CRACK AND SEAT PERFORMANCE

Review Report

Federal Highway Administration

Demonstration Projects Division

and

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A. Executive Summary

Based on the findings of this review, the use of cracking, seating, and overlaying as a pavement rehabilitation alternate should be approached with caution. Since both positive and negative aspects of cracking and seating (C&S) were identified during the review, State agencies contemplating the use of C&S should do a thorough project by project analysis to determine if it is the most cost effective rehabilitation technique to employ.

Of the 22 projects reviewed, only four showed appreciably less reflective cracking in the C&S sections than in the control sections. Observations by the review team, coupled with previous State reports, indicate that there generally is a reduction in the amount of reflective cracks through the overlay during the first few years following construction of a C&S project. However, after 4 to 5 years the C&S sections exhibited approximately the same amount of reflective cracks as the control sections. A significant reduction in reflective cracks occurred on two of the projects reviewed. These projects are located on I-4 in Florida and on SR-99 in California. Both had the following similarities:

1. Constructed on a strong base (cement treated),
2. Small changes in seasonal temperatures, and
3. Non-reinforced pavement.

The main concern with C&S is the reduction of the structural capacity of the pavement. To compensate for the reduction in structural capacity caused by cracking the pavement, more overlay thickness is required, thus increasing the cost. In addition, study is needed to determine if the delay in reflective cracking actually extends the life of the pavement as opposed to conventional overlays and if so, is it cost effective.

B. Background/Introduction

When portland cement concrete pavement (PCCP) approaches the end of its design life, a decision must be made on what action to take. The most common rehabilitation technique currently used for PCCP is to construct an overlay of asphalt concrete (AC). In time, cracks in the underlying PCCP reflect into the overlay. These cracks are primarily caused by stresses that develop at the bottom of the new overlay directly over the in-place cracks and joints of underlying pavement. These stresses are a result of vertical and horizontal movements of the underlying pavement. Vertical movements are differential movements at the joint/crack in the underlaying pavement and are caused by moving loads. Horizontal movements are due to expansion and contraction caused by temperature and/or moisture changes.

In addition to these changes in the underlying slab, total movement at a crack or joint is affected by slab length and the stiffness of the underlying material. The horizontal movement of cracked slabs under a bonded bituminous surface causes high tensile stresses in the immediate area over the crack. Likewise, vertical movement causes high stresses in the overlay. Because an AC surface is stiffer at lower temperatures, it loses some of its flexible characteristics and can withstand only small temperature-induced stresses.

One method that several States have tried for control of reflective cracking in an overlay is to crack the concrete pavement slab into small segments before overlaying with AC. The intent of pavement cracking and seating is to create pavement sections that are small enough to reduce movement to a point where thermal stresses will be greatly reduced, yet still be large enough to maintain some aggregate interlock between pieces and retain a significant percentage of the original structural strength of the PCC pavement. Seating of the broken slabs after cracking is intended to reestablish support between the subbase and the slab where voids may have existed.

C. Objectives

The objectives of this review were to obtain a better understanding of the expected performance of C&S and overlaying, and to identify the conditions under which this technique has been used in a cost-effective manner. It is hoped that the information obtained from the review will aid States in determining when and how to use C&S as an effective rehabilitation strategy.

D. Selection Criteria

A total of 22 projects in 8 States were reviewed. All of the projects reviewed were of the classic crack and seat method (small hairline cracks, no rupturing of the reinforcing, and no rubblizing of the pavement). The following factors were considered in selecting the projects to be reviewed:

- preferably 3 or more years of service;
- located on a high volume facility;
- historical data accessible;
- overlay thickness of 6 inches or less; and
- a control section.

Using these factors, C&S projects were selected for review in:

- California
- Michigan
- Minnesota
- South Dakota
- Wisconsin

After analyzing the data obtained on projects built in the originally selected States, it was decided to extend the review to include projects in Florida, Tennessee, and Indiana, as well as additional projects in California.

E. Field Survey Results

The general condition of each C&S project reviewed is described in this section.

1. California

    a. I-80 Alameda and Contra Costa Counties

    I-80 is an 8-inch undoweled jointed plain concrete pavement (JPCP) on a 4-inch cement treated base (CTB) on 8 inches of select material. The original 6-lane pavement was opened to traffic in the mid-1950's.

    In 1982, a rehabilitation project which included C&S with an AC overlay and with edgedrains retrofitted on both the C&S and the control sections was constructed. The pavement was broken into 3- by 4-foot segments with an air operated pile driver and then rolled with a vibratory sheepsfoot roller weighing not less than 12 tons to seat the slabs. The control sections were overlaid with 3 1/4 and 5 inches of AC, but not cracked and seated. The C&S section was overlaid with 5 inches of AC. This was the first C&S project in California, therefore, the bid price of $12.50 per square yard was very high. The current average daily traffic (ADT) is 177,000 with 7.3 percent trucks.

    The original pavement was badly cracked and faulted (greater than 1/4 inch). Rocking slabs were reported.

With the exception of two reflective cracks from known rocking slabs, which were intentionally left unseated for evaluation purposes, no other reflective cracks were observed on the project. After nearly 4 years, both the 3 1/4-inch and 5-inch control sections and the C&S sections are performing about the same.

b. I-80 Yolo County

I-80 is a 9-inch undoweled JPCP with a 15-foot joint spacing over a 6-inch dense graded aggregate base (DGAB) over an additional 9-inch aggregate subbase. The original dual-lane facility was constructed in 1942 and two additional lanes were added in 1964.

In 1982, the pavement was C&S and overlaid with 4.8 inches of AC. A CMI hydraulic stamper was used to crack the pavement. The specified crack pattern was a minimum 2- by 2-foot and a maximum of 4- by 4-foot. A vibratory pneumatic tired roller weighing not less than 12 tons was used to seat the pavement. The project also included an uncracked control section with a 4.8 inch AC overlay. The C&S cost was $0.75 per square yard. The current ADT is 20,400 with 22.8 percent trucks.

After 4 years, no reflective cracks were observed. The C&S section and the control section are performing the same.

c. SR-99 Kern County south of Bakersfield

SR-99 is a 9-inch plain jointed, undoweled, PCCP. The pavement is 36 feet wide (three lanes) with AC shoulders. The "inside" two lanes were constructed in 1956 on an asphalt treated base (ATB). The "outside" lane (lane used for comparison purposes) was constructed in 1968 on a CTB. The C&S project, completed in June 1983, was an experimental project with seven 600-foot test sections:

Section	Description
A.	Control - 3.6 inch overlay no fabric
B.	Crack and seat, seated with vibratory sheepsfoot roller, 3.6 inch overlay
C.	Control - 3.6 inch overlay with fabric
D.	Crack and seat, seated with rubber tired roller, 3.6 inch overlay
E.	Crack and seat, seated with a vibratory sheepsfoot roller, 3.6 inch overlay

F.	Crack, not seated, 3.6 inch overlay
G.	Crack and seat, seated with a vibratory sheepsfoot roller, 3.6 inch overlay

The C&S cost was $1.60 per square yard.

(1) In the control section (Section A; no C&S, no fabric), 100 percent of the transverse joints had reflected through the overlay with low severity cracks.

(2) In the other control section (Section C; no C&S, with fabric), approximately 50 percent of the transverse joints had reflected through with low severity cracks.

(3) Sections B, D, E, F, and G all involved C&S and exhibited no reflective cracking.

(4) All of the cracking exhibited (Sections A & C) was in the right lane only. All cracks extended no further than the lane joint with an intersecting short longitudinal reflective crack at the joint, forming a "T." This was probably due to the different pavement age and base type.

(5) Deflection testing indicated generally higher deflections after the seating operation than just after cracking. A 13-ton roller was used with 10 passes.

In summary, after 3 years the C&S sections were exhibiting no reflective cracks and were outperforming both of the control sections.

d. Others

A number of other C&S projects were reviewed. Because there was not a true control section for comparison purposes and there was no distress evidenced on either the C&S or the normal overlay portions, these projects are summarized in one discussion.

Route	County	ADT (% Trucks)	Built	Total Overlay Thickness	C&S Cost Per Sq. Yard
I-5	Shasta	25,600 (23)	6/83	5.4 inches	0.75
I-580	Alemeda	56,000 (16)	3/84	4.2 inches	0.80
I-680	Contra Costa	152,000 (4.9)	11/83	4.8 inches	0.55
I-680	Contra Costa	157,000 (4.6)	10/83	3.4 inches	0.85
I-680	Contra Costa	69,000 (6.7)	11/83	4.2 inches	0.60

The projects consisted of 8-inch JPCP on 4-inches of CTB. All of these projects used a fabric interlayer between AC overlay courses and used the same specifications for C&S calling for 4- by 6-foot cracking pattern. These projects only called for C&S in the outer lane(s).

2. Michigan

a. US-10 in Clare County

The original pavement opened to traffic in the mid-1930's was a widened edge (9"-7"-9") jointed reinforced concrete pavement (JRCP). Joints were undoweled with a 60-foot spacing. The original PCCP was overlaid with approximately 4 inches of AC in 1960.

The 8-mile rehabilitation project, completed in October 1983, consisted of milling off the existing bituminous overlay, C&S the pavement, and overlaying with approximately 2 1/4 inches of AC. The pavement was cracked into 18- by 18-inch pieces and seated with a 50-ton vibratory steel wheel roller. The type of breaker was not specified. The C&S cost was $0.20 per square yard. Longitudinal edgedrains were added in select locations. A control section was not built. The current ADT is 1410 with an average of about 120 ESAL's/day since the rehabilitation.

(1) Nearly all transverse joints had reflected through the 2 1/4-inch overlay. The reflective cracks are primarily medium in severity. In addition, intermediate transverse cracks have also reflected.

(2) Less than 5 percent of the longitudinal lane joint has reflected through.

(3) Some minor rutting (1/4 inch) of the asphalt surface is evident.

(4) The ride quality on this project was very good.

b. US-23 in Monroe County

This was an experimental C&S project of approximately 1 1/4 miles within an overall 8-mile long overlay project. US-23 is a 4-lane freeway section with an original 9-inch JRCP with 99-foot doweled joint spacing.

The C&S experimental project, completed in 1983, consisted of 24-, 36-, and 48-inch cracking patterns plus control sections (no cracking), and two overlay thicknesses of 440 and 660 pounds per square yard (approximately 4 and 6 inches). A whip hammer was used to crack the pavement and a 50-ton rubber- tired roller was used to seat the pavement. The C&S cost was $0.19 per square yard. The current ADT is 11,350 with a daily loading of about 3,800 ESAL's per day.

(1) In all four of the comparisons (three different crack patterns and control section) the 660 pounds per square yard overlay (6 inches) had less reflective cracking than the 440 pounds per square yard (4 inches) overlay.

(2) Generally, the least amount of reflective cracking within the C&S sections occurred in the section with the 48-inch crack pattern.

(3) The test section with the least cracking (best condition) was the 660 pounds per square yard control section (no C&S) followed closely by the section with 660 pounds per square yard and the 48-inch crack pattern.

(4) The project showed no signs of distress, other than low severity reflective cracks.

3. Minnesota

a. T.H. 169, Scott County

This project is on T.H. 169 from 0.55 miles south of Belle Plaine's city limits to County Road 66. The original project was constructed in 1956 and consisted of a widened edge (9"-7"-9") non-reinforced PCCP. The joints were undowled with 20-foot spacing.

The rehabilitation project, completed in 1982, consisted of three 1,000-foot sections. One section had a 3-foot crack spacing with no crack closer than 5 feet from a joint or existing transverse crack, one section was cracked at 1 1/2-foot intervals, and the other section was not cracked. A spade type breaker was used to crack the pavement. A 30-ton rubber-tired roller was used to seat the pavement.

The three sections were overlaid with 5 3/4 inches of AC. The C&S cost was $50 per road station ($0.18 per square yard). The current ADT is 10,627.

The section with 3-foot crack spacing was exhibiting random reflective cracks at the joint and minor raveling. The section with the 1 1/2-foot crack pattern and the control section had low severity reflective cracks.

b. T.H. 60 and T.H. 169, Blue Earth County

This project is on T.H. 60 and T.H. 169 near the city of Mankato. The original project was constructed in 1961 and consisted of an 8-inch reinforced PCC pavement over 5 to 9 inches of aggregate base. The pavement was 25 feet wide and the joints were doweled with a 40-foot spacing.

The rehabilitation project, completed in 1982, consisted of eight 1,000-foot test sections. Test sections 1, 2, 5, and 6 were cracked with a spade type breaker. Test section 8 was cracked with a roller breaker. All the sections were seated with a 30-ton pneumatic-type roller. Each section was overlaid with a 6-1/4 inches of AC. The C&S cost was $55 per road station ($0.21 per sq. yd.) The current ADT is 8,454. A summary of the test sections follow:

Test Section	Rehabilitation
Section 1	3-foot crack spacing and edgedrains
Section 2	3-foot crack spacing, no edgedrains
Section 3	No cracking, no edgedrains
Section 4	No cracking, edgedrains
Section 5	1.5-foot crack spacing, edgedrains
Section 6	3-foot crack spacing, no edgedrains,
Section 7	Edgedrains, saw cut construction
Section 8	Edgedrains, cracked with pavement roller breaker

To date there has been very little difference in the performance of the test sections. Each section exhibited reflective cracks approximately every 40 feet (at each joint).

c. T.H. 71, Kandiyohi County

This project was the first C&S project in Minnesota and was completed in 1976. The original roadway structure was a widened edge (9"-7"-9") non-reinforced concrete pavement 22 feet wide with a continuous longitudinal centerline joint and undoweled transverse joints constructed every 15 feet. The surface had spalled at some of the joint locations and maintenance crews had patched these areas with bituminous mixture.

The rehabilitation called for a 6-inch thick AC overlay with the thickness being increased to 7 1/2 inches at some locations. The in-place PCC panels were cracked with a vehicle-mounted spade type breaker at the mid and quarter points thereby reducing the size of the PCCP to pieces about 3 3/4 by 11 feet. A control section of uncracked in-place PCCP with a 7 1/2-inch overlay was constructed to use as a comparison to the broken section. The overlay consisted of 3/4-inch plant-mixed AC wearing course, 1 1/2-inch plant-mixed AC binder course, and either 3 3/4 or 5 1/4 inches of plant-mixed AC base course depending on the location of the overlay. The C&S cost was $70 per road station ($0.26 per square yard). The current ADT is 3,974.

The 1981 final report by the Minnesota Department of Transportation(1) states, "the cracking of the in-place PCCP did reduce the amount of reflective cracking in comparison to similar sections where the PCCP was not cracked."

However, during our review, there were reflective cracks throughout the project. Thus, it appears that C&S did delay reflective cracks for the first 5 years, but after 10 years there was little or no difference in the performance of the C&S section and the control section.

4. Wisconsin

a. I-94, Eau Claire County

The original pavement, constructed in 1967, consisted of 9 inches of reinforced concrete with a 6-inch aggregate base and a 12-inch granular subbase. The joints were doweled with 80-foot spacing.

The rehabilitation project was completed in 1983. A pile drive hammer was used to crack the pavement with a maximun pattern of 18 inches. A 50-ton vibratory roller was used to seat the cracked pavement. The C&S cost was $0.30 per square yard. The current ADT is 16,000. The project consisted of the following:

Section	Overlay Thickness	Performance
Control	4 inches	Reflective cracks every 80 feet, some edgeline cracks
C&S #1	5½ inches	Random centerline reflective cracks
C&S #2	7 inches	Very few small reflective cracks
C&S #3	4 inches	Random edgeline and centerline reflective cracks

The C&S sections with the 5 1/2-inch and the 7-inch overlays were performing slightly better than the C&S section with the 4-inch overlay and the control section.

b. USH 14, Dane and Rock Counties

This was the first C&S project in Wisconsin and was completed in 1980. The original 9-inch non-reinforced PCCP pavement on a 9-inch aggregate base was constructed in 1952. The joints were undowled with 20-foot spacing.

The rehabilitation project, completed in 1980, was 6 miles in length. The pavement was cracked with hydro-hammer type breaker into pieces not exceeding 1 square yard in area. The cracked pavement was then rolled with a 50-ton pneumatic roller and overlaid with 4 1/2 inches of AC. The control section was not cracked and had a 4 1/2 inch AC overlay. The C&S cost was $0.45 per square yard. The current ADT is 4,000.

There were reflective cracks throughout the project and there was no difference in the performance of the C&S section and the control section.

c. STH 140, Rock County

The original project, a 9-inch non-reinforced PCCP with a 9-inch aggregate base, was constructed in 1931. The joints were undoweled with 20-foot spacing.

The C&S project, completed in 1982, required the pavement to be broken into pieces having a maximum dimension of 12 inches with a pile drive hammer and seated with a 50-ton vibratory roller. The control section and the C&S section were each overlaid with 4 inches of AC. The C&S cost was $0.35 per square yard. The current ADT is 2,000.

There were reflective cracks throughout each section with no difference noted in the performance.

5. South Dakota

a. US Route 18, Lincoln County

The original project consisted of mesh reinforced PCCP that was a widened edge (9"-6"-9") section, 20 feet wide, with a 6-inch aggregate base. The joints were undoweled with 20-foot spacing. The original construction was completed in 1930.

This rehabilititation project was completed in 1982. A total of 3.89 miles east and west of Canton was C&S and the 2-mile section through the town of Canton was just overlaid. A spade type breaker was used to crack the pavement at 5 foot intervals and a vibratory steel wheeled roller was used to seat the cracked pavement. The C&S section was overlaid with 3 1/2 inches while the non-C&S section had a 2-inch AC overlay. The C&S cost for this project was $4,000 per mile ($0.20 per square yard). The current ADT is 3,466 with 8.8 percent trucks.

There were reflective cracks about every 40 feet throughout the project. However, there were a few more cracks in the non-C&S section which is expected since it received 1 1/2 inches less AC.

b. US Route 50, Clay and Union Counties

The original project consisted of a mesh reinforced PCCP with a widened edge (9"-6"-9") section on a 6-inch aggregate base that was 20 feet in width. The original construction was completed in 1938. The joints were not doweled.

The C&S project was completed in 1980. It consisted of breaking the 40-foot panels at the quarter points with a spade type breaker, seating the pavement with a vibratory steel wheeled roller, and overlaying with a total of 4 1/2 inches of AC. There was no control section on this project. The C&S cost was $4,000 per mile ($0.20 per square yard). The current ADT is 1,492 with 8.8 percent trucks.

Approximately 90 percent of the project had centerline cracks. There were also random transverse and longitudinal cracks throughout the project.

c. US Route 14, Beadle County

The original construction consisted of a 22-foot wide, 8-inch thick mesh reinforced PCCP on a 6-inch aggregate base that was constructed in 1947. The panels were 15 feet long and the joints were not doweled.

The C&S project was completed in 1979. The 15 foot panels were cracked at 5-foot intervals with a hydro-hammer. A loaded scraper was used to seat the cracked pavement. A 500-foot section of the pavement was left uncracked to serve as the control section. The C&S and the control sections were overlaid with 4 1/2 inches of AC. The cost of C&S on this project was $3,258.90 per mile ($0.23 per square yard). The current ADT is 2,122 with 13.4 percent trucks.

There were random cracks observed at the joints throughout the project with little or no difference noted between the control and the C&S sections.

6. Florida

a. I-4, Hillsbourough County

The original pavement was a 9-inch plain jointed undoweled (except near expansion joints) PCCP with a 20-foot joint spacing on 12-inch cement stabilized base.

The rehabilitation project was completed in 1979. Four test sections were set up to evaluate C&S and two types of fabric to reduce reflective cracking. A drop hammer was used to crack the pavement into 36-inch maximum size pieces. Vibratory compacting equipment or traffic rollers weighing at least 15 tons were specified as equipment to seat the cracked pavement. All sections were overlaid with a 100 pound per square yard (approximately 1 inch) AC leveling course, 2 inches of AC binder, and a 5/8-inch open graded friction course. All sections also received underdrains.

The following is a breakdown of the performance of each section made by the Florida Department of Transportation in March 1986.

		Percent Reflected Joints			
Section	Description	Rt. Edge	Lt. Edge	Center Longitudinal	Transverse
A	Control with underseal No Fabric	100	50	0	94
B	Crack and Seat No Fabric	87	10	0	22
C	Control with underseal and fabric	100	80	35	72
D	Control with·underseal and fabric	80	36	35	35

7. Indiana

I-74 Montgomery/Boone County, a length of 12.4 miles.

The original pavement was a 10-foot reinforced (welded wire) and doweled PCCP on about 6 inches of open graded aggregate subbase. Contraction joints were spaced at 40-foot intervals. Longitudinal edgedrains were provided in the original construction. The pavement was very deteriorated prior to the rehabilitation with 100 percent of the slabs having intermittent cracking at a rate of about 45 feet of cracking per 100 square feet of pavement and about 22 breakups per 100 square feet. Every joint was "D" cracked.

This rehabilitation project was completed in 1984 and consisted of the following sections:

Sections	Description
A.	Asphalt underseal with 4 1/4 inch asphalt overlay
A.1	Same as A with fiber reinforced asphalt base layer
A.2	Same as A with fiber reinforced asphalt base and binder layers
B.	Cracked and seated with 5 1/2 inch AC overlay
B.1	Same as B with fiber reinforced asphalt base layer
B.2	Same as B with fiber reinforced base and binder layers
C.	Cracked and seated with 6 1/2 inch AC overlay
D.	Cracked and seated with 8 1/2 inch AC overlay

The C&S sections used two types of pavement breakers, a whip hammer and a drop hammer. The cracks were required to be mainly transverse, spaced 18 to 24 inches apart. A 50-ton rubber-tired roller was used to seat the pavement. The C&S cost was $0.64 per square yard.

Since the overlay thickness of the "control" does not match the C&S, a direct comparison is not possible. The performance results of the 5-inch overlay in the C&S section are compared below with the 4 1/4 inch "control" overlay.

a. There were no reflective cracks in the 6 1/2- and 8 1/2-inch overlaid C&S pavements. (sections C&D)

b. Only a couple of reflective cracks were observed in the 5-inch overlaid pavements (sections B, B1, B2) which amounted to about 1 percent of the joints.

c. About 40 percent of the transverse joints in the 4 1/4-inch "control" pavements (sections A, A1, A2) had reflected through.

d. All cracks observed were medium in severity and followed a "jagged line pattern" across the pavement at the joint.

e. There were isolated "blow-up" areas in both the control and C&S sections.

f. There was one area about 1/2-mile long of the 4 1/4-inch overlay control sections that showed no reflective cracking. The lack of reflective cracking in this one area could not be readily explained and is not indicative of the "control" sections in the project.

The 1986 Initial Construction and Interim Performance Report from the Indiana Department of Highways(2) concludes in part... "the drop hammer was the most effective machine for producing regular transverse cracks in the pavement. Cracking reduced the strength of the concrete slab without decreasing the subbase support. Rolling with the 50-ton roller decreased both the slab strength and subbase support. Therefore, a heavy roller should not be used as it does not seat the pavement, but rather unseats it."

8. Tennessee

SR-5 Bypass, Madison County

The existing pavement was a 9-inch PCCP on a 6-inch CTB, with no dowels and a 25-foot joint spacing.

The C&S with overlay was completed in November 1983. It consisted of cracking the slab from 18- to 24-inch pieces, seating with a 50-ton pneumatic-tired roller, and overlaying with 5 3/4 inches of AC. The control section had undersealing with fly ash/cement grout, full-depth joint repair, joint resealing, and a 5 3/4-inch overlay. The existing pavement was in fair condition with less than 5 percent of the slabs with cracks. The C&S cost was $0.40 per square yard.

a. About 20 percent of the transverse joints had reflected through the control section overlay with primarily low severity cracking.

b. About 3 percent had reflected through in the C&S section.

c. There were a few isolated locations where longitudinal cracking appeared in the wheel paths of the C&S section.

F. DISCUSSION

1. Of the 22 projects reviewed, only four projects showed appreciably less reflective cracking in the C&S sections than in the control sections. To quantify the benefits of C&S, a measure of the difference in the percent of transverse joints which had reflected through the overlay was employed. Observations made during this review coupled with previous State condition surveys, where available, indicated a reduction in the percent transverse joints reflecting through the overlay during the first few years when C&S is applied. However, after 4 to 5 years the C&S sections generally have approximately the same cracking as the control sections. Therefore, it can be concluded that overall, C&S appears to

provide benefits under some conditions by <u>delaying</u>, not eliminating, reflective cracking.

2. The two projects where the C&S sections performed best were:
   a. SR-99 near Bakersfield, California
   b. I-4 near Tampa, Florida

   Because of the notable difference in the percent of transverse joints reflecting through between the C&S and the control sections on these projects, similarities were investigated. It is believed that the following combination of conditions had the greatest impact on the success of these two projects.

   a. Strong base (cement-treated)
   b. Small changes in seasonal temperatures
   c. Non-reinforced pavement

   These similarities tend to indicate that C&S works best under the same limited conditions as other methods used to reduce reflective cracking (pavements that tend to have little vertical and horizontal movement). Small changes in seasonal temperatures understandably result in less thermal movement in the slab, thereby reducing tensile stress in the AC overlay and the possibility of reflective cracking. A strong base should help in reducing the vertical shear stresses in the overlay. With non-reinforced pavements, the aggregate interlock of the crack interface is the controlling factor in resisting differential deflection or vertical movement. A strong base helps maintain uniform support and should minimize differential deflections of the individual pavement pieces.

In addition, non-reinforced pavements should provide better performance since the presence of reinforcing steel in a slab will tend to inhibit the development of cracks which penetrate all of the way through the slab. Even when the pavement is cracked full depth the steel will tie the sections together concentrating the thermal movement at the original joints which should result in reflective cracking. Non-reinforced pavements generally have shorter slab lengths than reinforced pavements. This reduces the thermal movement at the joints and, therefore, should reduce reflective cracking.

3. The reduction of the structural capacity of the existing pavement appears to be an undesirable feature of C&S. The size of the cracked sections have a direct relationship to structural capacity.

The 1986 AASHTO Guide for Design of Pavement Structures includes a methodology for overlay of C&S pavements. Using this methodology, the suggested structural layer coefficients (indication of carrying capacity per inch of pavement) of the C&S pavement are as follows:

Crack Spacing	Structure Layer Coefficient
1 Foot	0.25
2 Feet	0.35
3 Feet	0.45

A research report(5), completed for the National Asphalt Pavement Association, concluded through back calculation of deflection testing performed on Minnesota's C&S projects that the structural layer coefficients for the C&S project test sections ranged from 0.21 to 0.53. The crack spacing and degree of cracking appeared to be related to the structural layer coefficients. This tends to support and verify the values used in the AASHTO Guide.

Since the structural capacity of the existing pavement is reduced by cracking, more overlay thickness is required to maintain the same structural number as the non-cracked pavement. Using an overlay analysis such as AASHTO would typically result in the need for up to 3 inches to maintain equivalent structural capacity.

The additional cost of: 1) the additional overlay thickness; 2) the cracking and seating; and 3) other required work such as shoulder and guardrail raising, must be evaluated to determine if these costs are justified.

Based on this review and the limited field performance data available to date, it appears these extra costs may not be justified since the condition of the C&S and control sections seemed to be the same after some period of time on most of projects reviewed.

One project where this type of comparison is possible is on US 23 in Michigan. This project had two overlay thicknesses, 440 pounds per square yard and 660 pounds per square yard (approximately 4 and 6 inches) on both the C&S and the control. The extra 2 inches alone has given added performance life because the amount of reflective cracking is much less for the thicker overlay. The C&S with the thicker overlay is performing no better than its control section which indicates no benefit can be seen at this point.

Other C&S projects where various overlay thicknesses were constructed are:

Wisconsin I-94:

	Section	Overlay Thickness
a.	Control	4 inches
b.	C&S #1	5 1/2 inches
c.	C&S #2	7 inches
d.	C&S #3	4 inches

During the review, 3 years after construction, it was observed that the sections b. (C&S-5½") and c. (C&S-7") were performing slightly better than sections d. (C&S-4") and a.(Control-4").

Indiana I-74:

	Sections	Overlay Thickness
a.	Control	4 inches
b.	C&S	5 inches
c.	C&S	6 1/2 inches
d.	C&S	8 inches

At the time of the review, 2 years after construction, there were no reflective cracks in Sections c and d indicating more time is bought by the additional AC thickness.

4. Very little deflection testing has been performed on C&S projects. Only two of the projects reviewed had completed research in this area. The following is a general description of the results of that research.

Indiana, I-74: A Dynaflect was used to measure deflections. Deflection measurements were made before cracking, immediately after cracking, and after the seating operation. The effectiveness of the seating operation was tested after three passes of a 50-ton rubber tired roller as required in the specifications. Test data was also obtained on seven subsections after a variable number of passes of the roller. The average increase in deflection per pass of the seating roller was:

2.3×10^{-5} inch/pass for No. 1 sensor

0.8×10^{-5} inch/pass for No. 5 sensor

Since the deflection increased with each pass of the roller for both sensors, the concrete slab and the subbase lost strength with each pass. The research report states "... the heavy roller caused the slab pieces to unseat rather than to seat as was originally intended. This means that the heavy roller should not be used to attempt to seat the cracked slab pieces."

California, SR-99: Deflection testing was done with the Benkleman Beam and an 18 kip axle load. Deflection measurements were taken before C&S, after cracking, and after seating. The results of the testing are summarized below.(4) Rolling was performed with a 13-ton roller.

After Breaking/Before Seating

Change in Deflection	Number of Joints	Amounts
Reduced	36 of 39 (92%)	Average = 0.006 inches
Increased	1 of 39 (3%)	Average = 0.001 inches
Unchanged	2 of 39 (5%)	-----

After Seating

Change in Deflection	Number of Joints	Amounts
Reduced	9 of 35 (26%)	Average = 0.001 inches
Increased	14 of 35 (40%)	Average = 0.001 inches
Unchanged	12 of 35 (34%)	-----

The results of these two projects cast doubt on the need for seating after cracking. More research is needed in this area.

5. A review of the two projects where a direct comparison of the cracking pattern is possible, Michigan U.S. 23 and Minnesota 60/169, reveals that the larger crack spacing generally performed better than the smaller crack spacing. This would

be expected since for the same overlay thickness, the larger crack spacing is structurally superior to the smaller crack spacing.

Figure 1 shows the results of specific research by Michigan and Minnesota which compared performance of different cracking patterns. In both cases, the larger crack patterns performed better than the smaller crack patterns. Line "0" on Figure 1 is the performance of the control section. Any value above "0" indicates better performance and values below "0" means worse performance.

CRACK PATTERN COMPARISON

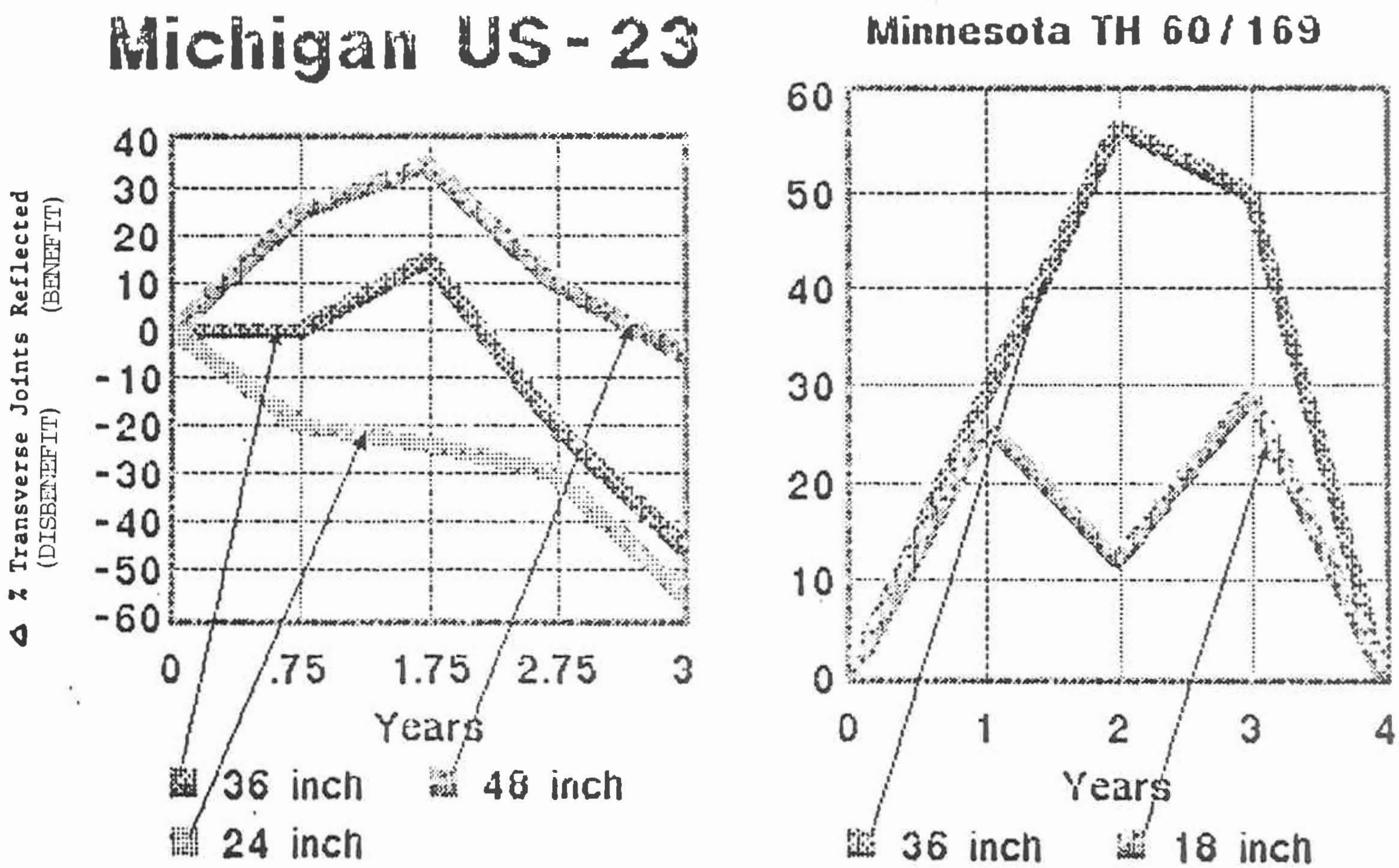

Figure 1

STATE	PROJECT	REINFORCED	DOWELS	JOINT SPACING	PAVEMENT THICKNESS	BASE TYPE	BREAKER TYPE	BREAK PATTERN	ROLLER TYPE	ROLLER WEIGHT	OVERLAY (INCHES)	YEARS	COST	REMARKS
FLORIDA	I-4	NO	NO	20	9"	CTB	DROP HAMMER	36" MAX	OPTIONAL	15T	3 5/8	7	-	C&S PERFORMING BEST
CALIFORNIA	SR-99	NO	NO	-	9"	CTB	DROP HAMMER	4' X 6'	VIB & RUBBER	13T	5	3½	1.60	NO CRACKS IN C & S
CALIFORNIA (ALEMEDIA & CONSTRA COSTA)	I-80	NO	NO	-	8	CTB	PILEDRIVE HAMMER	3' X 4'	VIBRATORY	12T	3¼, 5	4	12.50	NO DIFFERENCE IN PERFORMANCE
CALIFORNIA (YOLO COUNTY)	I-80	NO	NO	15	9	AC	HYDRAULIC STAMPER	2' X 2'	VIBRATORY	12T	4.8	4	0.75	NO DIFFERENCE
TENNESSE	SR-5	NO	NO	25	9"	CTB	PILE DRIVER	18"-24"	RUBBER	50T	5 3/4	3	0.40	C&S SLIGHTLY BETTER
INDIANA	I-74	YES	YES	40	10	AG	WHIP & DROP HAMMER	18"-24"	RUBBER	50T	5	2	0.64	C&S MARGINALLY BETTER
SOUTH DAKOTA	U.S. 18	YES	NO	20	9-6-9	AG	SPADE	5 FEET	VIBRATORY	-	3½	4	0.20	3½" C&S SLIGHTLY BETTER THAN 2" CONTROL
SOUTH DAKOTA	U.S. 50	YES	NO	40	9-6-9	AG	SPADE	10 FEET	VIBRATORY	-	4½	6	0.20	NO CONTROL SECTION
SOUTH DAKOTA	U.S. 14	YES	NO	15	8	AG	HYDRO-HAMMER	5 FEET	LOADED SCRAPER	-	4½	7	0.23	NO DIFFERENCE BETWEEN C&S AND CONTROL
MINNESOTA	TH 169	NO	NO	20	9-7-9	AG	SPADE	18", 36"	RUBBER	30T	5 3/4	4	0.18	LOW SEVERITY CRACKS IN EACH SECTION
MINNESOTA	TH 60/169	YES	YES	40	8"	AG	SPADE	18", 36"	PNEUMATIC	30T	6¼	4	0.21	NO DIFFERENCE IN PERFORMANCE
MINNESOTA	TH 71	NO	NO	15	9-7-9	-	DROP HAMMER	3 3/4'	RUBBER	-	6, 7½	10	0.26	AFTER 10 YEARS PERFORMANCE THE SAME
WISCONSIN	I-94	YES	YES	80	9	AG	PILEDRIVE HAMMER	18"	VIBRATORY	50T	4,5½,7	3	0.30	THICKER OVERLAYS PERFORMING SLIGHTLY BETTER
WISCONSIN	USH14	NO	NO	20	9	AG	HYDRO-HAMMER	"36 X 36"	PNEUMATIC	30T	4½	6	0.45	NO DIFFERENCE IN PERFORMANCE
WISCONSIN	STH140	NO	NO	20	9	AG	PILEDRIVE HAMMER	12"	VIBRATORY	50T	4	4	0.35	PERFORMANCE IS THE SAME
MICHIGAN	U.S.10	YES	NO	60	9-7-9	-	NOT SPECIFIED	"18 X 18"	VIBRATORY	50T	2¼	3	0.20	NO CONTROL SECTION REFLECTIVE CRACKS IN C&S
MICHIGAN	U.S.23	YES	YES	99	9	SELECT MATERIAL	WHIPHAMMER	24, "36", "48"	RUBBER	50T	4,6	3	0.19	6" C&S & CONTROL PERFORMING THE SAME

G. References

1. Minnesota Department of Transportation, Research and Development, Crack Reflectance on Bituminous Overlaid PCC Pavement (August 1981).

2. Indiana Department of Highways, Division of Research and Training, Initial Construction and Interim Performance Report (September 1986).

3. State of Florida Department of Transportation, Memorandum Inspection of Asphalt Over Concrete, Test Section Located on I-4 in Hillsboro County, (March 1986).

4. California Department of Transportation, Memorandum, Report of Construction, "Effects of Slab Breaking and Seating on Differential Vertical Movement at PCC Slab Joints and Cracks."

5. Midwest Pavement Management, Inc., Structural Evaluation of Crack and Seat Overlay Pavements, (in Minnesota), (September 1986).