evaluation. This was based on the assumption that at least two more years would pass before the next biennial evaluation at which time any further distress would be noted. Those overlays which did not exhibit any distress were also included in the service life calculation if their life, when extended 24 months, as above, exceeded the average life of those overlays which had exhibited the distress condition.

In analyzing the service lives of these overlays they were grouped into four separate categories based on the method used for their design:

- Deflection Analysis
- Gravel Equivalent
- Subjective Judgement
- Reflective Cracking

Deflection Analysis

Previous investigations have indicated that overlays designed using the deflection method (Test Method No. Calif. 356) have an average life of 10 years. However, for the previous study many city and county roads were included because prior to 1969 state highways represented a small percentage of the roads overlaid using the deflection design recommendations. Therefore, relative to the number of overlays examined there were few deflection-designed overlays included in this work as only state highways are considered.

Only one third of those state roads on which deflection measurements were performed ever received the full recommended overlay thickness. Many of those projects were later widened, channelized, or received surface treatments due to raveling, bleeding, or skid problem before reaching ten years of service life. This obfuscated the biennial pavement evaluation ratings and prevented a satisfactory determination of their service lives. Eight projects on state highways remained on which to determine the service life. A normal distribution was assumed and a mean and estimated standard deviation calculated.

Gravel Equivalent

Sixteen locations reportedly designed using the gravel equivalent method are included in this category. This method requires the engineer to make an intuitive assessment of in-place pavement conditions and assign a "gravel factor" to the existing AC pavement. Then an overlay is designed based on the future traffic and gravel equivalent of the in-place roadway. A normal distribution was assumed and a mean service life and estimated standard deviation calculated.

Subjective Judgement

This grouping of overlays included all thick overlays placed over AC not constructed to those thickness recommendations obtained using either the Deflection Analysis, or Gravel Equivalent, or Reflection Cracking criteria. Thirty-six projects were obtained which represented in excess of 250 lane miles.

Not all of these projects had yet reached failure at the time of the last biennial pavement evaluation survey due to their relatively recent placement. The service lives of the usable projects was determined. A normal distribution was assumed and a mean service life and estimated standard deviation calculated.

Reflective Cracking

Fourteen projects were located for which the thickness recommendations for overlay were controlled by reflection cracking criteria rather than the deflection criteria. Ten of these were either not overlaid or the recommendations were not followed. The remaining four projects, representing less than four lane miles, only lasted approximately six years to the end of service life. The other two projects at the time of the last biennial pavement evaluation survey were still in good condition after almost seven years of service. The data from this design method is insufficient to develop a service life for those overlays placed over AC pavements in accordance with this method.

Overlays Over PCC Pavement

PCC overlay failures do not show up as alligator cracking; therefore, the end of service life had to be evaluated using different criteria. That point in time at which more than five transverse cracks per 100 feet had reflected through the overlay is defined as an end of service life of an overlay of this kind.

Twenty-four overlays placed during the period 1965 to 1969 were analyzed to develop the service life. A normal distribution was assumed for the service lives and a mean service life and estimated standard deviation calculated.

Much of the variation in the service life of these overlays can be explained by their variable thicknesses. The thickness of the overlay is directly related to the time period for cracks to reflect through. The overlay thicknesses were regressed against the service life of the overlays. This is plotted in Figure 5. Those points identified in the figure with a plus mark indicated they had not yet reached the end of service life criteria at the time of the last biennial survey. Therefore, twenty-four months was arbitrarily added and the points plotted.

Strategy 4 <u>Coarse and Medium Screening Seals</u>

The service life for these seals was based solely on the extent of alligator cracking criteria. Coarse or medium screening seals are placed to eliminate raveling conditions,, increase skid resistance, seal cracks and prevent intrusion of surface water, and for lane delineation purposes. Correction of a fine aggregate raveling condition or increasing skid resistance is usually effective if the seal is placed correctly. The real question is, are those coarse or medium screening seals placed to seal the cracks effective?

Approximately 800 lane miles of these seals were evaluated for their ability to seal cracks. Although many of these seals may not have been placed <u>solely</u> to seal the cracks, they were nevertheless placed over cracked pavements. These seals were divided into two groups for evaluation, those placed over pavements with 1% to 15% alligator cracking, and those placed over pavements with greater than 15% alligator cracking. Normal distribution were assumed and the mean service lives and standard deviations for each group were calculated. A comparison of the groups indicated there was not significant difference and that the initial extent of alligator cracking had little effect on their return to a 10% extent alligator cracking. Therefore, the data was combined and an average service life of 16.2 months with an estimated standard deviation of 11.3 months was obtained. The three distributions are presented in Figure 6. This indicates that placement of an ordinary coarse or medium screening seal to seal cracks and prevent surface intrusion of water is a short-term strategy.

Strategy 5 <u>Sand Seals</u>

The sand seal service life was calculated in the same manner as that used for the coarser screening seals. This is, How long did they seal the cracks? The sand seals were divided in two groups, those placed over pavements with 1% to 15% alligator cracking, and those placed over pavements with greater than 15% alligator cracking. The data was assumed to be normally distributed and a mean service life and standard deviation was calculated for each group. A comparison of the groups indicated there was no significant difference and that the initial extent of alligator cracking had little effect on their return to a 10% extent alligator cracking. Therefore, the data was combined and an average service life of 13.5 months with an estimated standard deviation of 8.5 months was obtained. The three distributions are presented in Figure 7. This indicates that placement of a sand seal to seal cracks or permeable pavements to prevent surface instrusion of water is a short-term strategy.

Strategy 6 Fog Seals

Research work performed relative to emulsion seals, binder modifiers, and softening agents was evaluated as preventive maintenance strategies. The biennial pavement evaluation survey did not provide the type of information necessary to evaluate these as preventive maintenance strategies.

Therefore, a review of previous and ongoing research in these areas was performed. Also several inquires were made with maintenance and other personnel to maximize the available information. None of these treatments had any significant effect below the top 1/2 inch of the pavement.

FIGURES AND TABLES

FIGURE I. GEOGRAPHIC / TOPOGRAPHIC AREAS

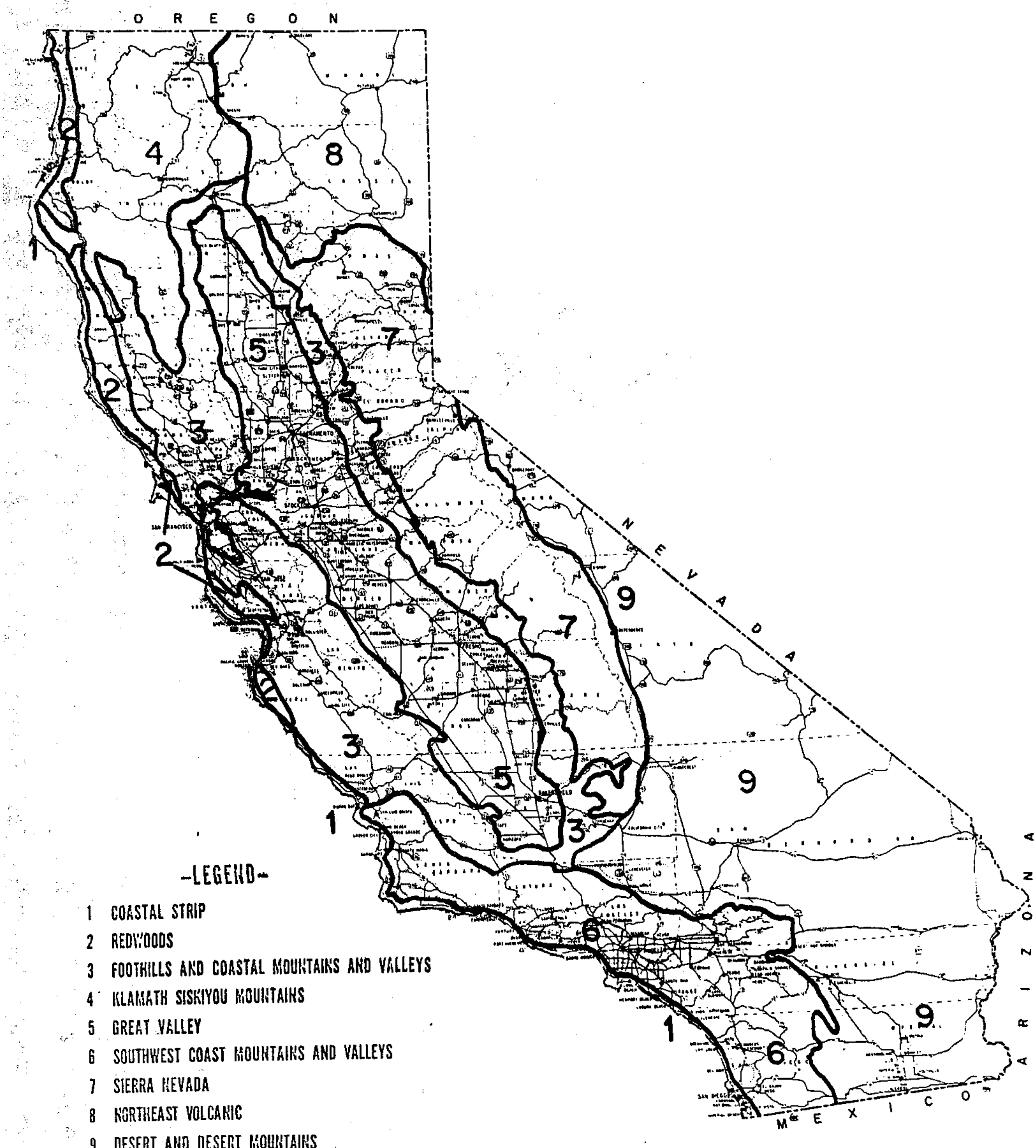


FIGURE 2. THIN BLANKETS

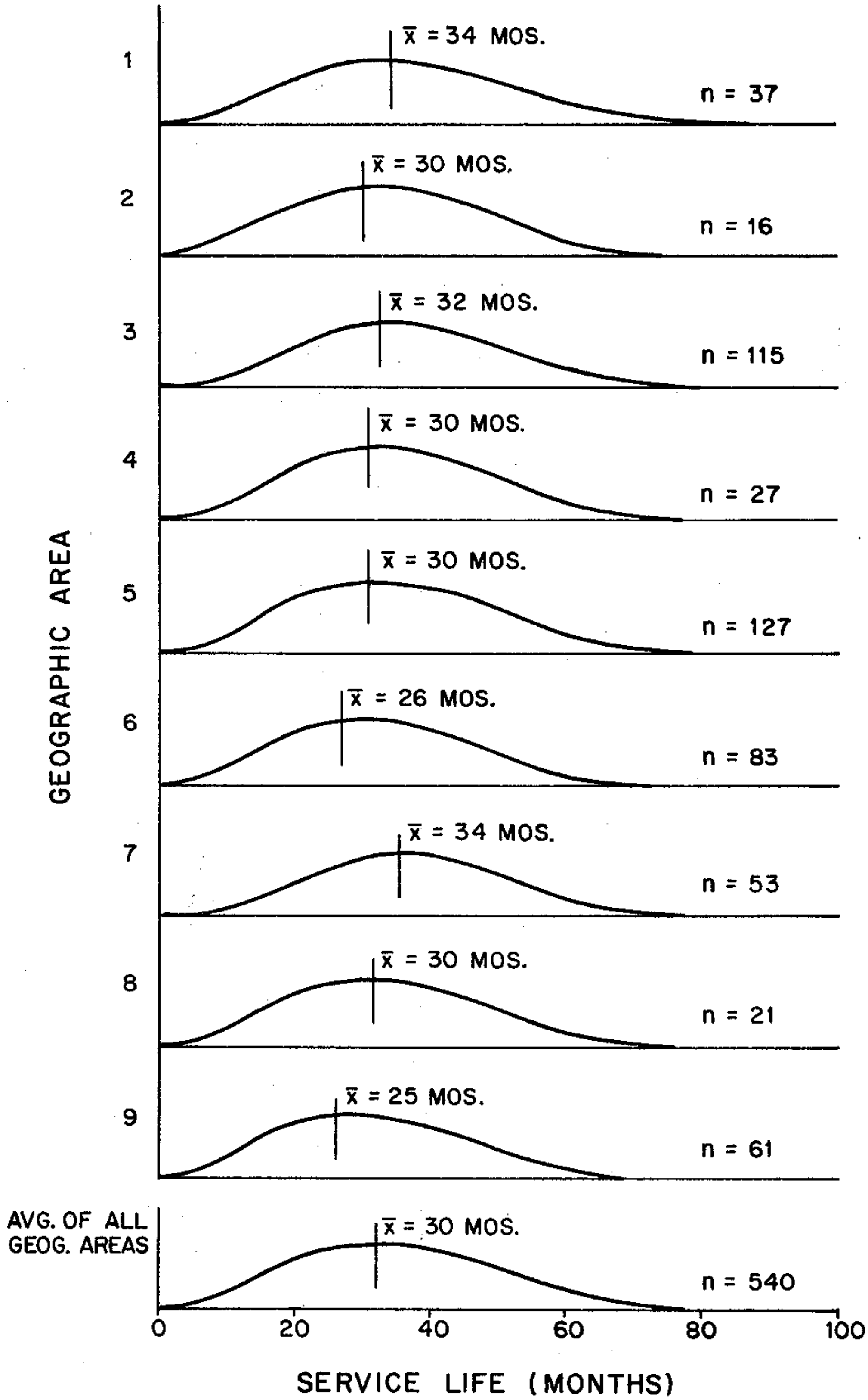
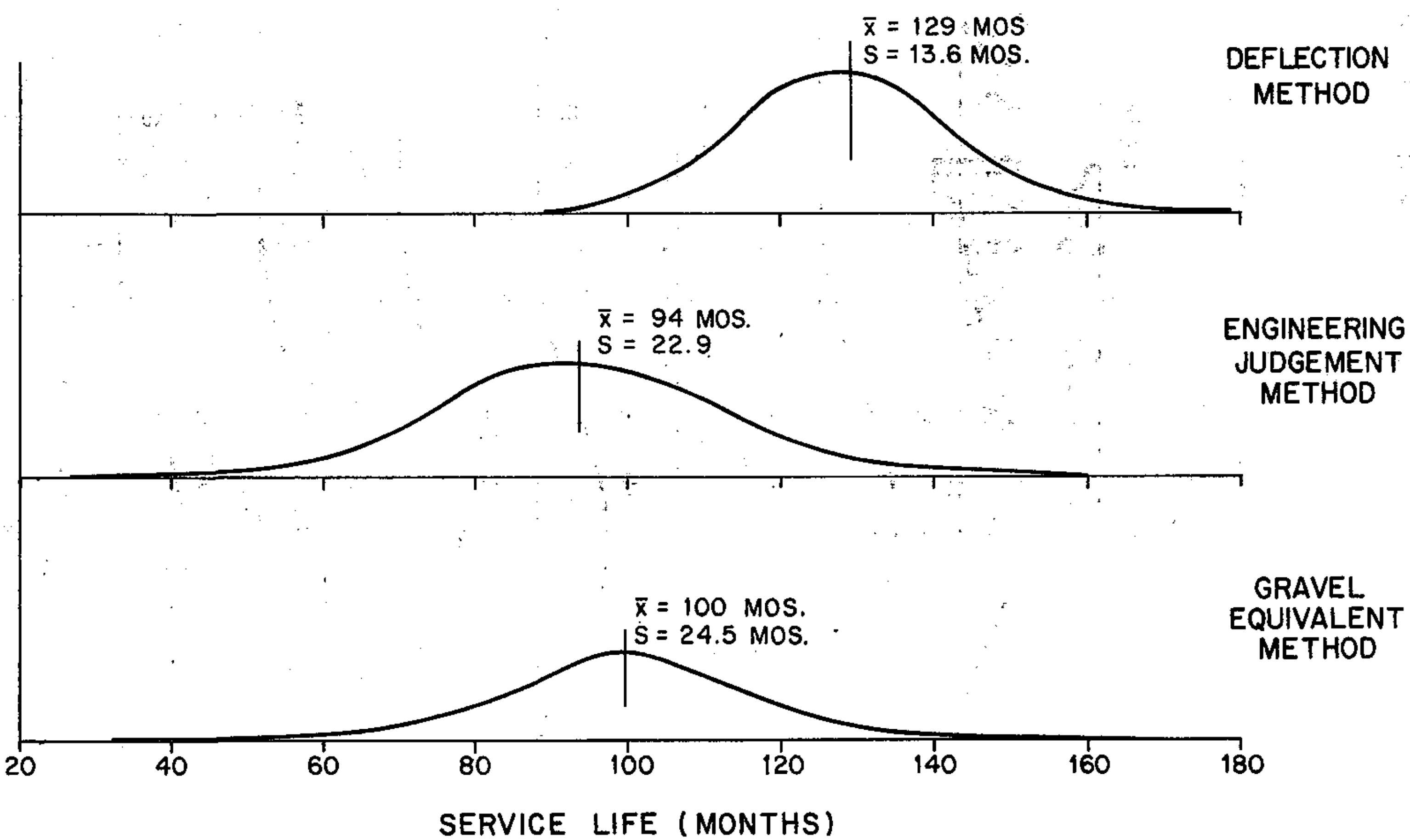


FIGURE 3. STRUCTURAL OVERLAYS*



* These curves are based on California's experience with three design methods for structural overlays over flexible pavement.

FIGURE 4. AC OVER PCC, SERVICE LIFE
> 5 TRANSVERSE CRACKS PER 100 FEET

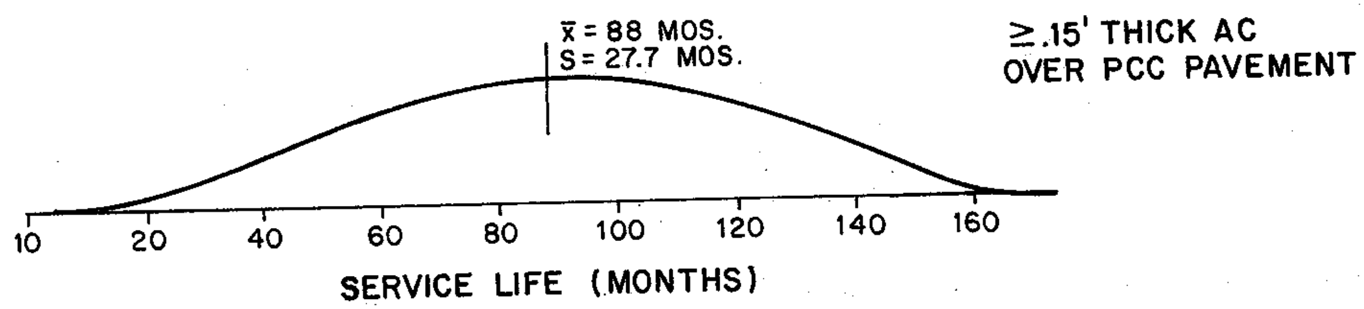


FIGURE 5. AC OVER PCC, THICKNESS VS LIFE
> 5 TRANSVERSE CRACKS PER 100 FEET

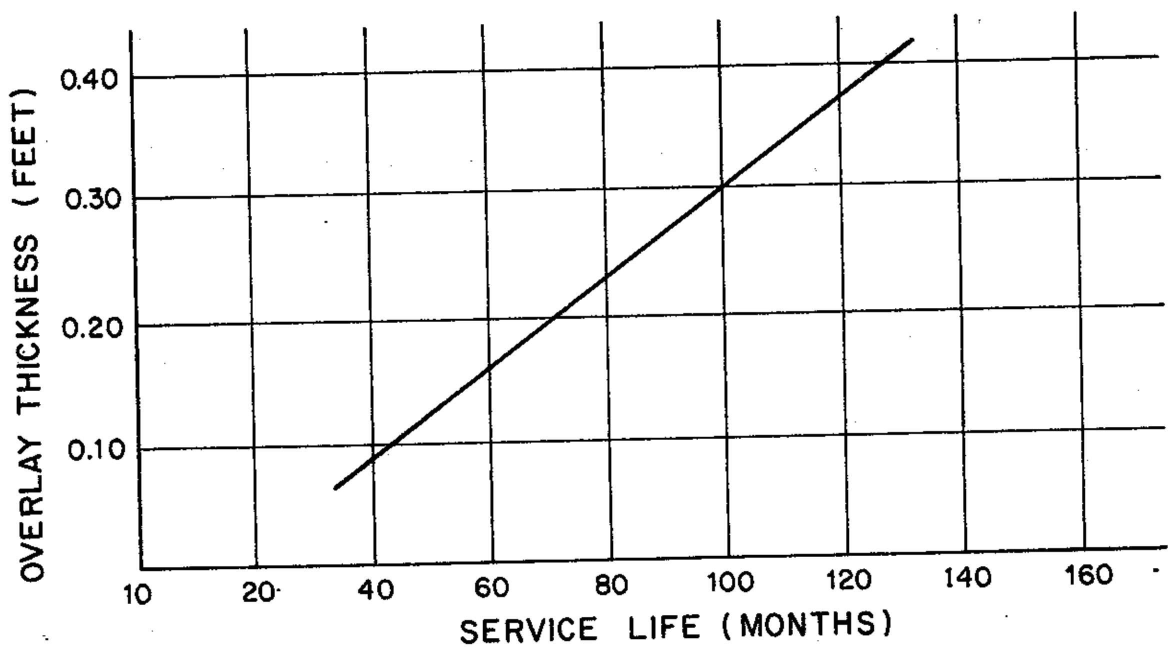


FIGURE 6. SCREENING SEAL COATS

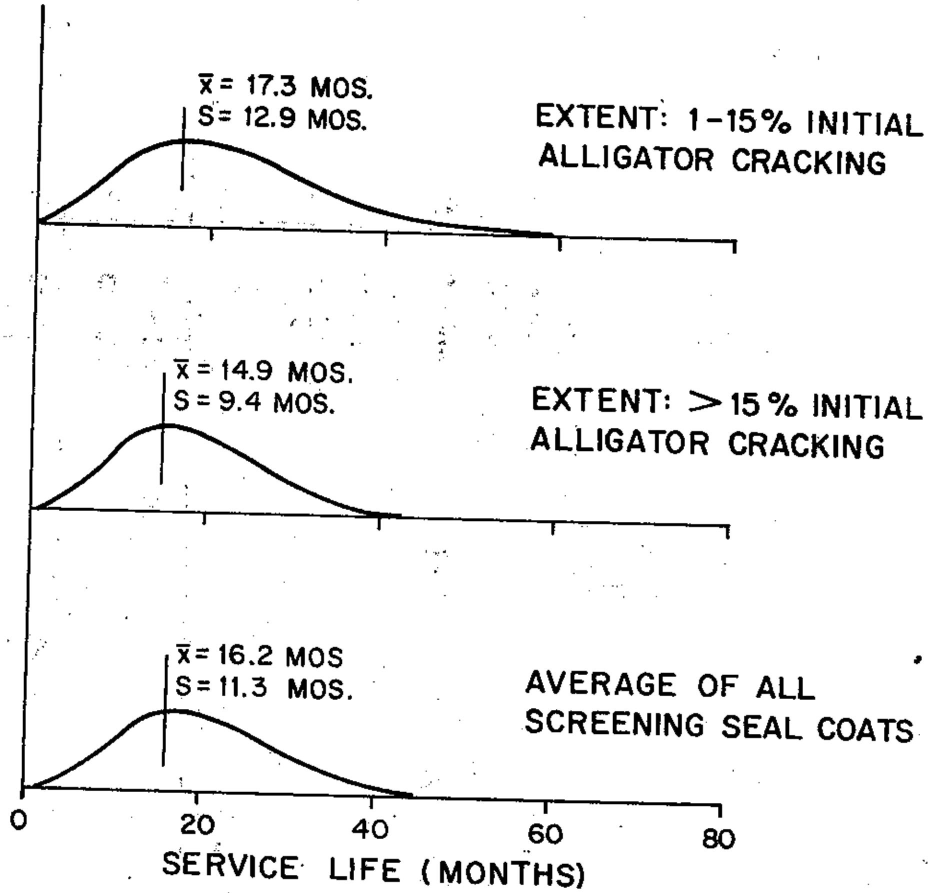


FIGURE 7. SAND SEAL COATS

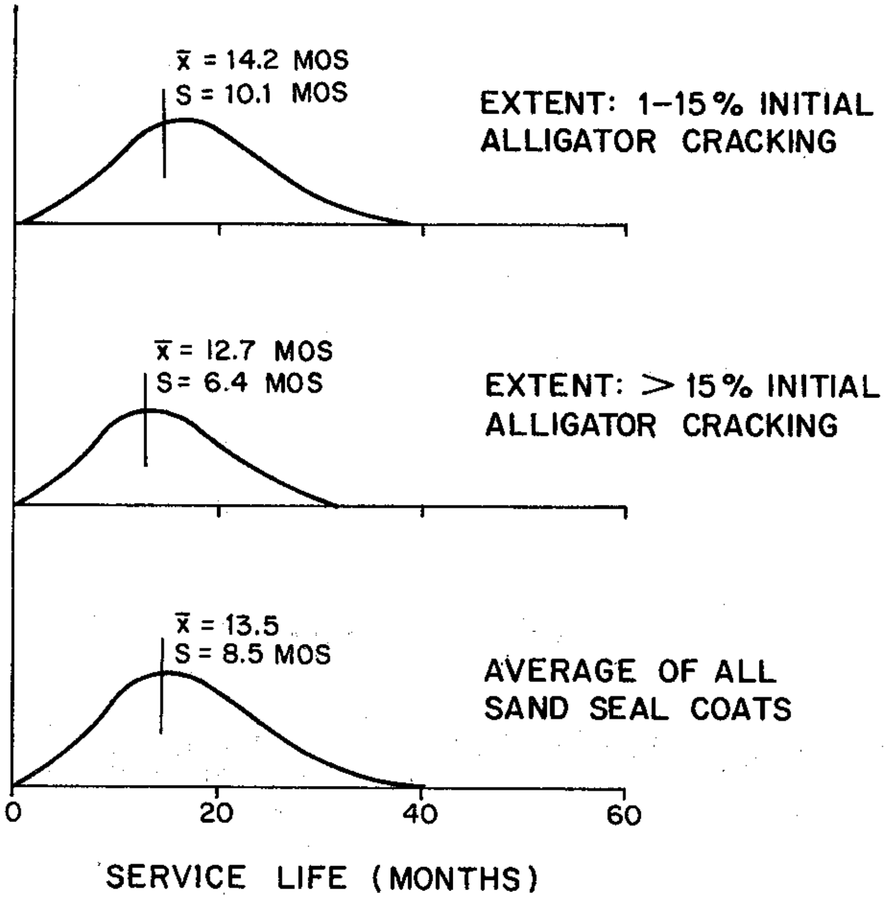


TABLE 2
COARSE AND MEDIUM SCREENING SEAL EFFECTIVENESS

Project	Purpose of Seal	Year Placed	Last Year Evaluated	Did it Retard Raveling?	Did it Retard Asphalt Hardening?	Did it Retard Cracking?
01-Lak-29 Lakeport	Maintenance	1976	1978	Yes	Unknown	No
02-Teh-99 Los Molinos	Preventive (1 yr. after construction) 3" PMS & 6" CTB new align.	1956	1961	Yes	No[1]	No[1]
03-Sut-99 P.M. 36/39	Maintenance	1974	1977	No[2]	Unknown	No[3]
03-Sut-99 P.M. 25/30.6 29.6-30.6 Untreated	Maintenance	1974	1976	No[2]	Unknown	No
03-Yub-20 P.M. 9.2/18.0	Maintenance	1973	1978	No[4]	Unknown	No[5]
03-Sac-104 P.M. 0.0/4.7	Placed at early signs of cracking	1971	1977[6]	--	Unknown	No
02-Tri-3 Contract 59-2TC13 Hayfork	Preventive	1958	1969	--	Unknown	No[7]
05-SBt-101	Preventive	1958 and 1951	1959 1959	--	No	No[8]

[1] An April 3, 1961 report on this project (Skog to Zube) concluded that "all 3 paving grade asphalts have responded about the same in terms of hardening rates in the sealed and unsealed sections". Since hardening of asphalts would influence crack development no significant difference in cracking would be expected (cracking began to develop in both test and control sections between 1971 and 1973).

[2] Screening "whip off" occurred in wheelpath areas some continued ravel of old pavement surface.

[3] In 1976 a thin blanket was placed over this part, and a deflection study performed in 1977.

[4] Raveling continued - shows in 1976 rating.

[5] A 1975 maintenance blanket was placed on westerly end (1/2 mi), alligator cracking reflected through remainder in 1976.

[6] Overlay placed in 1977 after cracking developed.

[7] Alligator cracking appeared 1969 in both control and test sections.

[8] Memo John Skog to Ray Forsyth dated Sept. 10, 1959 states that pavement cracking began about <u>one year</u> after construction. A medium fine seal coat had been placed as a construction seal. Adjacent <u>pavement</u> constructed in 1951 also showed cracking even though it appeared that asphalt from the seal coat may have penetrated into the surface about 1/2" (truck lane cracking).

TABLE 3

EMULSION SEAL EFFECTIVENESS

Project	Year Placed	Last Year Evaluated	Type of Seal	Did it Retard Raveling?	Did it Retard Asphalt Hardening?	Crack Healing?
06-Ker-58,178 Bakersfield	1966	1970	Maint Seal, on cracked pavement	No	No	Yes, during hot weather
09-Mno-203 Mammoth Lakes	1965	1970	Preventive, on uncracked pavement	Yes, but only slightly	Unknown	Not applicable
09-Ker-58 Edwards Jct.	1974	1978	Preventive, on uncracked pavement	Yes	No	*
10-Cal-4 Copperopolis	1972	1978	Preventive, on uncracked pavement	Yes	No	*

*Cracking has not developed in any of the emulsion test sections or control sections on any of these projects to date (1978).

TABLE 4

RECLAMITE FOR PREVENTIVE MAINTENANCE

Project	Year Placed	Last Year Evaluated	Did it Retard Raveling	Did it Retard Asphalt Hardening?	Any Difference in Cracking? (Test vs. Control Sections)	Years to Final Eval.
02-Las-36 Susanville	1972	1976	Not placed[1] for raveling control.	Unknown (no cores taken)	No	4
05-SB-101 Zaca/Wigmore	1965	1970	Yes	Only in top 1/2" (based on cores)	No	8[2]
06-Ker-58,178 Bakersfield	1966	1970	Yes	Only in top 1/2" (based on cores)	No	4
06-Ker-CR Panama Lane	1961	1970	--[3]	Yes, based on 9-61 visual inspection	No	9
09-Mno-203 Mammoth Lakes	1965	1970	Yes	Unknown (no cores taken)	Yes[4]	5
09-Ker-48 Edwards Jct.	1974	1978	Yes	Only in top 1/4"-1/2" (based on cores)	No[5]	4
10-Cal-4 Copperopolis	1972	1978	Yes	Only in top 1/4" (based on cores)	No[5]	6
11-SD-78 Vista	1972	1976	Not placed[1] for control of raveling	Unknown (no cores taken)	No	4

[1] Old surface did not show signs of ravel. Reclamite was placed on new 1" blanket as a test to retard reflection cracking.

[2] Cracking had not developed in any of the test sections or control sections after 5 years. The Maintenance rating system shows that alligator/block cracking developed after about 8 years in all test and control sections.

[3] Raveling did not occur in either the test sections or control sections on this project.

[4] Cracking was less noticeable in Reclamite test section than in control section.

[5] Cracking has not developed in any of the Reclamite test sections or the control sections (1978).

TABLE 5

RECLAMITE EFFECTIVENESS AFTER SIGNS OF DISTRESS

Project	Year Placed	Last Year Evaluated	Did it Retard Raveling?	Did it Retard Asphalt Hardening?	Was it Effective in Crack Healing or Retarding Reflection Cracks?
01-Lak-29 Lakeport	1977	1978	Yes	Unknown	No
06-Ker-43 Taft	1972	1976	Treatment made for other purpose*	Unknown	No
09-Ker-14 Red Rose Canyon	1962	1970	No	Unknown	No
11-Imp-111	1966	1970	Yes	Only in top 1/2"	Unknown**

*Reclamite applied after heater scarifier treatment and prior to placement of 1" AC blanket. Cracking began to reappear through the blanket in both the test section and control section in 1974. In 1976 the test section was judged to show less cracking than the control section. In 1977, a deflection study was requested for the overall project and a structural overlay is now needed.

**Six Reclamite test sections (each 100' in length) were placed in efforts to retard raveling. Cracking is not mentioned in the evaluation report dated July 1970.

TABLE 6

OTHER BINDER MODIFIER EFFECTIVENESS FOR PREVENTIVE MAINTENANCE[1]

Project	Year Placed	Last Year Evaluated	Did it Retard Raveling?	Did it Retard Asphalt Hardening?	Any Difference in Cracking? (Test Section vs. Control Section)
Astec					
09-Ker-58 Edwards Jct.	1974	1978	Yes	Top 1/4" only (based on cores)	No[2]
10-Cal-4 Copperopolis	1972	1978	Yes	Top 1/4" only (based on cores)	No[2]
Gilsabind					
06-Ker-58,178 Bakdersfield	1966	1970	Slightly	---------	Yes[3]
09-Ker-58 Edwards Jct.	1974	1978	Yes	Top 1/4" only	No[2]
10-Cal-4 Copperopolis	1972	1978	Yes	Top 1/4" only	No[2]
Petroset					
09-Ker-58 Edwards Jct.	1974	1978	Yes	Top 1/4" only	No[2]
10-Cal-4 Copperopolis	1972	1978	Yes	Top 1/4" only	No[2]
Satin Black					
09-Ker-58 Edwards Jct.	1974	1978	Yes	Top 1/4" only	No[2]
10-Cal-4 Copperopolis	1972	1978	Yes	Top 1/4" only	No[2]

[1] For Reclamite See Sheet No. 1

[2] Cracking has not yet developed in any of the test or control sections (1978).

[3] Gilsabind test section shows more cracking than adjacent test sections and control sections.