Paper No. 02-2394

The Long-Term Performance of Unsealed Jointed Concrete Pavements

For Presention at the
Transportation Research Board's
81st Annual Meeting
Washington, D.C.
January 13-17, 2002

By

Martin P. Burke, Jr., PE
Bridge Consultant

&

John W. Bugler
Innovative Projects Engineer

BURGESS & NIPLE

NewYorkState
DEPARTMENT OF TRANSPORTATION

THE LONG-TERM PERFORMANCE OF

UNSEALED JOINTED CONCRETE PAVEMENTS (02-2394)

by

Martin P. Burke, Jr., PE[1]
and
John W. Bugler[2]

ABSTRACT

Based on a number of pavement sealant research projects conducted in Wisconsin during the last several decades, and on the early experiences of some other transportation agencies, maintenance engineers of the Wisconsin Department of Transportation have come to believe that sealing of contraction joints of jointed concrete pavements is unnecessary. They believe even more. They claim that with respect to ride quality and total pavement performance, the performance of unsealed pavements is superior to that of sealed pavements. And they estimate "that Wisconsin saves $6,000,000 a year by not trying to have a sealed system." (1) In local and national forums, they suggested that similar savings await other states that in effect see the light and abandon the lost cause of pavement sealing. Finally, they challenged other professionals to prove them wrong.

Generally, when claims such as these are made by research individuals, claims that contradict the observations of their professional colleagues and their predecessors of the last several generations, they are usually dismissed as the result of bad science or faulty logic. But when such claims are made by experienced professionals from respected professional organizations, they cannot be so easily dismissed. Consequently, this paper was developed to examine the case for and against the use of unsealed jointed concrete pavements, with a primary focus on the performance of Wisconsin test-pavements as described and discussed in recent papers on the subject. It provides a brief summary of Western European observations about the long-term performance of such pavements. And it mentions changes taking place in California Department of Transportation's pavement design and construction practices.

This paper has found that valid generalized conclusions about the suitability of unsealed pavements cannot be made based on extrapolations of short-term visual performance observations. It has also found that, contrary to Wisconsin observations about the cost-effectiveness of unsealed pavements, transportation agencies with the most long-term experience with such pavements have discontinued their use. Instead, pavement specialists of these transportation agencies have concluded that well-maintained pavement with doweled and sealed joints, and stabilized well-drained bases provide the most functional, durable and cost-effective pavement applications.

[1] Bridge Consultant, Burgess & Niple, Limited, 5085 Reed Road, Columbus, Ohio 43220.
Phone (614) 459-2050, Fax (614) 451-1385, e-mail [mburke@burnip.com].

[2] Innovative Projects Engineer, Region 10, New York State Department of Transportation, State Office Building, Hauppauge, New York, 11788
Phone (631) 952-6185, Fax (516) 952-6910, e-mail [Jbugler@aol.com].

**THE LONG-TERM PERFORMANCE OF
UNSEALED JOINTED CONCRETE PAVEMENTS**

INTRODUCTION

This paper was motivated by a bold challenge issued at the 1996 Spring Convention of the American Concrete Institute in Sacramento, California. That challenge has subsequently appeared in the paper, "The Effect of PCC Joint Sealing on Total Pavement Performance" by Steve F. Shober and Terry S. Rutkowski of the Wisconsin Department of Transportation (WisDOT)**.** (1) The challenge essentially stated that WisDOT researchers had shown that total pavement performance was not significantly effected by joint sealing or lack thereof. And they challenged other researchers to prove otherwise.

Although the first author prepared a Discussion of the paper that contained this challenge (2), a Discussion of a subsequent paper on the same subject (3), and an original paper on the pavement growth/pressure phenomenon and its destructive potential (4), it wasn't until an engineer colleague saw a blowup of an interstate pavement featured on a recent television news program in Sacramento, California (Figure 1) that the form of this response to WisDOT's challenge began to emerge and take shape. Subsequently, after a thorough literature search, an extensive internet exploration, and voluminous correspondence with pavement engineers both in the United States and abroad, the following discussion and documentation of the long-term unsealed pavement experience was developed.

Figure 1. A 1998 blowup of a 24-year old unsealed Sacramento, California interstate pavement. Joint spacing, about 12 feet. This blowup was preceded by others in the same general vicinity several years earlier.

This paper was also motivated by an increasing concern that transportation planning and design professionals were being grossly misled by widespread propagation of one agency's evaluation of pavement performance based essentially on pavement surface manifestations occurring during relatively brief time periods, on pavements that were not scrupulously maintained (sealants neglected), on pavements that were modified during test periods (full-depth repairs), and on pavements located in one narrow climatic region. Also troubling was the

awareness that in papers authored by Shober and Rutkowski and presented by Shober at Transportation Research Board meetings, American Concrete Institute conventions, et. al., test-pavement observations were generalized and extrapolated far beyond the actual data obtained during the early life of these pavements.

In arguing their unusual position with respect to the efficacy of using unsealed pavements, WisDOT engineers buttressed their conclusions and recommendations in two ways. First and primarily, they described the apparent results of their own extensive pavement sealing research projects. Secondly, they pointed to the apparent success of Western European countries with unsealed pavements. They probably also took comfort in the fact that the State of California has been constructing such pavements for more than two decades.

This paper describes and discusses these three aspects of the unsealed pavement argument. It concludes with the observation that WisDOT's belief in the efficacy of unsealed pavements is based on short-term appearances and not on long-term or life cycle function, durability and cost**.** That belief also appears to ignore the long-term effect of uncontrolled roadway drainage on pavement pumping and step-faulting. Unfortunately, and most critically**,** that belief appears to be based on the complete neglect of the pavement growth/ pressure phenomenon, a phenomenon recognized by many pavement and bridge practitioners as having a destructive effect with respect to pavements and bridges second only to seismic events, although its characteristics and destructive potential are better known and somewhat more predictable.

WISCONSIN CHALLENGE

> "WisDOT believes the burden of proof has shifted. No longer can anyone tout the merits of keeping water and incompressibles out of [pavement contraction] joints. Now the burden is on researchers to prove through total pavement performance analysis that sealing PCC joints somehow enhances performance enough to be cost effective…**.** Centuries ago the concept of a spherical earth was viewed as preposterous. Wisconsin's research has posed a position that may be viewed similarly, that is: **total highway pavement performance is not significantly effected by joint sealing or lack thereof**. The challenge awaits others to provide compelling research on this issue." (1)

It is a critical mistake to neglect or ignore changes made by moving water throughout a very long time period, as anyone will agree who has ever personally observed the placid Colorado river in the depths of the Grand Canyon. When evaluating the justifications for using sealed or unsealed pavement joints, it is similarly a critical mistake to ignore the potential effect of roadway drainage and/or fine roadway debris on the long-term performance of such pavements. Consequently, since jointed concrete pavements are intended to provide very long service lives, the choice of pavement characteristics must be based on the long-term performance of pavements with such characteristics. With this "time" and "change" aspect of pavement performance primarily in mind, the authors of this paper intend to review and critique the major aspects of the WisDOT argument using WisDOT's own research, the research of others, and the observations of those transportation agencies both in the United States and abroad that have the most experience with the long-term performance of unsealed pavements.

WISCONSIN RESEARCH

Although WisDOT engineers have been observing differences in sealed and unsealed pavement performance for at least 50 years, it wasn't until 1974 and thereafter that a number of partially-controlled research projects were constructed. These experimental investigations began with US-51 in Marathon County in 1974, followed by US-18/151 in Iowa County in 1983, WI-16/190 in Waukesha County in 1983, and WI-29 in Brown County and WI-164 in Waukesha County in 1988. In 1986, the results of the 10-year US-51 test-pavement investigation were summarized partially as follows:

> "When total pavement performance is considered, the results from 10 years of experience on US-51 indicate that shorter joint spacings (e.g., 20 ft) lead to better pavement performance than longer joint spacings, which was an expected result supported by other agencies. However, the conclusion that pavements with unsealed joints performed better than those with sealed joints, is provocative." (5, p.12)

Subsequently, in two similar 1997 papers on the evaluation of these same test-pavements, their conclusions and recommendations are given as follows:

"1. Research on the need for PCC joint sealants must remain focused on the customer's needs.
2. The customer's needs relate to total pavement performance (distress, ride, life, materials), convenience, and safety. These factors are not positively affected by joint sealing.
3. Joint sealing is not cost effective for PCC pavements.

"The following recommendations are made:

a. PCC pavement contraction joints should be left unsealed and sawed as narrow as possible.
b. Highway research must concentrate on user needs – the primary evaluation criteria for joint and sealant studies must be total pavement performance." (1, pp. 782-783 and 3, p. 30)

It must be emphasized here that at the time these observations and conclusions were made (1 and 3), two of WisDOT's pavement research projects had aged only 8 years (highly unlikely to exhibit pavement joint damage), two had aged 13 years (may begin to exhibit joint damage), while only one, the US 51 test pavements in Marathon County, had aged 22 years (a pavement age at which joint damage would be expected under WisDOT's environmental conditions). Note: Restrained pavements exposed to a wide range of temperature and moisture changes and with surfaces exposed to fine incompressible roadway debris will, over time, generate periodically and progressively greater longitudinal stresses (pressures) and concomitant pavement damage. Reference (4) describes the pavement growth/pressure phenomenon and the relationship between environmental changes, debris infiltration of contraction joints, and the generation of longitudinal pavement stresses. It also describes the relationship between these stresses and the progressive disintegration of pavement joints and the distress of bridges abutting such pavements.

The first author of this paper submitted a Discussion of the two papers concerning WisDOT's current research (2 and 3). These discussions found fault with the WisDOT research for one primary reason.

> "It is clear that Wisconsin's sealant research does not consider total pavement performance. Instead, only the short-term performance of some secondary pavement aspects is considered and evaluated. Missing from Wisconsin's evaluations is any recognition of the longitudinally oriented temperature- and moisture-generated pavement compressive stresses that over time can become severe enough to destroy the pavement and seriously damage adjacent bridges." (3, p.30)

And although WisDOT's research summary was done in 1996**,** a field review by the second author in 1995 of the then 21-year-old US-51 test pavements revealed the following:

> "During a recent examination he found that five full-depth lane-width repairs were made to the unsealed 6-m test sections of US-51, the oldest test section reported on in the paper. Pavement markings indicated that these repairs were made in June, July, and August (the hottest months) of 1993, at which time the pavements had aged for 19 years. Although Shober mentions that this section of pavement experienced premature joint spalling because of an irregularity in the location of reinforcement, two pavement joints (identified as Joints 37 and 41 on the test pavements) appeared to be in very good condition in 1987, just 6 years before their full-depth repair. Consequently, although misplaced reinforcement may have contributed to distress at some joints, it appears that high pavement compressive stresses [due to joints filled with fine incompressible debris] were probably responsible for most of the distress that necessitated the full-depth repairs to this oldest unsealed test section. It is instructive to note that in 1993 there were no full-depth repairs made to a companion sealed test section (N4F) [actually a misnomer since the seals were not maintained after the initial 10-year test period], although it presumably was constructed at the same time, by the same contractor. Also, except for the sealed joints, it had a similar design and was exposed to similar weather extremes, traffic volumes, and truck loadings." (3, p.32)

> On the basis of this evaluation of WisDOT's test-pavements, it was suggested that:

> "…present conclusions about this research are suspect because they are based on relatively brief pavement lives and on evaluations that did not consider the destructive potential of high pavement compressive stresses." (3, p.32)

WESTERN EUROPEAN EXPERIENCE

(1) Prelude

One of the main arguments used by Stephen Shober to justify the use of unsealed pavements is a quoted statement attributed by Shober to the Proceedings of the 16th PIARC (Permanent International Association of Road Congresses) World Road Congress that was held in Vienna in 1979. In using this quote, Shober writes:

> "The Europeans have an enlightened view. The 16th World Congress of the Permanent International Association of Road Congresses in 1979 concluded the following:
>
> " '[W]ith joint spacings of 4 to 6 meters there is no disadvantage in leaving narrow transverse joints unsealed when
>
> A) traffic is light
> B) traffic is heavy but climate is dry, and
> C) traffic is heavy and climate is wet, but pavement is doweled.' " (3, p. 23)

If an entire World Road Congress came to such a conclusion, Shober's argument would certainly be persuasive. However, an in-depth review of pavement sealant research literature revealed that the quoted statement was not extracted from the proceedings of the 16th World Road Congress. Instead, for that Congress, its Technical Committee on Concrete Pavements issued a report on "Sealed Joints – Unsealed Joints", the second of nine reports, that contained a summary statement about unsealed joints as follows:

> "Omitting sealing has the effect of accelerating faulting when the joints are not doweled, when the climate is humid and when heavy traffic is present. On the basis of actual experience, it seems that there are no drawbacks to leaving transverse joints unsealed when:
>
> - traffic is light
> - traffic is heavy but the climate is dry
> - traffic is heavy, the climate humid, and the joints are doweled." (7 and 8)

Notice that in this statement from the technical committee report, no mention is made about joint spacing although the quote used by Shober specifically mentions joint spacings of 4 to 6 meters. An explanation for the disparity in the above two quoted statements appeared when another reference to the 16th World Congress reports was discovered. Search of the literature on joint seals revealed the 1980 paper "Effect of Defective Joint Seals on Pavement Performance" by Gordon Ray of the Portland Cement Association. In Ray's paper, reference is not made to the conclusions of the entire World Congress, but only to the contents of a report about joint seals by the Technical Committee on Concrete Pavements, one of the Congress's ten technical committees**.** But Ray did not quote from the report. He merely summarized the report in his own words as follows:

> "The PIARC report concludes that, with joint spacings of 4-6 m (13 to 20 feet), there is no disadvantage in leaving narrow transverse joints unsealed when (a) traffic is light, (b) traffic is heavy but the climate is dry, and (c) traffic is heavy and the climate is wet but the pavement is doweled." (6)

Notice that Ray qualified the three-part report summary with a mention of joint spacings, an important qualification that appears in the body of the technical committee report but is not mentioned in the context of its summary.

When comparing Shober's quote with the conclusion of the 1979 technical committee report and Ray's 1980 summary statement of that report, it appears that Shober's 1997 quote is, except for the omission of English equivalents, an almost exact copy of Ray's statement. This apparent mistake of attributing Gordon Ray's statement as a quote from the proceedings of the 16th World Road Congress has a number of consequences:

1. Shober's introduction to the quoted statement incorrectly attributed the statement on unsealed joints to the conclusions of the entire 16th World Road Congress instead of to a single technical committee, a mistake that greatly distorts the significance of the report's summary statement.

2. This mistake in referencing the proceedings of the 16th World Road Congress and not the report on joint seals by the Technical Committee on Concrete Pavements makes it almost impossible for interested individuals to easily access the technical committee report (more on this below) to learn about the background that lead to its concluding statement.

3. This mistake in referencing the proceedings of the 16th World Road congress instead of the paper by Gordon Ray unfortunately attributed to others the work of Gordon Ray, a nationally respected authority on concrete technology, and consequently did not bring Ray's excellent discussion of pavement sealing to the attention of those who were interested in pursuing this subject.

4. Finally, this mistake took Ray's summary statement out of the context that he had intended. After summarizing the contents of the technical committee's report, Ray added a concluding paragraph to his discussion of unsealed joints that raised doubt about the general applicability of the European experience. Ray concluded:

   "Most research in the United States on test pavements with sealed and unsealed joints has demonstrated some improvements in performance when joints are kept reasonably well sealed." (6, p.1)

The complete contents of the Technical Committee on Concrete Pavements' report on "Sealing of Joints – Unsealed Joints" are informative and a resource that contains useful background with respect to the use of sealed and unsealed pavements. But as noted below, this report is difficult to access.

WESTERN EUROPEAN EXPERIENCE

(2) XVI PIARC Reports

The brief summary statement given above from a XVI World Congress technical committee report that **appears** to have been composed by Ray and mistakenly attributed to the World Congress by Shober, is certainly thought provoking. Consequently, it was decided to examine the report to learn about the background that formed the basis for the report's summary statement.

During an early literature search, the only reference available for the report was Shober's ("Proc., 16th World Congress of the [Permanent] International Association of Road Congresses, 1979"). (3, p.30) It was shortly discovered that the proceedings of this congress were voluminous with only three libraries in the United States having copies (the U.S. Department of Transportation Library, Washington, D.C., the Army's Cold Regions Research and Engineering Laboratory of Hanover, New Hampshire, and the Rare Book Section of the Library of Congress, Washington, D.C.). Upon examining these copies, it was discovered that each library had only part of the proceedings, each library had a different part; and none had the part containing the report on unsealed pavements. Eventually, copies of the technical committee reports for the 1979 World Road Congress were found to be still available from the World Congress office in Paris, France, but only the French language version (7). Copies of these technical committee reports were purchased and the report on "Sealing of Joints – Joints Unsealed" by the Technical Committee on Concrete Pavements was found and translated into English. (8) It was later confirmed through correspondence with the author of the report that the original report was written in English and that our recent translation of the French version into English was considered by the author to be an accurate rendition of the original.

This paper was burdened with the above background simply to save other individuals from a similar, seemingly endless and ultimately fruitless search through all of the partial copies of the World Congress Proceedings available at United States libraries for a technical committee report on "Sealing of Joints - Unsealed Joints." For those wishing to examine the English translation of this report, see Reference (8).

WESTERN EUROPEAN EXPERIENCE

(3) Prior to 1979

The PIARC Technical Committee on Concrete Pavement's Report on "Sealing of Joints – Unsealed Joints" (7 and 8) is very informative. It discusses blowups and mentions the measurement of high longitudinal compressive stresses; it compares step-faulting of sealed and unsealed pavements; it qualifies the French experience by stating that that experience "had shown [French engineers] that sealing and maintaining joints was advantageous if one considered the long-term performance"; for unsealed pavements, it stated that joints must be narrow and spaced at not more than 4 to 6 m [13 to 20 ft.]; and it concluded with the three-part qualification (traffic, weather and dowels) for the use of unsealed pavements, as quoted in the papers of both Ray and Shober. However, contrary to the impression given by Shober's statement that the World Congress supported WisDOT's findings which concluded "that pavements with [unsealed] joints performed better than pavements with [sealed] joints" (3, p.23), the report actually stated that of all of the countries represented with the Technical Committee on Concrete Pavements, only "Austria and Spain authorized unsealed transverse joints on highways and other main roads…."(8, p.6). Also, in considering this qualifying statement from the technical committee report, notice that the report states only that the use of unsealed joints was "authorized". It did not state that Austria and Spain had chosen or adopted unsealed pavements in lieu or sealed pavements, or that they had recommended the use of unsealed pavements, or that they considered unsealed pavements to be better than sealed pavements. It merely stated that these two countries had authorized the use of unsealed pavements. On the basis of the above statement, it is a considerable distortion of facts to state that with respect to the use of unsealed pavements, the "World Road Congress" supported WisDOT's findings about the superiority of unsealed pavements.

With the exception of Germany that was said to have more than 1000 km [600 miles] of unsealed pavements, some up to 20 years old, most observations (from Austria, Belgium, Denmark, France, Germany, Netherlands, Spain, and Switzerland) were for pavements less than 10 years old. The "oldest" Austrian pavement was just 13 years old.

Except for the German experience, it appears that the Western European experience prior to 1979 with various types of unsealed pavements was not long enough to justify the adoption of the unsealed concept for pavement applications that were intended for heavy traffic and service lives of up to 30 years or more. The observations upon which the report was based were for pavements that were just reaching the age when accumulating pressures could commence to fracture pavement joints and compress abutting bridges. Apparently, pavement pressure generation had not reached high enough levels by 1979 to manifest some of the more dramatic evidences of its destructive behavior.

WESTERN EUROPEAN EXPERIENCE

(4) As of 2001

After obtaining and translating a copy of the 1979 World Congress technical committee report on "Sealing of Joints – Unsealed Joints", the authors were not surprised to find that the experiences with unsealed pavements documented in the report were for pavements that were generally less than 10 years old. However, since more than 20 years had elapsed since that report was compiled and published, these same pavements had now matured to an age of about 30 years. Therefore, the accumulated experiences of these same European countries with these now older pavements represented a resource of unsealed pavement experiences that needed to be documented for those interested in this critical aspect of concrete pavement technology.

With this object in mind, a brief letter inquiry was undertaken by the authors with nationally recognized pavement authorities of those same countries. This inquiry focused on only two general aspects of the subject, namely:

A. Evaluation of their country's long-term unsealed jointed concrete pavement performance, and

B. Their country's present national practice with respect to the construction of unsealed jointed concrete pavements.

Responses to this inquiry were outstanding. With respect to all contiguous Western European countries, this inquiry was favored with responses from all countries except Portugal and the Netherlands. The primary and rather surprising finding was that without exception, after almost 30 years of trial applications, not a single country had adopted unsealed jointed concrete pavements as a national standard. Secondly, those countries with the most experience with such pavements (Germany, for example) came to the conclusion that control of surface and subsurface water is one of the most critical aspects affecting long-term pavement performance. The following slightly edited quotes from their recent letters give more specific meaning to the general observations noted above:

"Enclosed is an article on step-faulting that shows what can occur when water penetrates between the concrete slab and its base. As we have these damages already on sealed jointed concrete pavement with bonded base courses, without joint sealants it would be even worse, as former experiments with unsealed longitudinal joints have shown. That is why in Germany today the longitudinal and transverse joints are sealed even if there is an unbonded base under the concrete slab or a non-woven fabric between the slab and the bonded base."

"Turning now to present day joint sealing practice in the UK, it has been the practice for many years to seal joints. Unsealed joints under UK conditions have proven to be unsatisfactory and can lead to maintenance problems, which is something we are obviously keen to avoid. Consequently, in the UK, to minimise maintenance and to ensure long life durable pavements, we do not advocate the use of unsealed joints in jointed concrete pavements."

A report on the 1992 U.S. Tour of European Concrete Highways (9) contained the following:

"Sealing of Joints: European countries differ as to whether or not they seal joints and as to what type of seal they use. Most countries seal transverse and longitudinal joints. An exception to this is Austria, where in some areas a narrow (3 mm (0.1 in) wide) joint is saw cut and not sealed, which reduces construction cost by about 10 percent."

Even this 1992 exception has changed as described in the following recent inquiry response from Austria:

"You will not be astonished to hear that our road authorities changed their minds and are now building their pavements for heavily trafficked roads with sealed joints. Some have been doing so since 1988 and 1990, the last ones joined in 1998: Sealing the joints will prolong the life of the pavement under heavy traffic and it will reduce bridge problems. But even with sealed joints and good bond between the concrete pavement and its sub-base, the expansion joints at bridges will require regular inspection."

"All concrete pavement in Switzerland is jointed except for two short road segments, each about 800 meters [1/2 mile] long, constructed in non-jointed reinforced concrete. Since about 1978, spacing joints at about 5 meters [16 feet] has been common practice. To ensure that alignment of the segments remains true over time, since 1980 concrete pavements have been placed on a bonded sub-base or subgrade (asphalt sub-base or cement-stabilized subgrade). Joints in the pavement of the *autobahn*, streets, runways, and plazas are always sealed, usually with hot, fluid filler. Only less-important rural roads receive no joint sealant."

The response from Belgium was also qualified with respect to principal and secondary roads.

"On principal roads, transverse joints are generally doweled and sealed. The thickness of the pavement is generally between 20 and 23 cm [8 to 9 inches] and joint spacing is 5 m [16 feet]. The subbase is made of cement-bound materials (lean concrete), and on heavily trafficked roads a 6 cm [2 3/8-inch] asphalt interlayer is placed between the subbase and the concrete pavement (the same design is used as for CRCP – continuously reinforced concrete pavements)."

"On low-volume country roads, joints are constructed either by inserting a sheet of polyethylene in the fresh concrete, or by sawing in the hardened concrete. In this case the joints are generally not doweled, nor

sealed. These pavements are generally constructed directly on the existing subgrade, or with a crushed stone subbase. Thickness varies from 16 to 20 cm. [6 1/4 to 8 inches]. This technique has been used for more than 30 years, and no specific problems have occurred concerning their long-term behavior."

Spain's response was similarly qualified. Although Spain has not built jointed concrete pavements for some time, their experience with secondary country roads appears to reflect the experience of Belgium:

"With regard to the performance of unsealed pavements in Spain, it can be considered excellent up to now. Some examples are more than 25 years old. However, it should be pointed out that most of these pavements are placed in regions with a mild climate (no deicing salts), average annual rainfall not exceeding 30 inches and traffic volumes under 1000 trucks a day. In addition, all of them are placed on either cement treated bases or lean concrete ones. Joints are undoweled. Slotted drain pipes are installed to evacuate water infiltrated through the joints."

Although the authors expressed interest in the pavement growth/pressure phenomenon and its effect both on pavements and bridges, and this interest was specifically mentioned in some of our correspondence to them, most responders did not comment on this aspect of pavement behavior. Instead, the primary concern expressed by pavement engineers was the adverse effect of unsealed joints on step-faulting. However, with respect to Germany's experience, the adverse effect of the pavement growth/pressure phenomenon on bridges is clearly expressed by their approach pavement design illustrated in Figure 2.

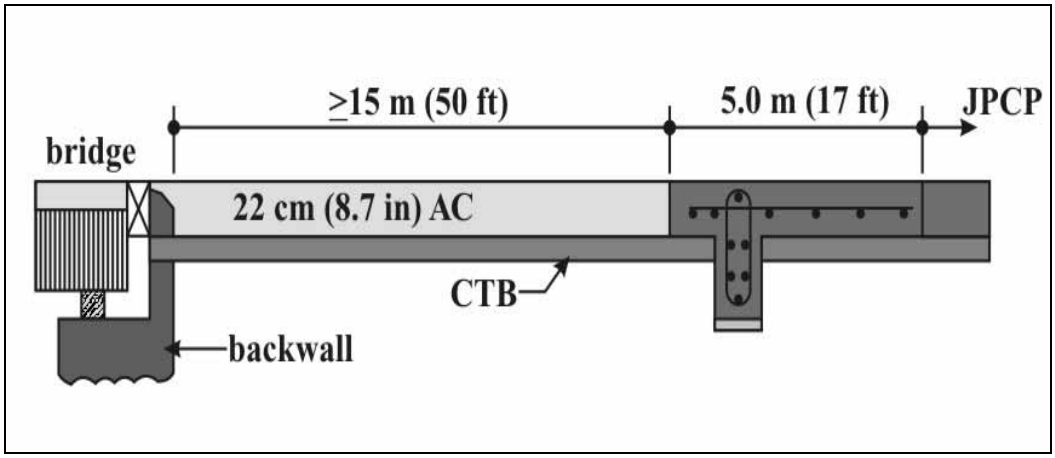

Figure 2. A German bridge approach pavement design from page 84 of Reference (9). Note the shallow anchor lug used to provide some restraint against pavement growth and the asphalt concrete slab used to minimize pressure transmission to the bridge. However, it appears that the cement treated base (CTB) may be counter productive depending upon its crashing strength.

THE CALIFORNIA EXPERIENCE

One can hardly discuss the long-term performance of unsealed jointed concrete pavements without considering the experience of the California Department of Transportation (Caltrans) where such pavements have been used as standard practice for the better part of three decades.

Although Caltrans' pavement design standards have progressively changed over the years as research and pavement age experience suggested, a continuing concern for step-faulting appears to have been primarily responsible for a 1990 memorandum recommending Caltrans' adoption of joint sealing as a standard practice.

"Although there has been a considerable amount of recent research by others pertaining to the sealing of pavement joints and cracks, this research has addressed the performance of the seal, as opposed to the performance of the pavement. Thus, the only research relating joint seals to PCCP performance is the

> Geyersville Study. Although the data are very limited, it is recommended that all joints be sealed with a… sealant installed in a joint with the proper depth/width (D/W) ratio….” (10, p.10)

This recommendation was followed by others that apparently resulted in the change of pavement practices as stated in the current Caltrans Highway Design Manual:

> “(2) *Joint Sealing*. Caltrans has rarely used joint seals in the past. However, with recent developments in joint design and joint materials, it appears that sealing of joints has a significant potential for cost effectiveness provided careful attention is given to selection of materials as well as construction of the sealed joints.
>
> “Entrance of fines, or incompressibles, into and through pavement joints may lead to, or contribute to, step-faulting, joint spalling, excessive pressure against bridge abutments, and pavement blowups. This is especially critical on high elevation routes where sanding is used during icing conditions, and in blow-sand areas where fine sand is deposited on the roadbed. The problems of step-faulting and joint spalling are also apparent, in varying degrees, under a wide range of conditions throughout the state. The entry of surface water into pavement joints has also played a major role in accelerating pavement deterioration.
>
> “Because of the factors discussed above and to minimize the spalling of transverse joints and the need for costly and disruptive repairs on heavily traveled urban freeways, the sealing of all joints to deter the entry of fine or incompressible materials and water is to be specified on all new concrete pavements. However, when one or more lanes are added for widening, the joints should not be sealed unless the transverse and longitudinal joints (and cracks) in adjacent lanes are also sealed.” (11) Article 607.6(2)
>
> With respect to the pavement growth/pressure phenomenon, the Caltrans Manual states:
>
> “….Since pavement blowups are relatively uncommon on State Highways in California, the need for pressure relief joints is primarily near the end of structures to prevent the transmission of expansive forces from the concrete pavement to the structure…” (11) Article 607.6(3)

With respect to the use of unsealed pavements by Caltrans, dramatic and unmistakable manifestations of long-term pavement distress have been featured in newspapers and local television news programs. One such event, the blowup of an interstate pavement in Sacramento (Figure 1), not only had an adverse effect on local Sacramento traffic, it and similar events in other localities were at least partially responsible for Caltrans’ recent changes in pavement design practices.

Recognizing that blowups and step-faulting are now not strangers to California pavements, it is not surprising that commentary statements in the new Caltrans Highway Design Manual mention those long-term aspects of pavement behavior. Although the manual states that “At present, Caltrans does not use dowel bars in PCCP transverse joints except on an experimental basis,” (11, Article 607.6 (1)) it would not be surprising if the use of dowel bars became standard practice for primary roadways in California in the near future.

SUMMARY

This paper has briefly examined the case for and against the use of unsealed jointed concrete pavements, with a primary focus on the performance of WisDOT test-pavements as described and discussed in recent publications on the subject (1, 2, 3, 4 and 5). It provides a brief summary of Western European observations about the long-term performance of such pavements. And it mentions changes taking place in Caltrans’ pavement design and construction practices.

With respect to the WisDOT experience, it appears that WisDOT observations of test pavement performance were based on the mistaken assumption that the performance of pavements during their first ten years of service was somehow indicative of their long-term performance. Such an assumption entirely neglects the characteristics of the pavement growth/pressure phenomenon that typically becomes more destructive with pavement age. It also neglects the adverse long-term accumulative effects of surface and subsurface water

movement on pavement pumping and step-faulting, especially for pavements without dowels serving heavy truck traffic.

With respect to the 1979 PIARC Report of the Technical Committee on Concrete Pavements, the report that was summarized by Ray and mistakenly quoted by Shober, it appears that the extreme inaccessibility of the report may have prevented WisDOT engineers from discovering that the report did not advocate the use of unsealed pavements or that the summary given in the report was based on test-pavement experiences of generally less than 10 years.

Although the report mentions compression of expansion joint filler, pavement blowups and faulting of undoweled primary roads, the summary of the report, like Wisconsin's observations, also appears to have been based on the mistaken assumption that the first ten years of pavement performance was indicative of its potential long-term performance.

Recent correspondence with Western European concrete pavement specialists has revealed that after up to 30 years of unsealed pavement experience, not a single country has adopted unsealed pavements as a standard pavement type for road construction.

However, one surprising finding of this survey was that at least three countries (Austria, Belgium and Spain) have achieved what was characterized as suitable service for up to 30 years with some unsealed and *undoweled* pavements for country roads with light truck traffic. A word of caution about such pavements. At this time, the authors have been unable to determine the other characteristics of these pavements (joint spacing, rainfall, base and subbase material characteristics, etc.) that have an effect on step-faulting and the pavement growth/pressure phenomenon. Nevertheless, 30 years of effective service is a remarkable accomplishment for unsealed pavements. Because of such reported service, one is forced to conclude that these lightly loaded secondary roads have been successful, cost-effective designs.

Caltrans, with a wide variety of climatic conditions to contend with and with up to 30 years of experience with unsealed pavements has recently discontinued their use. Presumably, pavement step-faulting, joint fractures, blowups and bridge distress, damages associated with long-term pavement behavior, have all contributed to this decision of Caltrans to adopt sealed pavements as the design standard for all new jointed concrete pavements.

CONCLUSION

It is clear that valid conclusions about the performance of concrete test-pavements can be made only if performance evaluations recognize that gradual, progressive and unseen changes are taking place within the pavement and supporting structure. Over time, these changes can and generally do have a progressively adverse effect on the long-term performance of these pavements. Consequently, observations about test-pavement performance that ignore these changes and their potential long-term consequences are short-sighted, misleading and generally counterproductive.

On the basis of the foregoing discussion and documentation, it is clear that the use of unsealed pavement joints has been largely ineffective in providing long-term cost-effective pavement performance. As a result, the use of unsealed pavement joints has been discontinued by many major users familiar with the long-term performance of such applications. Conversely, enhanced long-term performance requires more than just the use of sealed joints. Care must be taken in choosing high quality sealant material, the type and size of sealant for the chosen pavement joint and panel characteristics, as well as effective installation and inspection procedures, and periodic sealant repair and replacement practices.

The maintenance of bridge approach pavements (about 1500 ft. [460m] of pavement) needs special attention. Increased sealant maintenance will be necessary to compensate for the compression of pressure relief joints, the progressive enlargement of pavement joints and consequently the more rapid growth of those essentially unrestrained pavements (12, pp. 59-60). This is particularly important with pavement having deteriorated, failed or missing sealants.

This study has found that valid generalized conclusions about the efficacy of certain highway pavement characteristics cannot be achieved based on extrapolations of short term ($\leq$ 10 years) pavement performance observations, especially where such conclusions are concerned about the long-term ($\geq$ 30 years) performance of highway pavements exposed to heavy traffic, fine incompressible roadway debris, moving water, and a broad range of environmental variables. And this is especially true when those extrapolations, from a single local geographical area, are presumed to be applicable to a wide realm of geographical, geological and environmental applications.

This study has also found that contrary to WisDOT observations about the cost-effectiveness of unsealed pavements (1, 3 and 5), transportation agencies with the most long-term unsealed pavement experience (California and most Western European countries) have discontinued their use. Instead, for jointed pavements exposed to heavy traffic and broad environmental variables, pavement specialists of these transportation agencies have concluded that well-maintained pavement with doweled and sealed joints, and stabilized well-drained bases provide the most functional, durable and cost-effective pavement applications.

EPILOGUE

The U.S. 51 test-pavements, located north of Wausau, Wisconsin, between Brokaw and the Marathon County line, the primary subject of the Wisconsin jointed concrete pavement experience, were covered with an asphalt concrete overlay in July of 2001. Consequently, both the unsealed and initially sealed portions of these test-pavements are now no longer accessible for visual observations.

REFERENCES:

1. Shober, S.F. and T.S. Rutkowski**.** The Effect of PCC Joint Sealing on Total Pavement Performance. SP164, Vol. 2. American Concrete Institute, Farmington Hills, Michigan, 1997, pp. 769-798.

2. Burke, M.P., Jr. The Effect of PCC Joint Sealing on Total Pavement Performance (Discussion). *ACI Materials Journal*, Vol. 95, No. 6. American Concrete Institute, Farmington Hills Michigan, 1998, pp. 757-760.

3. Shober, S.F. The Great Unsealing: A Perspective on PCC Joint Sealing. *Transportation Research Record 1597*, Transportation Research Board, National Research Council, Washington, D.C., 1997, pp. 22-33.

4. Burke, M.P., Jr. Pavement Pressure Generation: Neglected Aspect of Jointed Pavement Behavior. *Transportation Research Record 1627*, Transportation Research Board, National Research Council. Washington, D.C., 1998, pp. 22-28.

5. Shober, S.F. Portland Cement Concrete Pavement Performance as Influenced by Sealed and Unsealed Contraction Joints. *Transportation Research Record 1083*, Transportation Research Board, National Research Council, Washington, D.C., 1986, pp. 7-12.

6. Ray, G.F. Effect of Defective Joint Seals on Pavement Performance. *Transportation Research Record 752*, National Research Council, Washington, D.C., 1980, pp. 1-6.

7. *Sealing of Joints – Unsealed Joints*. Report 2 of 9, Technical Committee on Concrete Pavements. Permanent International Association of Road Congresses (PIARC), Paris, France, 1979, pp. 49-53. (French)

8. *Sealing of Joints – Unsealed Joints*. Report 2 of 9, Technical Committee on Concrete Pavements. Permanent International Association of Road Congresses (PIARC) (English). By permission of the Road Congress, a complimentary copy of this report is available from Burgess & Niple's, Librarian, 5085 Reed Road, Columbus, Ohio 43220, [jgower@burnip.com].

9. *Report on the 1992 U.S. Tour of European Concrete Highways*. Publication No. FHWA-SA-93-012. Federal Highway Administration, Washington, D.C., 1993.

10. Wells, G.K. *Synthesize PCCP Design Parameters Researched by Caltrans and Others*. Report 65328-637391-31111. California Department of Transportation, Sacramento, California, 1991.

11. *Sealing of Joints.* Highway Design Manual. Caltrans Web-site, California Department of Transportation, Sacramento, California, 2001.

12. Burke, M.P., Jr., "Bridge Approach Pavements, Integral Bridges, and Cycle-Control Joints", *Transportation Research Record 1113*, Transportation Research Board, National Research Council, Washington, D.C., 1987, pp. 54-65.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the many individuals who gave assistance to the authors during the research and development of this paper, primarily Mrs. Julie Gower, Burgess & Niple (B&N) Librarian, for locating and gathering the numerous references that were consulted during the preparation of this paper, the B&N secretarial staff for their help with the voluminous correspondence that was generated by this effort; the many engineers both domestic and foreign who graciously provided their observations and advice during its preparation, especially Dr. Issam Minkarah of Ohio, Mr. Joseph Hannon of California, Mr. John Mercer of the United Kingdom, Dr. Hermann Sommer of Austria, Mr. Peter Sulten of Germany, Mr. Rolf Werner of Switzerland, Mr. Y. Guidoux of France, Mr. Frederic Fuchs of Belgium, Dr. Carlos Jafré of Spain, our anonymous TRB review colleagues for their many constructive comments and suggestions**,** and many others. Without their assistance, the development of this paper would not have been possible.