California Experience with Cracking and Seating of Concrete Pavements

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The California Department of Transportation (Caltrans) is currently using the portland cement concrete pavement (PCCP) rehabilitation technique of cracking and seating (C&S) before placement of an asphalt concrete (AC) pavement overlay to prevent or retard reflection cracking from the underlying PCCP. Field measurements of differential vertical slab deflections and AC overlay performance are compared for various C&S projects. Construction techniques, specifications, pavement breaking equipment, and cracking patterns are discussed, along with problem areas and solutions. An experimental procedure for seating broken slabs is also described. AC overlay performance data are presented for various projects constructed with and without C&S of PCCP, with variable overlay thicknesses and with and without pavement reinforcing fabric (PRF). It is concluded that the C&S strategy is beneficial in preventing and retarding reflection cracking in AC overlays on PCCP by reducing thermal movements of existing PCCP, restoring slab support, and reducing differential vertical deflections of PCCP slabs. These AC overlays, with a few exceptions, are providing excellent performance after 5 to 7 years of service.

The rehabilitation of severely distressed portland cement concrete pavement (PCCP) in California has historically been accomplished by overlaying with asphalt concrete (AC). Before about 1982, these overlays were generally selected using a standard thickness varying from 0.30 to 0.50 ft, depending on the condition of the existing PCCP. Although the initial ride quality was restored by these overlays, their performance varied and reflection cracking was inevitable, as shown in Figure 1.

Sherman (*1*) suggests that the thickness required to retard reflection cracking of AC overlays "appears to be a variable that depends on several factors: (a) type of pavement being overlaid (AC or PCC); (b) type of distress (alligator cracking, block cracking, transverse thermal cracks, longitudinal cracks, or PCC joint cracks); (c) climate; and (d) number and weight of axle loads."

Most reflection cracking in AC overlays over PCCP is the result of differential vertical movement or displacement (Δ-verts) at joints and cracks under loadings by heavy vehicles, especially where the existing PCCP slabs are curled or faulted. McGhee (*2*) has suggested that the rate of crack development is a function of the frequency of wheel loadings and the magnitude of vertical movement (Δ-vert) caused by these loadings. On the basis of his findings, McGhee has also suggested that, wherever Δ-verts are 0.002 in. or greater, early reflection cracking is a possibility but that, where Δ-verts are 0.008 in. or greater, reflection cracking is almost a certainty. Caltrans (*3*), in an investigation of AC overlays with paving fabric, has generally confirmed McGhee's findings. Also, Caltrans has found that, for the transitional area of Δ-verts (measurements between 0.003 and 0.008 in.), paving fabric interlayers in AC overlays were somewhat effective in delaying reflection cracking of joints or cracks for about 1 year, compared with overlays without a paving fabric interlayer.

Generally, Δ-vert is measured by applying a moving 18-kip single-axle load across each side of a joint or crack and measuring the maximum deflection relative to the adjoining slab. Caltrans uses a modified Benkelman beam apparatus, as shown in Figure 2.

For existing AC pavements, Caltrans assumes that an AC overlay of one-half the existing AC pavement thickness is required to sufficiently retard reflection cracking. Pavement-reinforcing fabric (PRF) is assumed to provide an AC thickness equivalency of 0.10 ft in retarding reflection cracking. No structural value is given to the PRF. Caltrans considers 0.35 ft of AC as the maximum overlay thickness required for reflection crack control over AC pavement.

The prevention of reflection cracking in AC overlays on AC pavement is generally solvable. However, reflection cracking of AC overlays on PCC pavement has been a continuing problem, and considerable effort has been made throughout the nation to address this issue (*1,2,4*).

The most promising strategy in recent years that has received national attention has been the cracking and seating (C&S), or breaking and seating, of PCC pavement as a pretreatment to AC overlaying.

An early, undocumented attempt to crack and seat a PCCP was tried by Caltrans near Tracy, California, in late 1960 using procedures that had previously been used in Minnesota with a heavy roller (*5*). For this operation Caltrans attempted to use a 50-t pneumatic roller before placing an AC overlay. However, the operation was considered unsuccessful because no cracking appeared in the PCCP surface after several passes of the roller. The main reason for the poor success of this operation was that it occurred in late summer when the subgrade was dry and provided good support.

The first genuine approach by Caltrans to the C&S strategy with actual pavement breakers in conjunction with heavy rollers was conducted in 1982. Since that date, Caltrans has rehabilitated approximately 100 projects, representing over 1,000 lane-mi of PCCP truck lanes, with generally good success. Before adopting its current strategy, Caltrans evaluated several C&S patterns and AC overlay thicknesses with and without PRF interlayers. Some of these projects, as well as projects by other states, are listed as state-of-the-art by Crawford

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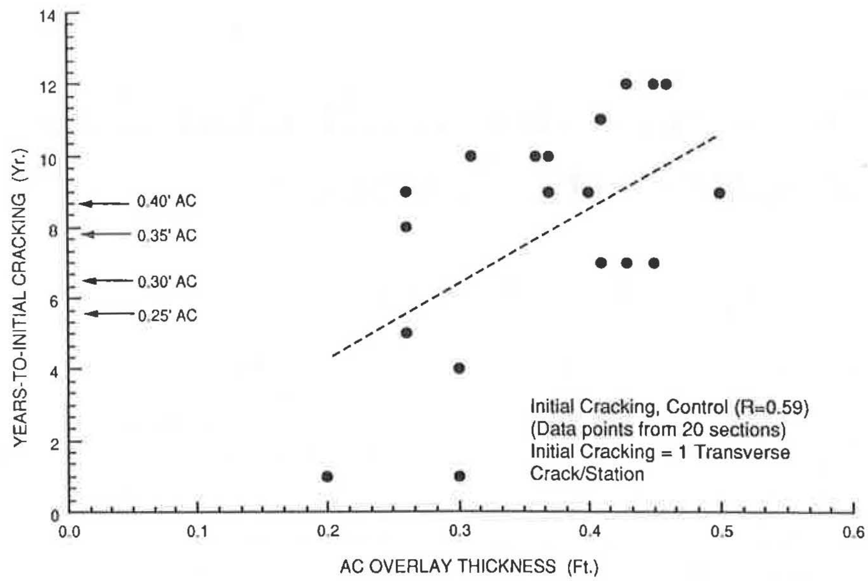

FIGURE 1 Effect of AC overlay thickness on overlay performance over distressed PCC pavement without C&S and PRF.

(*4*). In 1985 Smith (*6*) also discussed the overall strategy and evaluation procedures used by Caltrans.

The current strategy used by Caltrans calls for the nominal 6-ft (transverse) by 4-ft (longitudinal) C&S pattern described here, followed by placement of a 0.10-ft AC leveling course, a PRF, and 0.25 ft of additional AC (placed in lifts of 0.10 and 0.15 ft). The installation of edge drains, when combined with the PRF, minimizes the potential for entry and entrapment of storm water and the pumping action of the PCCP segments under the AC overlay.

Caltrans research (*6–8*) has shown that reflection cracking through AC overlays can be reduced by cracking PCCP into subpanels followed by rolling to seat and establish full slab support on the base before placing the AC overlay. The benefits of cracking and seating are as follows:

- Reduced slab size so that thermal movements of subpanels are negligible,
- Restored full slab support by the base,
- Reduced magnitude and effect of slab curl, and
- Minimized reflection cracking in the new AC overlay.

Caltrans has experimented with cracked subpanel dimensions of 6- by 4-ft, 4- by 4-ft, and 3- by 4-ft (transverse by longitudinal) and with rubblizing (*9*).

The main objective of C&S for Caltrans is to reduce slab size, which offsets thermal movements by only sacrificing a minimal loss in structural support and still allows a minimum amount of reflection cracking to be tolerated during the 10-year design life of the overlay. The most effective crack pattern to meet this objective for California PCC pavement is the 6-ft (transverse) by 4-ft (longitudinal) subpanel. A problem with the 4- by 4-ft subpanel occurs when traffic is allowed to use the cracked PCCP before overlay; the wheelpath areas then coincide with the 4-ft longitudinal crack, causing severe PCCP spalling. Rubblizing the PCCP is considered by Caltrans to be too severe because it reduces the pavement's structural value to an equivalent unbound base material requiring more AC cover. Also, traffic cannot use the rubblized lane the following day, which is critical in urban areas with high traffic volumes.

California PCCP that has been subjected to the C&S and AC overlay strategy has been plain jointed, undoweled PCCP with thicknesses ranging from 0.67 to 0.75 ft over cement-treated bases. Transverse joint spacings on these projects have averaged about 15 ft with a 2 ft in 12 ft counterclockwise skew. Before rehabilitation, these pavements experienced poor ride with joint faulting and third-stage cracking (slabs broken into three or more pieces with interconnected cracks) in excess of 10 percent for all truck lanes.

Cracking and seating of PCCP is considered by Caltrans to be one of the highest forms of recycling because it allows for the rehabilitation of an existing PCCP by an AC overlay and the PCCP retains most of its residual strength. The AC overlay can also be easily recycled when it reaches its design life.

CONSTRUCTION TECHNIQUES

Caltrans has investigated four types of cracking equipment currently in general use in California that incorporate unique modes to crack the PCCP (*8,9*). The following equipment was investigated:

- CMI Corporation; Model H16;
- Resonant Technology Company, Model B4;
- Wolverine Technology, Inc., whiphammer; and
- Wirtgen AG, guillotine drop hammer.

All of these devices proved capable of cracking California PCCPs to significantly reduce Δ-vert measurements at joints and transverse cracks. The CMI Model H16 and Wolverine whiphammer machines were found to cause shattering of the

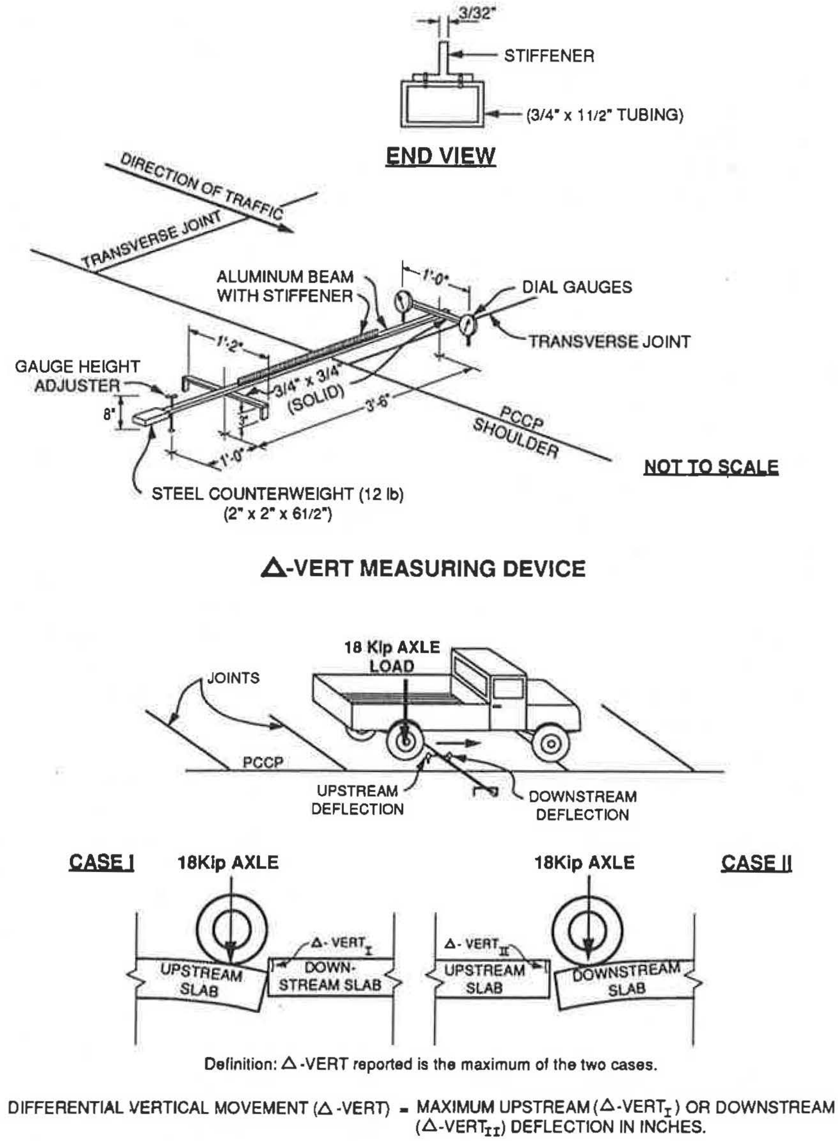

FIGURE 2 Δ-vert measuring device and procedure.

PCCP below the point of impact regardless of the shape of the impact bit used. Sharp impact heads caused the most severe surface shattering. Also, impacts within 1 ft of any existing joints or cracks or previously induced cracks caused severe spalling of the pavement, particularly at the intersections of cracked lines.

Resonant Technology's Model B4 resonant beam was found capable of producing a continuous, single longitudinal crack; however, it could not crack transversely on a 12-ft-wide lane because of its size and restricted maneuverability.

To determine if the PCCP had achieved continuous induced cracks, water was used to wash the surface and make the cracks more visible. This procedure was supplemented by cores taken at intervals throughout the project to determine if the cracks extended through the PCCP.

Caltrans currently specifies a nominal 6-ft transverse by 4-ft longitudinal subpanel after cracking. If existing panels are already cracked into segments, the segments are further cracked into nominally equal-sized square or rectangular pieces having a transverse dimension of not more than 6 ft and a longitudinal dimension of 3 to 5 ft, when feasible.

The current Caltrans Standard Special Provision (SSP 41.25) states that,

> equipment for cracking concrete pavement shall be capable of impacting the pavement with a variable force which can be controlled in force and point of impact in order to produce continuous cracking without extensive surface spalling over 0.10 foot in depth along the crack and without excessive shattering of the pavement or base. Unguided free-falling weights such as "headache balls" shall not be used. The Contractor shall demonstrate, to the satisfaction of the Engineer, the ability of the selected equipment and procedure to produce cracking of acceptable quality.

Seating cracked PCCPs may be performed either by an oscillating pneumatic-tired roller weighing not less than 15 t or by a vibratory sheepsfoot roller exerting a dynamic centrifugal force of at least 20,000 lb. A minimum of five passes of the seating equipment in either direction is made over the cracked lane at a speed not to exceed 5 mph. Construction experience shows that vibratory sheepsfoot rollers are effective in seating subpanels, but the operation has been destructive to these machines on hard pavements; therefore, this equipment is rarely used.

A promising technique that is currently under evaluation by Caltrans would eliminate the separate rolling operation to seat the cracked PCCP before overlay. This technique would take advantage of a vibratory steel-tired roller to provide slab seating when compacting the initial ½-in. maximum, dense-graded AC leveling course (G. K. Wells, unpublished memorandum, Caltrans). The first evaluation of this technique was conducted on a project north of Yreka, California, on I-5. A test section 500 ft long was not seated in the conventional manner using a pneumatic-tired roller. Instead, a Tempo RS188A steel-tired, vibratory breakdown roller, vibrating at 2,200 cycles/min, provided compaction to the 0.10-ft-thick leveling course on both a conventionally seated control test section and the unseated test section. After paving was completed, Dynaflect deflection measurements were taken on both test sections. A statistical analysis of the deflection data showed virtually no difference between seating the cracked PCCP with a rubber-tired roller before placing the leveling course and seating the cracked PCCP during the placement of the leveling course using vibratory rollers currently allowed for AC breakdown compaction. If further tests prove successful, this method will eliminate one operation and one lane closure.

After completion of the normal C&S operation, a 0.10-ft-thick, dense-graded AC leveling course is placed. This procedure is followed by a hot AR4000 asphalt tack coat applied to the traveled way width, plus an additional 2 ft into each shoulder. A nonwoven PRF is placed on the tack coat immediately after the tack coat application.

Caltrans experience indicates that the tack coat application rate is dependent on the surface texture of the underlying pavement and the absorptiveness of the PRF. The tack coat film has to be sufficient to saturate the fabric when drawn up through the fabric by the heat of the overlying AC layer during its placement and still provide adequate bond to that layer. If the tack coat is too thin, proper bonding of the upper and lower AC courses with the PRF will not occur, resulting in failure of the surfacing caused by slippage along the PRF interface. A tack coat applied at too heavy a rate will not only saturate the PRF but may result in surface bleeding. For the current Caltrans strategy, the overlying AC courses would normally consist of a 0.10-ft-thick, ½-in. maximum, dense-graded layer followed by placement of a 0.15-ft-thick, ½- or ¾-in. maximum, dense-graded AC (DGAC) surface course.

On the basis of finite element analyses performed during a cooperative research study with the University of California (*10*), it is considered optimum to place the fabric on the AC leveling course 0.10 ft above the PCC pavement surface. An alternative to the total DGAC strategy for areas of high traffic volume in combination with high rainfall might also consist of placing the 0.15-ft DGAC layer directly on the PRF followed by a 0.10-ft open-graded AC (OGAC) surface course.

Another modification of the current overlay strategy following C&S of the PCCP consists of placing an Arizona three-layer system of either 0.10 ft of DGAC or 0.10 ft of OGAC directly on the C&S PCCP before placing a rubberized stress-absorbing membrane interlayer (SAMI) (i.e., preheated, precoated screenings with rubber asphalt binder). This procedure is followed by either a 0.08-ft or a 0.10-ft OGAC surface course. In 1985 a project was constructed by Caltrans with test sections of this type on Route 4 near Pittsburg, California. The pavement on this project is uncracked after 4 years of service. The success of this project has encouraged Caltrans engineers to propose construction of similar test sections on two other projects to be constructed in the near future. This strategy allows the overlay thickness to be reduced from the current strategy (0.23 versus 0.35 ft).

AC OVERLAY PERFORMANCE

Effect of C&S on Δ-vert

Because the reduction in Δ-vert of PCCP slabs is essential in preventing reflection cracking in AC overlays, Δ-vert measurements, as previously described, were obtained on test sections of several initial C&S projects to evaluate this construction procedure. However, only two of these projects were monitored for measurements during various phases of the construction operation (i.e., before cracking, after cracking, after seating, and after traffic had driven on the C&S PCCP for periods up to almost a month). A summary of Δ-vert measurements for these two projects is presented in Table 1. The results show that the magnitude of Δ-vert measurements is reduced by the cracking (breaking) operation to an average of 0.002 in. or less in all sections. This finding is also graphically portrayed in Figure 3 for the Bakersfield site. Generally, the results show that Δ-vert measurements may be further reduced by the seating operation. For sections on which traffic was allowed to use the C&S roadway before overlaying, it appeared that unseating may have resulted with a slight increase in Δ-vert measurements. The magnitude of these measurements tended to increase with longer periods of traffic exposure. Although the magnitude of Δ-vert measurements on these two projects was not extreme, other projects with higher magnitudes before C&S are presented in Table 2 for projects at Albany and Los Banos. Included in this table are performance data and other pertinent design and construction information for test sections at seven different locations constructed between 1982 and 1984. These projects were constructed to analyze the effects of C&S of PCC pavement and the inclusion of PRF in AC overlays. In addition, Δ-verts measured just before the C&S operation are shown in Figure 4 for the Albany project.

The AC overlay performance data for the previously described experimental sections are presented in Table 3 using the current Caltrans C&S and AC overlay strategy (0.35-ft DGAC overlay with a fabric interlayer) as an index for comparison. Most of these experimental sections were modifications of the current strategy with variable AC overlay thicknesses. Thus, the table compares overlays less than 0.35 ft and those greater than 0.35 ft with the current strategy. The data show that C&S has been effective in retarding and reducing transverse reflective cracking during the 5- to 7-year service life of these overlays. Figure 5 shows that the C&S

TABLE 1 SUMMARY OF Δ-VERT MEASUREMENTS (18-kip LOAD)

Section Const. (Date)	Number of Test Locations	Δ-Vert (10^{-3} inches) Before C&S Range	Before C&S Average	After Cracking Range	After Cracking Average	After Seating Range	After Seating Average	After Seating & Traffic Range	After Seating & Traffic Average
Davis (6/82) (03-Yol-8.0-0.0/2.2) (WB #3 lane)	37 to 40 (Sta 180 to 195)	0 to 10	4	0 to 5	1	0 to 4	2	(After 3 Weeks) 0 to 9	3
Bakersfield (5/83) (06-Ker-99-9.0/10.5 SB#3 lane)	13 (Sta 881 to 887)	5 to 16	9	—	—	—	—	(After 1 Day) —	—
	10 to 13 (Sta 875 to 881)	3 to 15	9	0 to 4	2	0 to 3	1	0 to 2	1
	14 (Sta 869 to 875)	3 to 19	10	—	—	—	—	—	—
	13 (Sta 863 to 869)	1 to 19	8	0 to 3	1	—	—	0 to 4	2
	12 to 13 (Sta 857 to 863)	2 to 13	5	0 to 2	1	0 to 3	1	0 to 3	1
	4 to 13 (Sta 851 to 857)	3 to 15	6	0 to 2	2	—	—	—	—
	7 (Sta 845 to 851)	2 to 9	5	—	—	—	—	—	—
Average of all Sections	13 to 86 (Sta 845-887)	1 to 19	8	0 to 4	1	0 to 3	1	0 to 4	1

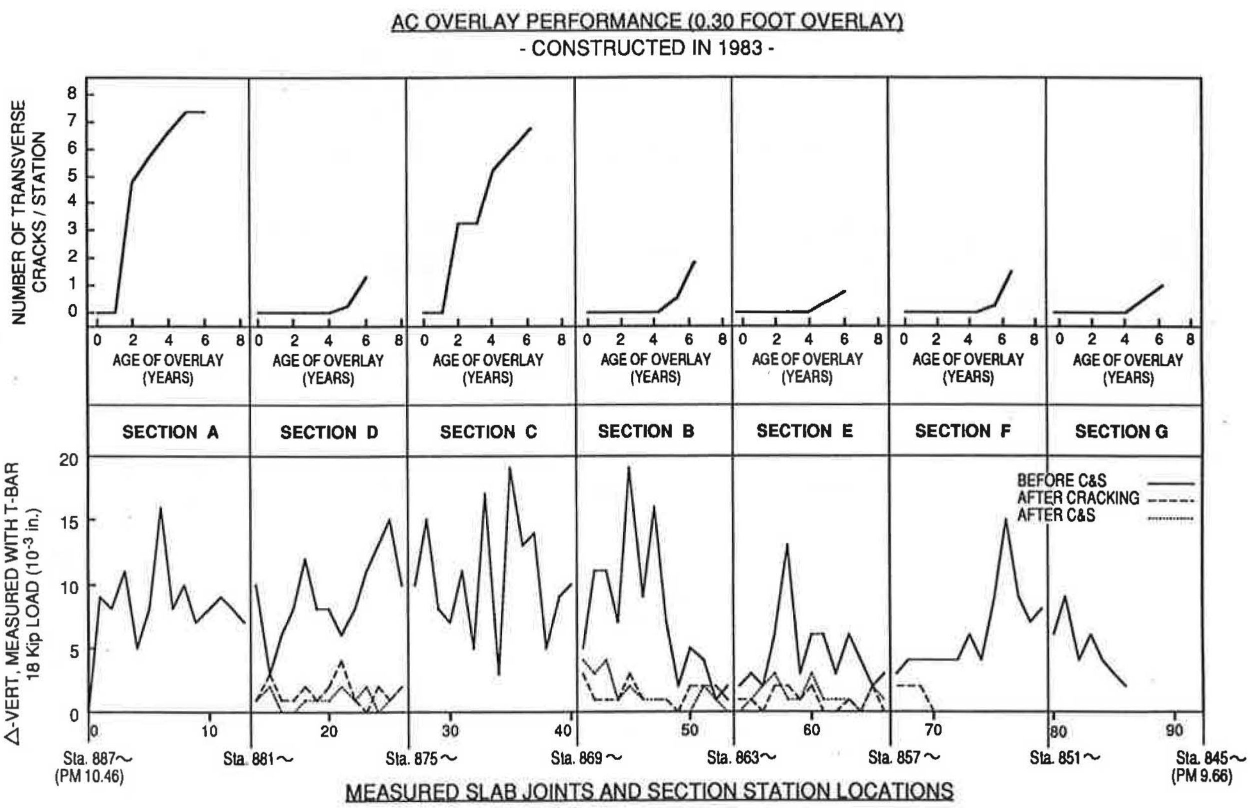

FIGURE 3 Record of Δ-vert measurements and reflective transverse cracks by year at Bakersfield.

TABLE 2 AC OVERLAY PERFORMANCE OF PRF TEST SECTIONS OVER C&S PCC PAVEMENT

Location (Outside or Truck Lane Unless Indicated)	Overlay Construction Date (Climate Data)	C&S Equipment Name of Breaker Type - Load - Type Bit	Section (length-feet)	Overlay[2] Thickness (feet)	Differential Vertical Movement (Δ-Vert) (10^{-3} inches)	Initial[3] Cracking (years)	Latest Cracking Summary: Alligator % w.t. length	Trans-verse No/100'	Longi-[4] tudinal Ft/100'	Last Survey Year
ALBANY (04-Ala-80-7.68/7.52) Contract 04-382434 Project CA-81-10 ADT = 160,000 (1985) % Trucks = 8 (1984)	6/1982 Northern coastal climate. Mild summers, cool wet winters. Rainfall = 16 in/yr	Breaker: ENSCO Breaker Hydraulic Vertical Acting Ram-impact 43,000 lb., 3"x5" Head, 3'x4' slabs.	PRF (Petromat) C&S (648)	0.26 (Surface 0.10' OGAC)	Prior to C&S, 33 to 41	Uncracked after 7 yrs	0	0	0	1989
# Trucks/day = 12,800 T.I. 14.0 (10 year)		Seating: 5 passesVib. 15 ton Sheepsfoot roller-Dynapac CA25PD 5 passes Bros Rubber-Tired Roller SP4000) 31,000 lb.	Control PRF, (Petromat). Not cracked, but was seated (252)	0.26 (Surface 0.10' OGAC)	Prior to seating, 48	2	0	4	26	↓
BAKERSFIELD (06-Ker-99-9.0/10.5) Contract 6-213504 Project CA-82-11	5/1983 Valley climate. Hot summers, Cool wet winters.	Breaker: BMC Broderson MH42B Drop Hammer, 10'-13' drop,	Control, No PRF, No C&S (600)	0.30	5 to16, Avg. 9	2	0	7	27	1989
ADT = 23,000 (1985) % Trucks = 32 (1984) # Trucks/day = 7360 T.I. 13.0 (10 year) Typical C&S:	Rainfall = 6 in/yr	1300 lb Head, Chisel End & Blunt End Bits used. Seating: Pneumatic Roller 13T	PRF, C&S, (Pneumatic Roller) (600)	0.30	Before C&S, 9 Avg. After C&S, 1 Avg.	6	0	1	30*	↓
Blunt end bit, Vibratory Roller Seating.		10 passes, Michigan R805 (one section),	Control, PRF No C&S (600)	0.30	3 to 19, Avg.10	2	0	7	21	↓
PRF = Petromat		Vibratory Sheepfoot 13T, Bomag BW210 PDB 10 coverages. (Remaining	No PRF C&S (600) (Typical)	0.30	Before C&S, 8 Avg. After C&S, 2 Avg.	5	0	2	26	↓
		Sections)	PRF, C&S (600) (chisel end bit)	0.30	Before C&S, 5 Avg. After C&S, 1 Avg.	6	0	1	12	↓
			PRF, Crack No Seat (600)	0.30	Before C&S, 6 Avg. After C&S, 2 Avg.	6	0	1	29*	↓
			PRF, C&S (600) (Typical)	0.30	Before C&S, 5 Avg. After C&S, Not Determined	5	0	1	27	↓

Remarks: (*) Some of the longitudinal cracking at this location occurred in the wheelpaths in these sections.

Location (Outside or Truck Lane Unless Indicated)	Overlay Construction Date (Climate Data)	C&S Equipment Name of Breaker Type - Load - Type Bit	Section (length-feet)	Overlay[2] Thickness (feet)	Differential Vertical Movement (Δ-Vert) (10^{-3} inches)	Initial[3] Cracking (years)	Latest Cracking Summary: Alligator % w.t. length	Trans-verse No/100'	Longi-[4] tudinal Ft/100'	Last Survey Year
DAVIS (03-Yol-80-0.0/5.8) Contract 03-229804 Project CA-81-04 ADT = 65,000 (1985)	6/1982 Valley climate Hot dry summer. Cool wet winter. Rainfall = 16 in/yr	Breaker: Hydraulic Ram CMI-H16 impact force 12000 lb 1st day,	C&S, PRF (500')	0.54	Before C&S, 4 Avg. After C&S, 2 Avg.	Uncracked after 7 yrs.	0	0	1	1989
% Trucks = 9 (1984) # Trucks/day = 5850 T.I. 12.0 (10 yr)	C&S (500)	6000 lb 2nd day. 3'x4' slabs, 5'x6' slabs	C&S, No PRF, (500)	0.51	" "	" "	0	0	3	↓
PRF = Petromat		Seating: Vibratory sheeps-foot Roller,	C&S, PRF (500)	0.52	" "	" "	0	0	0	↓
		Dynapac CA 25P 10 passes, 44000 lb load	No C&S, Double PRF, (600)	0.48	Not Determined	" "	0	0	0	↓
			Control No C&S No PRF (400 ft.)	0.45	Not Determined	7	0	1	24	↓
			No C&S No PRF (400 ft.)	0.41	" "	7	0	1	7	↓

TABLE 2 *(continued on next page)*

TABLE 2 (*continued*)

Location (Outside or Truck Lane Unless Indicated)	Overlay Construction Date (Climate Data)	C&S Equipment Name of Breaker Type - Load - Type Bit	Section (length-feet)	Overlay[2] Thickness (feet)	Differential Vertical Movement (Δ-Vert) (10^{-3} inches)	Initial[3] Cracking (years)	Latest Cracking Summary: Alligator % w.t. length	Latest Cracking Summary: Trans-verse No/100'	Latest Cracking Summary: Longi-[4] tudinal Ft/100'	Latest Cracking Summary: Last Survey Year
			No C&S No PRF (400 ft.)	0.30	" "	4	0	3	79	↓
LOS BANOS (10-Mer-152-11.32/12.43) Contract 10-260904	6/1984 Valley Climate. Hot dry summers.	Breaker: Falling wt. Breaker, Rounded	Control, C&S No PRF, (900)	0.30	Not Determined	Uncracked after 5 yrs.	0	0	0	1989
Project CA-83-10 ADT= 8100 (1985) % Trucks = 44 (1984) # Trucks/day = 3564	Cool wet winters. Rainfall = 8 in/yr	Impact Bit or Tool Hammer wt 1300 lbs Dropped 7ft (9100 ft-lb)	C&S PRF, (Petromat) (900)	0.30	Not Determined	" "	0	0	0	↓
T.I. 12.0 (10 yr)		Seating: 30 Ton Pneumatic Roller	C&S, PRF, (Reepav) (900)	0.30	Before C&S, 12 to 38, Avg. 23	" "	0	0	0	↓
			C&S, PRF (Reepav) (900)	0.20	Not Determined	" "	0	0	0	↓
			C&S, PRF (Petromat) (900)	0.20	Not Determined	" "	0	0	0	↓
			Control, C&S No PRF (900)	0.20	Not Determined	" "	0	0	0	↓
SANTA BARBARA (05-SB-101-1.28/2.42) Contract 05-293604	9/1984 Coastal climate. Mild summer.	Breaker: Arrow-Hydro Hammer, Drop	C&S, PRF (Trevira) (500)	0.30	Not Determined	" "	0	0	0	1989
Project CA-83-09 ADT = 48,500 (1985) % Trucks = 7.5 (1985)	Wet winter. Rainfall = 20 in/yr	Hammer, Std. Spec, 4'x6' slabs Seating:	Control (500), C&S. No PRF	0.19	Not Determined	" "	0	0	8	↓
# Trucks/day = 3637 T.I. 11.0 (10 yr)		Spec provisions Min. 25 ton roller with min 25000	C&S, PRF, (Reepav) (500)	0.20	Not Determined	" "	0	0	7	↓
		pound effective load, 10 coverages.	C&S, PRF (Petromat) (500)	0.19	Not Determined	4	0	1	88	↓
			C&S, PRF (Reepav) (500)	0.30	Not Determined	Uncracked after 5 yrs.	0	0	1	↓
			C&S, PRF (Reepav) (500)	0.26	Not Determined	" "	0	0	68	↓
			Control, C&S, No PRF (500)	0.28	Not Determined	" "	0	0	42	↓
			C&S, Inverted OGAC-Control, No PRF, (500)	0.29	Not Determined	" "	0	0	0	1989

<u>Overall Summary</u>: Edge raveling in almost all sections in the above project and some severe raveling in wheel track of thicker control section. Appears to be the result of possible insufficient binder or segregation. Break-outs in some raveled areas but no cracking. Generally, longitudinal cracking is at outer pavement edge.

Location (Outside or Truck Lane Unless Indicated)	Overlay Construction Date (Climate Data)	C&S Equipment Name of Breaker Type - Load - Type Bit	Section (length-feet)	Overlay[2] Thickness (feet)	Differential Vertical Movement (Δ-Vert) (10^{-3} inches)	Initial[3] Cracking (years)	Alligator % w.t. length	Trans-verse No/100'	Longi-[4] tudinal Ft/100'	Last Survey Year
YREKA (02-SIS-5-43.0/51.2) Contract 02-195904 Project CA-83-07	7/1984 Northern interior. Mild to hot summers.	Breaker: Falling wt. Hydro-Hammer Per Spec Provision	No C&S PRF (600)	0.30	Not Determined	Uncracked after 5 yrs.	0	0	0	1989
ADT = 9400 (1985) % Trucks = 30 (1985) # Trucks/day = 2820	Cold snowy winters. Rainfall = 19 in/yr	Seating: Per Special Provisions	C&S, No PRF (600)	0.30	Not Determined	" "	0	0	0	↓
T.I. = 11.5 (10 yr)			No C&S, No PRF (600)	0.30	Not Determined	5	0	2	0	↓
			C&S, PRF (600)	0.30	Not Determined.	Uncracked after 5 yrs.	0	0	0	↓
			No PRF No C&S (600)	0.20	Not Determined	4	0	5	0	↓

TABLE 2 (*continued on next page*)

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Location (Outside or Truck Lane Unless Indicated)	Overlay Construction Date (Climate Data)	C&S Equipment Name of Breaker Type - Load - Type Bit	Section (length-feet)	Overlay[2] Thickness (feet)	Differential Vertical Movement (Δ-Vert) (10^{-3} inches)	Initial[3] Cracking (years)	Latest Cracking Summary: Alligator % w.t. length	Trans-verse No/100'	Longi-[4] tudinal Ft/100'	Last Survey Year
			No PRF C&S (600)	0.20	Not Determined	3 trans-verse cracks in 600' in 5 yrs.	0	0.5	0	↓
			C&S, No PRF (600)	0.20	Not Determined	4	0	3	0	↓
			No C&S PRF (600)	0.20	Not Determined	1 trans-verse crack in 600' in 5 yrs.	0	0.2	0	↓

Remark: Yreka sections were inadvertently chip sealed in summer of 1988 (4 years old). May have concealed some cracks for approximately 1 year.

1. PRF = Pavement Reinforcing Fabric.
2. All fabric interlayers were placed over a 0.08 foot to 0.10 foot leveling course which is included in the overlay thickness.
3. Initial cracking = 5% to 10% alligator cracking (Caltrans Type B) or 1 transverse crack/100 feet.
4. All longitudinal cracking over construction joints (edge of lane at shoulder or adjoining lane) unless indicated. Longitudinal cracking not counted in determining initial cracking.

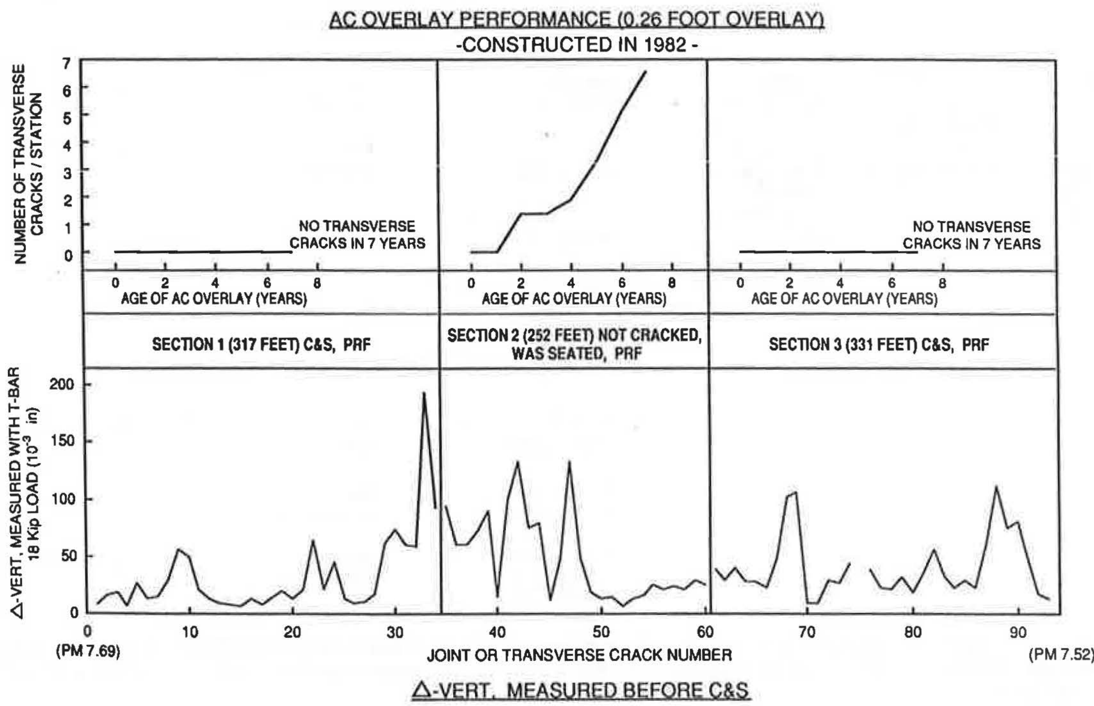

FIGURE 4 Record of Δ-vert measurements and reflective transverse cracks by year at Albany.

operation was the most significant factor in the performance of these overlays through 5.5 years of service.

A further comparison of the effects of C&S can be made by referring to Figures 3 and 4, which compare AC overlay performance with the Δ-vert measurements taken on the existing PCC pavements before overlay. These figures show that a reduction in Δ-vert to approximately 0.003 in. or less was very effective in retarding and reducing reflective transverse cracking in AC overlays, regardless of pre-C&S Δ-vert measurements. The plots in Figure 3 confirm McGhee's assertion (*2*) that AC overlays placed over pavements with a Δ-vert of approximately 0.008 to 0.010 in. and larger will have reflective transverse cracking.

Performance Review of C&S Projects

Since the first rehabilitation project (1982) that used C&S of a PCC pavement to reduce horizontal and vertical stresses, approximately 100 projects have been constructed using the C&S strategy. Seven of the earliest of these projects were studied as test sections. The performance of these test projects

TABLE 3 SUMMARY OF AC OVERLAY PERFORMANCE OVER C&S PCC PAVEMENT

Type Section	AC Overlay Thickness (Foot)	Average Δ-Vert* (10^{-3} In)	Number of Sections Locations	Average Age of AC Overlays	Latest Cracking by Type (1989): Alligator Type B** % W.P.	Transverse No/STA	Longitudinal L. Ft/100 L. Ft.	Years*** to Initial Cracking
C&S w/PRF	(0.19 to 0.34) Avg. .26	<3	16 (5)	5.4	0	<1	16	Does not yet qualify as having initial cracking.
	(0.35 to 0.53) Avg. .52	<3	2(1)	7.0	0	0	0	
	Overall Avg. 0.29	<3	18(5)	5.5	0	<1	14	
C&S No PRF	0.19 to 0.34 Avg. .25	<3	7(4)	5.3	0	<1	11	Does not yet qualify as having initial cracking.
	0.35 to 0.51 Avg. 0.51	<3	1(1)	7.0	0	0	3	
	Overall Avg. 0.29	<3	8(5)	5.5	0	<1	10	
No C&S w/PRF	0.19 to 0.34 Avg. 0.27	2 of 4 Sect. Range 3 to 133 Avg. 29	4(3)	5.8	0	4	12	3.3+
	0.35 to 0.49 Avg. 0.49	Range 0 to 10 Avg. 4	2(1)	7.0	0	0	0	7+
	Overall Avg. 0.31		6(4)	6.2	0	2	8	4.5+
No C&S No PRF	0.19 to 0.34 Avg. 0.27	One location Range 5 to 16 Avg. 9	4(3)	5.8	0	4	27	4.5
	0.35 to 0.45 Avg. 0.43	Not determined	2(1)	7	0	1	16	7
	Overall Avg. 0.33		6(4)	6.2	0	3	23	5.3

Note: Data from Table 2.

* After C&S, all sections that were measured had Δ-Verts of less than 3 x 10^{-3} inches. Refer to Table 2 for measurements.

** No connected wheel path cracking (Caltrans Type B alligator cracking) in any of the sections, but in some sections (indicated for Bakersfield and Santa Barbara sites) there are minor amounts of longitudinal cracking in the wheelpath (Caltrans Type A alligator cracking).

*** Initial Cracking = one transverse crack/Station (100 lineal feet) or 5 to 10% alligator cracking (Caltrans Type B).

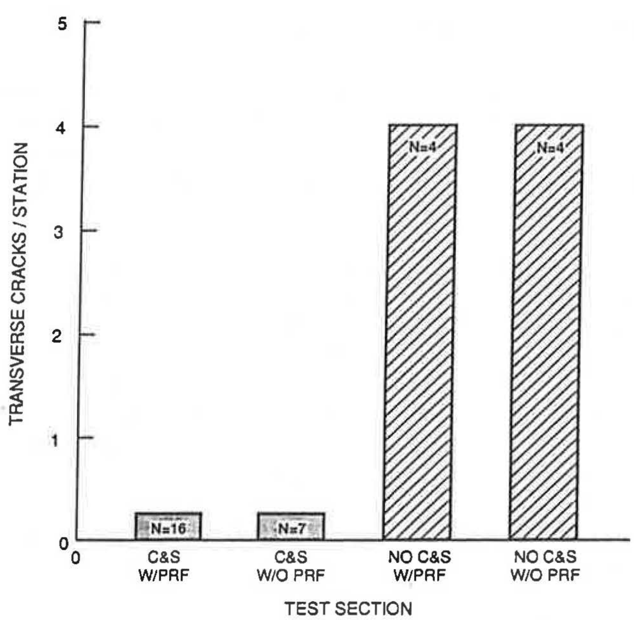

FIGURE 5 Comparison of C&S and non-C&S sections with AC overlays <0.35 ft (data from Table 3, average age 5.5 years).

is reported in Table 3 and Figure 5. Their performance after an average of 5.5 years of service shows that C&S is an effective strategy in retarding and reducing reflective transverse cracking in the AC overlays of underlying PCCP joints and cracks.

A performance analysis of 36 other projects that were rehabilitated with variable AC overlays using the C&S strategy is shown in Figures 6 and 7. Figure 6 shows that only a small portion (about 10 percent) of the 36 projects selected from the 1989 Pavement Management System (PMS) survey have initial cracking (no more than one transverse crack per station) after approximately 5 years of service. These data compare favorably with the data from the C&S test sections presented in Table 3. Figure 7 shows that some of the projects with AC overlay thicknesses ≤0.30 ft also have minor amounts of small block and alligator cracking (≤3 percent type "B"), probably due to localized partial slab movements.

The benefits of the C&S strategy are shown in Figure 8, which compares the performance of AC overlays over C&S and non-C&S, with and without PRF. Also compared is a plot of the performance of the 36 projects (PMS surveys), which confirms the findings from the initial test sections.

In general, the C&S and AC overlay strategy has worked successfully in minimizing reflection cracking on most Caltrans projects. However, seven projects have been constructed on I-5 in Caltrans District 2 (northern California) with mixed results. Several of these projects have experienced

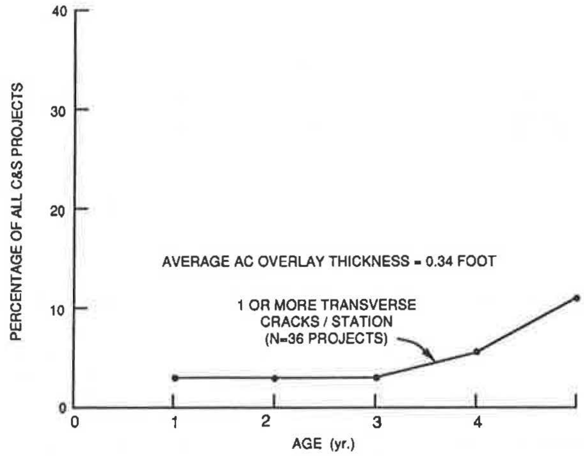

FIGURE 6 Transverse cracking on C&S projects (on the basis of 1989 PMS).

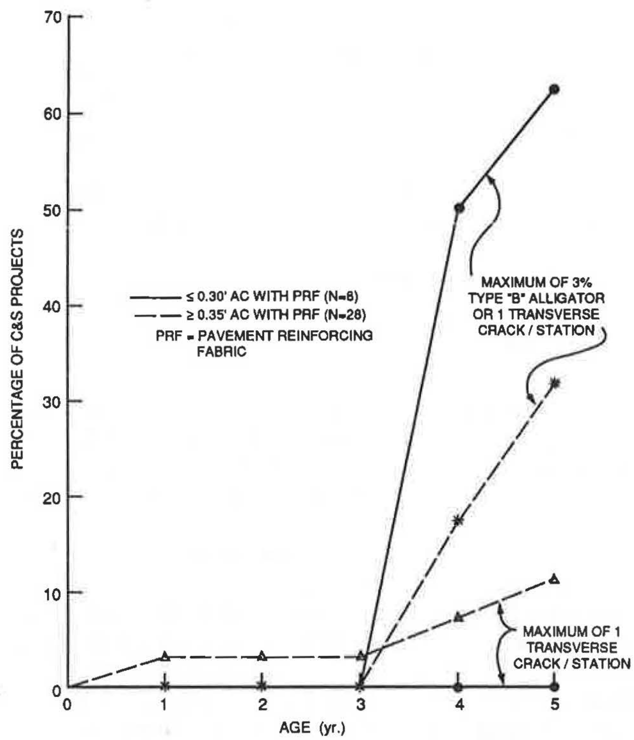

FIGURE 7 Distress history of C&S projects with different AC overlay thickness (on the basis of 1989 PMS).

premature distress (longitudinal and alligator cracking) of the AC surface. The reasons for this early distress are the subject of an ongoing study. The majority of the projects may have been constructed with aggregates in the AC overlay, which tend to strip in the presence of moisture. The early failures appear to be the result of stripping above and below the PRF layer and are the only Caltrans C&S projects that have experienced any significant levels of distress. This occurrence is believed to be a materials problem and is not a fault of the C&S strategy. Thus, these projects are not included in this overall evaluation of C&S.

The current strategy of C&S with 0.35-ft AC and a PRF interlayer has, with the exceptions described, provided ex-

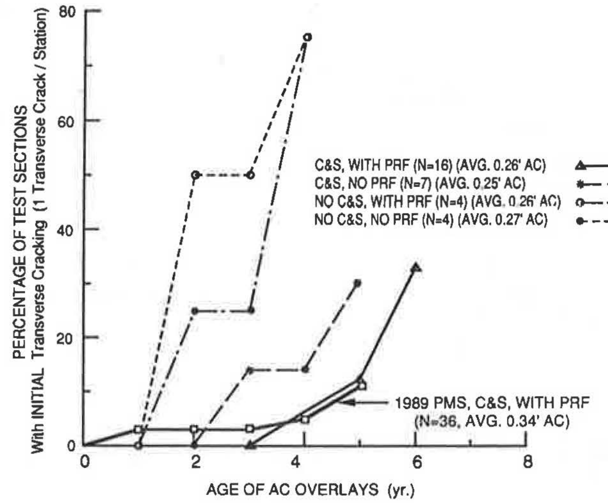

FIGURE 8 Transverse cracking in C&S test sections, ≤0.40-ft AC (data from Table 2 and Figure 6).

cellent performance for most situations in California. However, it is proposed that this strategy be modified somewhat for future projects in which a structural need exists (i.e., projects in areas with a high water table in combination with soft, unstabilized subgrades). The current strategy is questionable for these potential problem areas, where the need for structural adequacy governs over reflection cracking. One strategy that is proposed is to increase the AC overlay thickness above the fabric by an additional 0.25 ft. The final overlay strategy would consist of a 0.10-ft DGAC leveling course, PRF, and a 0.50-ft DGAC placed in three lifts. This modified strategy complements the current strategy by providing a recyclable AC surface or a base for new PCCP to be placed at some future date.

COST-EFFECTIVENESS OF C&S

The current strategy of C&S with a 0.35-ft AC overlay and a PRF interlayer has proven to be a cost-effective solution for rehabilitation of PCCP in California. This strategy has provided significant savings when compared with other alternatives. For example, the AC thickness required to provide equivalent crack retardation performance over non-C&S PCCP would probably be an additional 0.15 ft or more. Currently, the estimated cost of C&S is \$0.50 to \$0.75/yd^2, which is less than the cost of the additional AC thickness.

Other alternatives to the current strategy could include an unbounded PCCP overlay and removal and replacement or recycling of the existing PCCP and base. However, preliminary cost comparisons using initial and life cycle costs have shown the current strategy to be more cost-effective in addressing reflection cracking. The recycle alternative could become more cost-competitive as good aggregate sources become scarce.

CONCLUSIONS

1. Cracking and seating of unreinforced, undoweled PCCP is effective in retarding and reducing reflection cracking in AC overlays.

2. C&S is effective in reestablishing base support for existing PCCP and in reducing Δ-verts to acceptable levels.

3. The current Caltrans C&S and AC overlay strategy is cost-effective and, with minor exceptions, will provide the desired service life of 10 years.

4. Preliminary findings suggest that it may be possible to eliminate the PCCP seating operation, and additional research is under way.

5. Only about 10 percent of the AC overlays constructed with the C&S strategy exhibited initial cracking after 5 years of service, compared with 75 percent of AC overlays on non-C&S PCCP after 4 years.

6. PRF in an AC overlay over C&S PCCP is primarily a moisture barrier but can retard initial cracking an average of 1 year longer than overlays without PRF.

7. Modifications to the AC overlay and C&S strategy using OGAC layers have been effective in retarding reflection cracking.

8. The use of PRF in AC overlays of C&S PCCP requires further study for situations in which stripping can occur.

9. The 6-ft (transverse) by 4-ft (longitudinal) PCCP subpanel cracking pattern has generally been effective in controlling reflection cracking in AC overlays on PCCP.

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