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Cost-Effectiveness of Joint/Crack Sealing

by

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Joint Transportation Research Program
Project Number: C-36-37JJ
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Prepared as Part of an Investigation Conducted by the
Joint Transportation Research Program
Purdue University

In cooperation with the
Indiana Department of Transportation
and the
U.S. Department of Transportation
Federal Highway Administration

The contents of this report reflect the views of the authors who are responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

School of Civil Engineering
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TECHNICAL Summary

Technology Transfer and Project Implementation Information

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Introduction

The sealing and resealing of joints and cracks in concrete (PCC), asphalt (HMA), and composite pavements is assumed to be an important component of pavement maintenance and restoration. It is also assumed that if performed effectively and in a timely manner joint and crack sealing will help to reduce pavement deterioration and thereby prolong pavement life. The objectives of joint/crack sealing activities are to reduce the amount of moisture that can infiltrate a pavement structure, thereby reducing moisture-related distresses and to prevent the intrusion of incompressible materials into joints and cracks so that pressure-related distresses are prevented.

It is generally accepted that minimizing water infiltration into a pavement structure via joint and crack sealing reduces moisture-related distresses, such as pumping and loss of support in rigid pavements and stripping in flexible pavements. Additionally, sealing is performed to prevent the intrusion of incompressible materials into joints and cracks with the belief this will eliminate clogging thereby reducing harmful contraction and expansion pressures which may lead to further deterioration of joints and cracks. Historically sealing and resealing of joints in rigid, flexible and composite pavements has been an accepted practice by highway agencies, including the Indiana Department of Transportation (InDOT).

In the past several years, this practice has been challenged by some research that indicates sealing may not be cost-effective, at least in some applications. Additionally, studies that support a clear quantitative defense that crack sealing as cost-effective are few in number and limited in scope. Research conducted by the Wisconsin Department of Transportation (WDOT) on jointed concrete pavement over an extended period of time has led the agency to discontinue joint sealing of concrete pavements. In 1990, WDOT implemented the “no-seal” policy on new pavements and claims to have saved six million dollars annually with no loss in pavement performance and with increased customer safety and convenience.

InDOT currently spends approximately four million dollars annually to accomplish crack and joint sealing. About one-half of this amount is allocated for sealing old pavements that are selected through a subjective process. There is no quantitative evidence to justify this expenditure. The sealing operations are conducted because the “industry” assumes the benefits of sealing out weigh the costs. The knowledge of assumptions stated above along with the recent WDOT policy change lead to this research.

The primary objective of this research was to investigate the cost-effectiveness of joint/crack sealing in relation to pavement performance. The study focused on two specific questions:

1. Does joint/crack sealing in any way improve the service life or serviceability of pavements (performance); and
2. If sealing does improve performance, is it cost-effective and in what situations?

The researchers believed that the questions could only be addressed through a rigorous review of the literature, a survey of practice, and finally the design and analysis of a field experiment.

The research was divided into two phases. The first being a synthesis of practice intended to form a basis for determining whether or not further research were needed to determine the cost effectiveness of crack/joint sealing in Indiana. The results of the first phase are presented in this report along with a research plan for the proposed second phase.

Findings

The literature search and review considered over one hundred potential references and revealed that only eighteen specifically discussed cost-effectiveness of joint/crack sealing. Of these only four provided useful quantitative information related to the cost-effectiveness of joint/crack sealing. This in itself suggests the need for further research. In addition to the literature search, individuals who are recognized experts on this topic were contacted and asked to comment on the merits of the proposed research. Both of these efforts revealed little quantitative evidence to prove the cost-effectiveness of joint/crack sealing and suggested the need for further research.

The conducted survey of practice included responses to eleven questions by forty-two of the fifty state highway agencies polled. The survey revealed that like most other agencies, InDOT’s joint/crack sealing policy is based on long standing policy rather than research. The statistical analysis of the survey results also showed that most of states, including Indiana, do not have quantitative justification for sealing policies nor do they know the cost-effectiveness of the operations.

The literature search and review, as well as the survey of practice clearly indicated the need to develop and conduct a field study to answer the question of whether joint/cracking sealing is cost effective in Indiana. This lead the researchers to develop an experimental design for such a field study. The field study would be carried out in the second phase of the research.

Implementation

It is highly recommended that the second phase of this research (field study) be conducted. An experimental design for a field study was developed through a series of meetings with pavement technologists and a statistician. Three main factors, specifically roadway classification (national and state routes), pavement type (concrete, asphalt, and composite), and drainage (drained and undrained) are included in the experiment design as they are expected to have the greatest influence on pavement performance relative to joint/crack sealing effectiveness. The objective of the experiment is to provide adequate evidence to answer the age old question of whether joint/crack sealing is cost effective and under what conditions. The experimental design incorporates twelve cells. For each cell in the design, two projects each with two test sections (one sealed and one unsealed) are recommended.

Pavement performance should be monitored periodically throughout the duration of the field study. Performance response variables should include ride quality (IRI), seasonal pavement deflection (FWD), composite performance indices PSI and PCR, individual pavement distresses, and physical and mechanical properties of in-service pavement cores.

The performance data should be analyzed statistically to determine the effectiveness of joint/crack sealing. It should also be coupled with remaining life predictions to evaluate the cost effective of sealing. These analyses would provide the basis for formulating a joint/crack sealing policy for INDOT.

InDOT currently spends approximately four million dollars annually to accomplish joint/crack sealing even though there is no quantitative evidence to justify this expenditure. Thus, a well designed field experiment is strongly recommended to investigate the cost-effectiveness of joint/crack sealing in relation to pavement performance in Indiana.

It is suspected that sealing will be conditional and the results of this study will identify those applications for which it is cost-effective. The results would then be formulated into a set of guidelines for implementation by maintenance and design personnel. The potential savings associated with this research could very well amount to a significant portion of the four million dollars now spent annually on joint and crack sealing by InDOT.

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16. Abstract

The sealing and resealing of joints and cracks in concrete (PCC), asphalt (HMA), and composite pavements is assumed to be an important component of pavement maintenance and restoration in that if performed effectively and in a timely manner joint/crack sealing may retard pavement deterioration and thereby prolong pavement life. Historically sealing and resealing of joints/cracks in pavements has been an accepted practice by highway agencies, including the Indiana Department of Transportation (InDOT). More recently this practice has been challenged by some research that indicates sealing may not be cost-effective. Additionally, studies that provide a clear quantitative defense that joint/crack sealing as cost-effective are few in number and limited in scope. InDOT currently spends approximately four million dollars annually to accomplish joint and crack sealing with no quantitative evidence to justify this expenditure. The sealing operations are conducted simply because the "industry" assumes the benefits of sealing out weigh the costs.

The primary objective of this research was to investigate the cost-effectiveness of joint/crack sealing specifically in relation to pavement performance. The research was divided into two phases. The first being a synthesis of practice (literature review and survey of practice) intended to form a basis for determining whether or not further research were needed to determine the cost effectiveness of crack/joint sealing in Indiana. The results of the first phase are presented in this report along with a research plan for the proposed second phase.

The literature search and review considered over one hundred potential references and revealed that only eighteen discussed cost-effectiveness of joint/crack sealing. Of these, only four provided quantitative information related to the cost-effectiveness of joint/crack sealing. The survey of practice included responses to eleven questions by forty-two of the fifty state highway agencies polled and revealed that most agencies joint/crack sealing policies were based on long standing policy rather than research. The synthesis of practice clearly indicated the need to develop and conduct a field study to answer the question of whether joint/cracking sealing is cost effective in Indiana. This lead the researchers to develop a comprehensive experimental design for such a field study. The field study would be carried out in the second phase of the research.

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Implementation Recommendations

The synthesis study conducted, which incorporated both a rigorous literature search/review and a survey of practice revealed that only very limited research has been conducted on and even less quantitative evidence exists to justify joint and crack sealing in the U.S. and particularly in Indiana. Joint and crack sealing is simply conducted due to long-standing practice which assumes the benefits of doing so out way the costs. In Indiana the cost is in excess of four million dollars annually. Thus, a well designed field experiment is strongly recommended to investigate the cost-effectiveness of joint/crack sealing in relation to pavement performance in Indiana. The potential savings associated with the research could very well amount to a significant portion of the four million dollars now spent annually on joint/crack sealing by InDOT.

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1. Problem Statement and Study Objectives

1.1 Introduction

The current industry philosophy on joint and crack sealing is summarized in this introduction. The sealing and resealing of joints and cracks in rigid (PCC), flexible (HMA) and composite pavements is assumed to be an important component of pavement maintenance and restoration. If performed effectively and in a timely manner, it is accepted that joint and crack sealing will help to reduce pavement deterioration and thereby prolong pavement life. Joint and crack sealing are two of the more commonly performed pavement maintenance activities. One objective of these activities is to reduce the amount of moisture that can infiltrate a pavement structure, thereby reducing moisture-related distresses. The second objective is to prevent the intrusion of incompressible materials into joints and cracks so that pressure-related distresses are prevented.

With PCC pavements, it is believed that free water entering a joint or crack can accumulate beneath the slab, causing distress such as loss of support, faulting, and corner breaks. In addition, incompressible materials that infiltrate poorly sealed joints or cracks in PCC pavements interfere with normal expansion and contraction movements, thus creating compressive stresses in the slabs and increasing the potential for joint deterioration. If the compressive stresses exceed the compressive strength of the pavement, blowups or buckling may occur. It is also believed that resealing joints in PCC pavement is necessary if the existing sealant has deteriorated to the extent that incompressible materials and water can infiltrate the pavement structure.

In HMA pavements, most believe that unsealed or poorly sealed cracks allow moisture and debris to enter the pavement structure, contributing to asphalt stripping, secondary cracking, lipping (elevated transverse crack edges), and cupping (depressed transverse crack edges). In addition to the presence of excess water in the pavement base and subgrade, there tends to be reduced compressive and shear strength in the supporting materials immediately below and adjacent to the cracks. As a result, applied traffic loads in the vicinity of a crack create greater pavement deflections, additional cracking, cupping, and eventually potholes.

Sealing operations on HMA pavements address various forms of cracking that may occur, such as thermal cracking, reflection cracking, block cracking, and alligator cracking. However, crack sealing is believed to be most effective on transverse thermal and transverse refection cracks; sealing individual alligator cracks is generally not believed to be cost effective. A more appropriate measure for alligator cracks would be a localized chip seal.

1.2 Background and Problem Statement

It is generally accepted that minimizing water infiltration into a pavement structure via joint and crack sealing reduces moisture-related distresses, such as pumping and loss of support in rigid pavements and stripping in flexible pavements. Additionally, sealing is performed to prevent the intrusion of incompressible materials into joints and cracks with the belief this will eliminate clogging thereby reducing harmful contraction and expansion pressures which may lead to further deterioration of joints and cracks. Historically sealing and resealing of joints in rigid, flexible and composite pavements has been an accepted practice by highway agencies, including the Indiana Department of Transportation (InDOT).

In the past several years, this practice has been challenged by some research that indicates sealing may not be cost-effective, at least in some applications. Additionally, studies that support a clear quantitative defense that crack sealing as cost-effective appear to be few in number and limited in scope. Research conducted by the Wisconsin Department of Transportation (WDOT) on jointed concrete pavement over an extended period of time has led the agency to discontinue joint sealing of concrete pavements. In 1990, WDOT implemented the "no-seal" policy on new pavements and claims to have saved six million dollars annually with no loss in pavement performance and with increased customer safety and convenience.

InDOT currently spends approximately four million dollars annually to accomplish crack and joint sealing. About one-half of this amount is allocated for sealing old pavements that are selected through a subjective process. There is no quantitative evidence to justify this expenditure. The sealing operations are conducted because the "industry" <u>assumes</u> the benefits of sealing out weigh the costs.

1.3 Study Objectives

The primary objective of this research is to investigate the cost-effectiveness of joint/crack sealing in relation to pavement performance. This study will focus on two specific questions:

1. Does joint/crack sealing in any way improve the service life or serviceability of pavements (performance); and
2. If sealing does improve performance, is it cost-effective and in what situations?

There are essentially three potential out-comes of this study; sealing is cost-effective, sealing is not cost-effective or sealing is cost-effective in specific applications. The questions can only be addressed through a rigorous review of the literature, a survey of practice, and finally the design and analysis of a field experiment. All of the potential outcomes would have immediate application to INDOT operations. It is suspected that sealing will be conditional and the results of this study will identify those applications for which it is cost-effective. The results would then be formulated into a set of guidelines for implementation by maintenance and design personnel. The potential saving associated with this research could very well amount to a significant portion of the four million dollars now spent annually on joint and crack sealing by InDOT.

In order to determine if field experiments would be required to answer the primary question “is crack and joint sealing cost-effective?”, a literature search and survey of practice were conducted. The literature review is presented in Chapter 2 and the survey of practice is presented in Chapter 3.

2. Literature Review

In an effort to obtain any and all available pertinent literature, the following databases were searched:

1. Transportation Research Information Services (TRIS);
2. Strategic Highway Research Program Reports (SHRP);
3. American Society of Civil Engineers (ASCE Journal of Transportation Engineering);
4. American Society of Testing and Materials (ASTM); and
5. Association of Asphalt Paving Technologists (AAPT).

The initial searches revealed well over one hundred potential references. However a review of the references revealed that the bulk of this literature focused on sealing materials and procedures rather than on the cost-effectiveness of sealing. Only eighteen specifically discussed cost-effectiveness and of these only four provided useful quantitative data.

The fact that the bulk of the literature focused on sealing materials and procedures reinforces the hypothesis that the industry's general perception is that sealing is cost-effective. Thus recent research has focused on refinement of the materials and procedures rather than on the fundamental issue of whether or not sealing is cost-effective.

In addition to the literature search, individuals who are recognized experts on joint and crack sealing were contacted and asked to comment on the merits of the proposed research. This effort did not lead to any additional references, but many of the individuals contacted reinforced the need for research on the cost-effectiveness issue.

The eighteen sources that contained some information on cost-effectiveness were separated into three categories: non-supporters of sealing, supporters of sealing, and others. A synopsis of each of categories is presented in Sections 2.1, 2.2, and 2.3 respectively.

Section 2.4 is a summary of the literature review based on the information presented in these individual sections.

2.1 Non- Supporters of Sealing

2.1.1 *The Great Unsealing-- A Perspective on PCC Joint Sealing*, S.F. Shober, Wisconsin Department of Transportation. April, 1997.

In 1997, Shober of the Wisconsin Department of Transportation stated that there was significant information available on PCC pavement joint sealing by the early 1970's, but that most of it focused on joint and/or sealant performance [1]. Shober stated that there was a definite lack of information available on overall pavement performance as influenced by joint sealing. Therefore, he conducted a study with the objectives of determining the benefits of joint sealing and whether or not it was cost-effective.

In 1974, the Wisconsin Department of Transportation (WDOT) initiated a study of pavement performance as influenced by sealed and unsealed contraction joints at various spacings. Over 50 test sections were constructed from 1974 to 1988 incorporating both doweled and un-doweled PCC pavements with joints of various spacings placed on subgrades ranging from sand to silt to silty-clay exposed to a range of traffic loading. The performance of five pavements that incorporated 51 test sections was summarized in Shober's report. The pavements ranged in age from eight to ten years at the time the performance data were collected. All five pavements had sealed sections and control sections that were not sealed. The seals in one pavement, USH51, were kept perfectly intact for at least 10 years. Any time a significant sealant failure was observed, it was corrected by resealing as soon as possible. The seals on the other four pavements were not replaced if they failed.

Shober used four factors to evaluate pavement performance. They included:

1. overall pavement distress;
2. ride quality;
3. encroachment on bridges; and
4. material integrity.

The Pavement Distress Index (PDI) was used to characterize pavement distress. PDI is a combined pavement performance index that is a function of the severity and extent of several distresses obtained through visual condition surveys. Shober employed the International Roughness Index (IRI) to characterize pavement ride quality. Encroachment of the pavement on bridges was also evaluated by the observation of pavement expansion at bridges. The effect of joint sealing on material integrity was assessed by coring pavements at random locations. The cores were centered on pavement joints. The physical appearance of cores from both locations was used to determine if joint sealing had an effect on material integrity.

Statistical analyses were performed to compare the performance of sealed and unsealed test sections. The analyses indicated that joint sealing did not have a significant effect on pavement distress, ride quality, bridge encroachment, material integrity, and most importantly pavement life. The following quote was taken directly from the WDOT report summarizing the ten-year findings of the study, “The pavement with unsealed joints performed better than the pavement with sealed joints.”

This study suggested that pavement performance was not positively influenced by joint sealing and that joint sealing may not be cost-effective for PCC pavement, at least within the State of Wisconsin. In some test sections there was improved (or at least equal) performance when joints were left unsealed. Several potential explanations were proposed for these findings. They included:

1. stress concentrations;
2. construction and maintenance; and
3. funneling water.

Truly sealed joints deteriorated and became partially sealed, and the partially sealed condition allowed incompressible material to enter at the sealant failure locations. Extreme stress concentrations could have been generated when the pavements experienced expansion, which could have resulted in significant concentrated forces at the locations of the incompressible materials in the joints. The various operations involved in the resealing process itself often caused some joint spalling. Resealing could also cause bumps at the joint locations which would adversely affect ride quality. Wide joint sealant reservoirs could also cause tire noise and affect ride quality. Finally, the situation where partially sealed joints resulted in a water funneling effect existed in some sections. This could allow more water to enter a joint than would occur with a narrow, unsealed joint.

In concluding, Shober suggested that research on PCC joint sealant must remain focused on the customers needs. The customers needs related to total pavement performance (distress, ride, life, materials), convenience and safety. The customers performance needs were not positively influenced by joint sealing of the test sections considered in the research, and thus joint sealing was not cost-effective for PCC pavements.

2.1.2 The Effect of Sealed vs. Unsealed Joints on the Performance of Jointed PCC Pavement – A Synthesis, K.H. Dunn, Wisconsin Department of Transportation, June, 1987.

Dunn, another Wisconsin DOT engineer, developed a synthesis on the same topic in 1987, entitled, “*The Effect of Sealed vs. Unsealed Joints on the Performance of Jointed PCC*

Pavement – A Synthesis." [2]. In the synthesis he reported that the majority of State Highway Departments did seal and re-seal joints in rigid pavements, and that very few actual evaluations of the true effectiveness of sealing or resealing had been conducted. The basic objective of the synthesis was to summarize the available information relative to joint sealing of rigid pavements. The synthesis included the following statement by Stratton Hicks, Deputy State Highway Engineer, Wisconsin Highway Commission, "we have some misgivings about the importance of sealing." The statement was made in a technical session at the annual Transportation Research Board (TRB) meeting in January 1967. Hicks provided the following five specific reasons for the misgivings:

1. The use of granular or stabilized bases has tended to reduce the pumping problem;
2. Random observations of pavement performance indicated a lack of correlation between pavement durability and the maintenance of joints sealed;
3. There is only a slight of success in maintaining a truly effective seal over an extended period of time;
4. There are cost and traffic hazards associated with the periodic renewal of joint seals; and
5. The locations where there are concentrations of blow-ups and spalling are not apparently related with the locations of the joint seals in poor condition.

The synthesis was simply a synthesis of practice and did not attempt to incorporate specific research results. However, based on the information compiled by Dunn to formulate the synthesis he suggested that several factors needed to be considered and evaluated as part of the process of making a policy decision on sealing or not sealing joints in PCC pavements. He suggested that the following nine factors be considered:

1. pavement slab design;

2. base type;
3. pavement subsurface drainage;
4. concrete properties;
5. sealant properties;
6. maintenance commitment to continued resealing as needed;
7. site-specific environment;
8. traffic loading; and finally
9. economics.

In concluding, Dunn summarized that although the majority of highway engineers believed the purported benefits of sealing joints in rigid pavements, the only documented evidence available concerning the possible realization of the longer or improved service attributed to sealing and resealing joints, were studies being conducted in Wisconsin. As described in the previous reference, the results of these studies have indicated that there was no statistical difference in the performance of PCC pavements regardless of whether joints were sealed or unsealed. In addition to providing information relative to the cost-effectiveness of joint sealing, this research provides useful information for the development of an experimental design for future studies.

2.1.3 *Joint Sealant Study, Interim Report*. Rutkowski, T.S. Report WI-02-90, Wisconsin Department of Transportation, May 1990.

In 1990, Rutkowski reported on another PCC joint sealant study that was commissioned in Wisconsin in 1983 [3]. The original objective of the study was to compare the pavement performance of sealed and unsealed joints in PCC pavements. The research encompassed the analysis of seventeen projects, eight of which had test sections with unsealed traverse joints. Four pavement distress measures were considered for pavement performance comparisons;

faulting, spalling, corner breaks and general cracking. The AASHTO present serviceability index (PSI) was also given consideration. Other distress types were initially considered, but had such low frequencies of occurrence that they will not be discussed.

Pavement performance data was collected for the project pavements for the period from 1975 to 1989. A statistical analysis was conducted using the thirteen years of performance data for each test section. The results of the analysis indicated that sealed or partially sealed transverse joints in PCC pavements did not provide for significantly better distress ratings than unsealed joints with regard to faulting, spalling, corner break and general cracking. Additionally, the PSI of the pavements with unsealed transverse joints was similar to that of pavements with sealed or partially sealed transverse joints over the observation period. Another finding of the study was that better pavement performance was not insured when an inspector continually monitored sealing operations.

The research resulted in the recommendation that WDOT cease to seal transverse joints in PCC pavement placed on dense-graded or open-graded base courses, since no obvious advantage was obtained when distress rates of sealed and unsealed test sections were considered.

2.1.4 *Performance Evaluation of Drained Pavement Structures*, Rutkowski, T.S., S.F. Shober, and R.B. Schmeidlin, Wisconsin Department of Transportation, December, 1998.

A performance evaluation of drained pavement structures was conducted by Rutkowski, Shober and Schmeidlin of WDOT in 1998 [4]. The research focused on positive drainage of pavement structures, but included provisions for assessment of cost-effectiveness of joint and crack sealing. The objectives of the study were to determine:

1. which drainage features had the greatest impact on pavement serviceability;

2. which drainage features were most effective in draining;
3. which drainage features were the most cost-effective; and
4. whether or not transverse joint sealing was effective.

Initially, five PCC surfaced projects were included in the study. During the course of the study, seven other projects were selected as the secondary projects. Three of the secondary projects were PCC, three were AC surfaced, and one project had both PCC and AC test sections. Test sections and control sections were developed within each project site in 1987 or 1988. The test sections were used to compare various formats of positive drainage features. The control sections contained no positive drainage elements. The pavement performance was monitored annually for ten years.

Four items were used to assess pavement performance influenced by drainage and to use in statistical performance analyses. They included; PDI (the combined distress index), faulting, ride quality as indicated by IRI, and the physical properties of cores taken at transverse joints. Statistical “paired t-tests” were conducted at the 95 percent confidence level on control and test section PDI, faulting and IRI data. Investigating the efficiency of joint sealing was one of the original study objectives. When the experimental designs were established, a redundant test section featuring sealed transverse joints was incorporated.

In this study, no statistical comparisons were performed on the pavements with sealed and unsealed joints. However, when the data results of PDI, faulting and IRI were ranked, the effect of sealed transverse joints did not appear to have noticeable effect or benefit in this study. The results of this study supported the conclusions of Shober’s earlier study [1], which stated that transverse joint sealing did not benefit pavement performance and therefore was not cost-effective.

The bulk of the literature that is non-supportive of joint sealing is relative to PCC pavements and all of the research was conducted by the WDOT.

2.2 Supporters of Sealing

2.2.1 Rout and Seal Cracks in Flexible Pavement-A Cost-effective Preventive Maintenance Procedure, G. J. Chong, Ontario Ministry of Transportation, December, 1989.

Chong performed a cost-effectiveness analysis of the “rout and seal” technique when applied to flexible pavement for the Ontario Ministry of Transportation (OMT) in 1988 [5]. The objectives of his research were to determine the:

1. appropriate definitions and standards for rout and seal operational specifications;
2. effectiveness of the treatment;
3. extension of pavement service life due to the treatment;
4. importance of timing of the treatment for cost-effectiveness; and
5. consequences of deferred treatment.

The experimental design employed in this research dictated that pavement sections selected for study represent three pavement age categories; less than 3 years, 4 to 6 years, and 7 to 9 years. Each age category had to have a minimum of two test sections. Each test section was divided into five subsections, each of which was 150 meters in length. The treatments applied to the five subsections were as follows: the middle one was left unsealed and used as a control, two subsections had a rout size of 40x10mm, and two subsections had a rout size of 19x19mm. When the test sections were set up a single crew with standardized equipment was employed to minimize installation variables.

A total of thirty-seven test subsections were established for the three different age categories. The distributions of test sections by pavement age and geographic regions are presented in Table 2.1 and Table 2.2, respectively.

Table 2-1 Distribution of test sections by age category

Age Category	Number of Subsections
1-3 years	10
4-6 years	13
7-9 years	14

Table 2-2 Distribution of test sections by region category

Geographic Region	Number of Subsections
Northern	6
Eastern	9
Central	2
Southwestern	20

Pavement condition surveys were conducted for each section using a standard survey form, which incorporated total length of transverse cracks, total length of longitudinal cracks, transverse crack cupping/lipping, crack spalling, and crack opening sealant bond failure. Roughness measurements were also made with a Mays Meter. Monitoring of the rout and seal test sections and their corresponding control sections was conducted between January and March for a three-year period from 1987 to 1989.

In this study, the value of “crack factor” was used to assess crack development. Crack factor was defined as the total linear length of transverse and longitudinal cracks on the pavement surface in meters divided by the total surface area of the pavement section in square meters. For the combination of transverse and longitudinal cracking, the performance monitoring data showed that crack development initiated in year one of the pavement service life and increased steadily until year six. Crack development then became static until the eleventh year, when the increase became quite dramatic. For transverse cracking alone, cracks developed fully in the first year of the pavement service life and remained quite static until the eleventh year, when a sharp increase began to take place.

Crack deterioration was assessed based on evaluation of deformation in the form of lipping or cupping. The monitoring data showed that the performance of the rout and seal cracks remained static with time, whereas the cracks in the control sections showed significant increase in lipping/cupping deterioration after three winters.

The author concluded that rout and seal treatment of cracks did not appear to have significant influence on crack development since there was no discernable difference in crack development between the sealed test sections and the unsealed control sections. The criteria used to determine crack deterioration was the degree of deformation at the transverse crack, known as either lipping or cupping. After three winters of service, it was shown that the unsealed control sections indicated a marked increase in the severity of lipping/cupping distress.

The study suggested that the rout and seal treatment would either stop or retard the deformation commonly known as lipping/cupping, which is detrimental to pavement serviceability and, therefore pavement service life. It also suggested that maximum cost-effectiveness was achieved when the initial rout and seal treatment was performed between the third and the fifth year of the pavement service life. Finally it suggested that deferred maintenance, particularly on transverse cracks, was not an acceptable engineering or economical option.

2.2.2 *Crack Sealing in Flexible Pavements: A Life-Cycle Cost Analysis*, J.E., Ponniah and F.J. Kennepohl, Transportation Research Record 1129, TRB, National Research Council, Washington, D.C., 1996.

In 1996, Ponniah and Kennepohl of the OMT conducted life-cycle cost analyses to determine the influence of crack sealing of pavement performance [6]. The objectives of this study were to develop an effective crack sealing procedure and to study the influence of crack sealing on pavement distress and performance. Specifically, the study targeted acquiring statistically based data that could be used for objective assessment of crack sealing benefits in extending pavement life. This was an extension of the previously discussed study. The experimental design, test site selection, and data collection used in this research were the same as were employed in the previous study, Reference [5].

Crack maps were developed for each test section each winter to assess crack growth. Statistical analysis confirmed that the rout and sealed sections, in general, performed better than the control sections. However, the data associate with some test sites indicated that crack sealing had no effect on crack growth. Further investigation revealed that the crack sealing treatment was effective only for pavements in certain conditions. In general, it was more effective for pavements in relatively good condition and less effective for pavements in relatively poor condition. For example, it was concluded that the performance of pavements with extensive cracking would not benefit from sealing.

On the basis of the field data obtained during the seven-year monitoring period performance curves were developed for both rout and sealed and control sections. The performance curves indicated that the crack treatment could extend pavement life by at least two years, depending on the original condition of the pavement, the environment it resides in, and the applied traffic volume. Further analysis confirmed that the observed difference in performance as measured by pavement condition index (PCI), was statistically significant.

For the life-cycle cost analyses (LCCA) conducted as part of this research, a mathematical model was developed and used to assess the loss in PCI due to both traffic and environment. The model predicts PCI at any given time in the pavement service life and is stated below.

$PCI_t = PCI_i - LT - LE$

where,

PCI_t = the PCI at any time t;

PCI_i = the initial PCI immediately after construction or rehabilitation;

LT = the loss due to traffic, expressed as a function of a number of equivalent single axle load applications; and

LE = the loss due to the environment, expressed as a function of time in year (t).

The model was calibrated using data collected over a twelve year period on several projects in Ontario with known performance histories. The calibrated model was used to estimate pavement service life after each major rehabilitation considered in the analysis period used for the LCCA.

Because the calibrated model could be employed to estimate pavement service life, different alternative rehabilitation and maintenance strategies could be economically evaluated. The present-worth cost of alternative strategies incorporating user delay costs and salvage value for remaining pavement service life at the end of the analysis period, as well as effectiveness (defined as the area under the performance curve) were used to determine the most cost-effective strategies. Figure 2.1 illustrates a comparison of two alternatives. The PCI curves indicated in the figure were predicted using the project developed PCI performance model. The area between the PCI curves and the axes of the charts was termed the “effectiveness.”

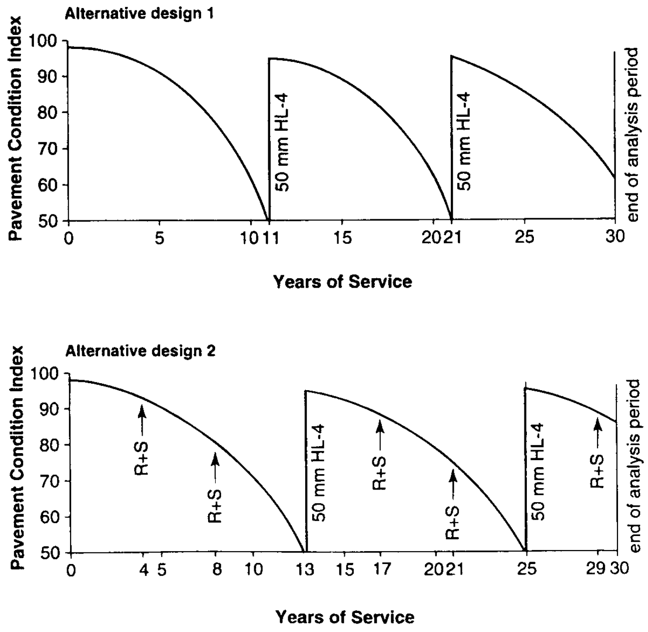

Figure 2-1 Two Alternative PCI Curves

The authors concluded that routing and sealing cracks could minimize secondary crack growth and increase service life by at least two years based on these types of analyses. The LCCA indicated that the rout and seal treatment was a cost-effective pavement maintenance procedure.**2.2.3 *Evaluation of Asphaltic Concrete Crack Sealing,* T.S. Rutkowski, WI-08-96, Wisconsin Department of Transportation, January 1998.**

Rutkowski of WDOT conducted a study in 1998 with the objective of determining the effect of crack sealing and crack filling of hot mix asphalt (HMA) pavements on overall pavement performance [7]. He defined crack sealing as crack routing and sealing. He defined crack filling as sealing without routing. Three test projects, each with six or seven test sections, were included in the study. The projects consisted of different pavement structural sections. Pavement performance parameters used in analyses included Pavement Distress Index (PDI), a combined distress index and the AASHTO Present Serviceability Index (PSI). The statistical paired-t test was used to determine if there was a qualitative benefit to either PDI or PSI as a result of crack filling or sealing. Additionally, the WDOT Customer Service Index (CSI) was used to determine if there was a cost benefit associated with crack filling or sealing relative to the PSI.

Pavement performance data was collected on one control (unsealed) section and multiple test sections at each project over a six-year period from 1987 to 1993. PSI was surveyed in both summer and winter. PDI was surveyed annually, usually in the summer. Statistical “paired t-tests“ were performed at the 95 percent confidence level for both PSI and PDI to compare the data from the control section and test sections. The PSI was used as a tool to evaluate all pavement types and treatments for the purpose of assessing the quality of customer service.

The study concluded that crack filling and sealing in general rather than a specific sealant or filler provided the measured benefits. Crack filling and sealing appeared to have a beneficial effect on both AC overlay on existing AC pavement as well as for AC overlay on PCC pavement. Rutkowski recommended that crack filling/sealing be considered as a means of benefiting ride quality (PSI) rather than to mitigate pavement distress (PDI), as crack filling/sealing could improve the ride quality of a pavement which PSI is very sensitive to.

In this study, there were no useable comparison parameters to compare project PDI histories and determine whether the severity or extent of pavement distress influenced the need for crack filling/sealing. Additionally, due to limited data, no analysis was performed to determine the effects of base thickness and/or subgrade quality on crack development or pavement performance.

2.2.4 *Bituminous Crack Filling Test Section on US-10 Near Evart*, M.J. Eacher, and A.R. Bennett, Michigan Department of Transportation, April, 1998.

Eacher and Bennett of the Michigan Department of Transportation (MDOT) conducted a study on bituminous crack filling in 1998 [8]. The purpose of the study was to have side by side comparisons of several different filler materials used for bituminous pavements at a single location. The study primarily focused on the effect of filler materials on performance, but it incorporated a control (unsealed) section also. Twenty-one test sections involving nine materials with different additives were placed in May 1995. The different test sections were visually rated by several different groups. The properties considered in the rating included: bridging, abrasion, adhesion/cohesion loss, bleeding and tracking. They were rated on a scale of 1 to 5 with 5 being the best. Ratings were conducted one, three, seven, eleven, fifteen, and twenty-four months after the test sections were placed.

Based on the pavement condition of the test sections after two years, it was concluded that several of the materials could slow the deterioration of the cracks, since the sections sealed with these materials showed less crack deterioration than the untreated section. It was estimated that these materials could add 3-5 years to the life of the pavement. The study also showed that the performance of pavements sealed with different materials were significantly different.

Because the findings of this research are based on several test sections on a single pavement monitored over a short time period, they should be viewed cautiously.

2.2.5 *Pavement Treatment Effectiveness, 1995 SPS-3 and SPS-4 Site Evaluation*, National Report D.A Morian, J. A. Epps, S.D. Gibson, Nichols Consulting Engineers, May 1997.

In 1997, Morian and Epps concluded an evaluation of the Long Term Pavement

Performance (LTPP) Special Pavement Studies-3 (SPS-3) and SPS-4 sites which included various maintenance treatments including crack sealing [9]. The objectives of this study were to define the most effective timing for the application of various treatments and to evaluate the effectiveness of treatments in prolonging the life of the pavement. The project report presented an evaluation of the performance of LTPP SPS-3 (flexible pavement) and SPS-4 (rigid pavement) experiment sites based on field reviews after 5 years of service. The flexible pavement preventive maintenance treatments studied included; cracking sealing, slurry seals, chip seals and thin hot-mix asphalt overlay. The PCC surfaced pavement preventive maintenance treatments studied included joint/crack sealing and undersealing.

The field experiment was designed in 1987 by the Texas Transportation Institute (TTI) to evaluate the effectiveness of various preventive maintenance treatments. The main variables in the experimental design for asphalt pavements were climate, subgrade type, traffic volume, and treatment type. A total of 96 test sites were considered for the asphalt pavement preventive maintenance study. The main variables in the experimental design for the PCC pavements were climate, base type, pavement type and treatment type. A total of 24 test sites were considered for the PCC preventive maintenance study. The performance of each of the SPS-3 and SPS-4 sites was being evaluated under the LTPP program and by an Expert Task Group (ETG) for each LTPP region. The LTPP program determined the condition of the pavement before the preventive maintenance treatment was applied and at regular intervals after the treatment was applied. The evaluation tools used as part of the LTPP effort included the following:

1. Visual condition using the SHRP distress identification manual;
2. Photo log using the PASCO, USA device;

3. Deflection using the falling-weight deflectometer;
4. Ride quality using the K. J. Law-type profilometer;
5. Rut depth using the "dip stick" and PASCO data; and
6. Friction number as collected and submitted to LTPP by individual States.

Observed data for HMA crack seal treatments in terms of pre-treatment condition, climate region, and predicted performance life were evaluated. The treatment was observed in this study to have slowed the rate of pavement deterioration in several cases. The crack seal treatment was effective in the wet-freeze environmental zone. The wet-no freeze region also experienced good performance from the crack seal treatment using an overband technique, but the crack seal treatment did not perform well in the dry regions of the country.

Based on the limited number of PCC sites reviewed, the study found that unsealed joints in the control sections contained significantly more debris than sealed joint sections and unsealed joint sections had significantly more joint spalling than the sealed joint sections.

In this study, only five years of performance data were statistically analyzed. The author stated more time might be required to obtain meaningful results for the PCC sections.

2.2.6 *Energy Saving from Increased Preventive Maintenance on Indiana highways*. E.A. Sharaf and K.C. Sinha, Transportation Research Record 1102, TRB, National Research Council, Washington, D.C., 1986.

In 1986, Sharf and Sinha investigated the trade-off relations between two routine pavement maintenance activities used in Indiana, namely, patching (corrective maintenance) and sealing (preventive maintenance) [10]. In this study several cost models were developed. For model development purposes, the two highway systems (interstate and other) were subdivided by climatic zones (north and south) and pavement types (flexible, rigid and resurfaced). Data were collected and analyzed for a total of eight hundred twenty pavement sections. For each section, four major groups of information were summarized: traffic (AADT, % trucks and ESAL), pavement characteristics (type, layer thickness and age), climatic zone (snowfall rainfall, temperature difference, and etc), and pavement maintenance records (total production units, total man-hours, and type and quantities of materials). Pavement maintenance information was summarized for each highway by activity and fiscal year.

Three different prediction models; a total routine pavement maintenance cost model, a patching maintenance cost model, and a sealing maintenance model, were developed with this historical data routinely collected by the Indiana Department of Highways (InDOT). The cost savings in routine pavement maintenance in terms of direct fuel consumption could be assessed by one application of those models.

The authors concluded that if more sealing is done prior to winter, less pavement repair is required in the spring and summer. Moreover, a direct cost savings of reduced fuel consumption could be achieved by increasing the level of sealing activity.

With the trade-off relationships between routine pavement maintenance activities, the savings in fuel used in pavement maintenance in Indiana were estimated. However, the different impact on pavement performance by different maintenance activities and the different costs of different activities were not considered in this study.

2.2.7 ***Improved Preventive Maintenance: Sealing Cracks in Flexible Pavements in Cold Regions*. Chong, G.J. and W.A. Phang, Transportation Research Record 1205, TRB, National Research Council, Washington, D.C., 1988.**

In 1988, Chong and Phang stated that during the early 1970s, the OMT began to seal cracks using the rout and seal program to minimize the effects of cracking, particularly lipping and cupping of transverse joints on pavement roughness [11]. At the same time, the

Ministry sought to improve the rout and seal technique and identify sealant materials that provided better performance. A study was conducted to address these issues.

The authors stated that at that time the majority of asphalt pavement mileage with untreated transverse cracks were developing either lipping or cupping deformations at the cracks. These deformations were costly to redress under the rehabilitation program, and simply resurfacing with hot-mix asphalt only perpetuated the cycle of reflective cracking and subsequent lipping or cupping. The authors further stated that not sealing cracks could result in:

1. Increased maintenance costs because deteriorated cracks were difficult and expensive to repair through corrective maintenance;
2. Increased user costs (vehicle repair and operation);
3. Increased rehabilitation costs, because deteriorated cracks demanded special treatment from the designer when pavement rehabilitation was scheduled; and
4. Loss of serviceability and, therefore, service life.

A study initiated by the Ottawa District Maintenance Office of OMT in 1981 was summarized in this report. The study included several rout and seal sections as well as a control section. In 1985, an investigation was made on the deferred maintenance control unsealed section and one of the rout and seal study sections, which were adjacent to each other. The study concluded that the rout and seal treatment of transverse cracks effectively retarded internal and external pavement deterioration. It also suggested that the rout and seal treatment of transverse cracks effectively retarded the progression of cupping deformations. Finally, the comparison of the treatment sections with the control section indicated that the rout and seal treatment of transverse cracks could extend the serviceability of the pavement by at least four years.

2.2.8 *Joint Seal Practices in the United States Observation and Consideration*, D.A. Morian and S. Stoffels, Transportation Research Record 1627, TRB, National Research Council, Washington, D.C., 1998.

In a 1998 TRB publication entitled “Joint Seal Practices in the United States – Observations and Considerations,” Morian and Stoffels summarized joint sealing practices for jointed rigid pavements that have developed throughout the country based on local experience [12]. The authors stated that although the LTPP SPS-4 sections (rigid pavements) had only been in service for five years, which was not long enough to truly see the benefits of the maintenance treatments on the pavement life, early findings indicated that joint-seal sections were performing better than unsealed sections.

It was stated that a misconception of some agencies is the belief that the entrance of both water and incompressibles into joints could be reduced by the use of a single sawcut, rather than joint sealing, without constructing a sealant reservoir. Further the authors stated that, in the Shober study [1], insufficient performance history was provided to substantiate his conclusion that the performance of sealed and unsealed joint sections was indeed equivalent. His conclusions were drawn based on analysis of test section with less than ten years of performance history available for evaluation. However, numerous examples of rigid pavements with early failures, including material-related, load-transfer and slab-erosion problems, were available to confirm that 10 years is often too short a performance period to identify problems with rigid pavements. The authors stated that no comprehensive field tests thoroughly evaluating joint sealing of rigid pavements in terms of pavement performance in an appropriate manner over a significant period of time existed.

2.3 Others

2.3.1 Evaluation of Crack Sealing Performance on Indiana's Asphalt Concrete Surfaced Pavements, D. R. Ward, Indiana Department of Transportation. October, 1993.

Ward of the InDOT reported on the evaluation of crack sealant performance on Indiana's pavements in 1993 [13]. The objective of his study was to determine the most economical and effective sealing materials for routine transverse crack sealing applications in Indiana. He performed comparison tests of the typical sealing materials used in Indiana at that time (AE90) with eleven other sealants. All sealants were applied on a typical asphalt concrete surfaced pavement (US-52 seven miles north of West Lafayette), and their performance was observed over a three year period. Success Rate (SR), was the basis of comparison among and between different sealants, cleaning techniques, and application methods. The study stated that there were significant differences in the performance among sealant/treatment combinations, and routing appeared to improve the performance of most of the sealants. This study did not determine the cost-effectiveness relative to pavement performance.

2.3.2 *Value Engineering Study of Crack and Joint Sealing*, Blais, E.J., FHWA-TS-84-221, Federal Highway Administration, December, 1984.

Blais summarized the results of a cooperative value engineering study of crack and joint sealing undertaken by the Delaware, Georgia, Montana, Tennessee, and Utah DOTs under the sponsorship of the FHWA [14]. The objective of the study was to optimize the expenditures of maintenance resources through a study of crack and joint sealing materials and placement techniques. In this study, there was no evaluation of the cost benefits of sealing versus not sealing. However, the study members felt that sealing was necessary and believed that many referenced papers, as well as several other studies, had properly addressed the needs for sealing cracks and joints as a preventative maintenance activity. The study also stated that, before sealing, a crack analysis was necessary to determine if crack sealing was effective. The study suggested that climatic conditions varying across the country could greatly affect material placement, but if pavement conditions were dry, a good bond could be formed regardless of the season. The title of this study was obviously misleading.

2.3.3 Cost – Effectiveness of Crack Sealing Materials and Techniques for Asphalt Pavements, R.B. Freeman and D. Johnson, Montana State University, February, 1999.

The cost–effectiveness of crack sealing materials and techniques for asphalt pavements was evaluated by Reed and David in 1999 [15]. The objective of this research was to determine the most economical and effective materials and methods for sealing cracks in flexible pavements in the state of Montana. Four experiment test section sites were selected for study as part of this project. Two test sites each included a control section, where cracks were left unsealed. Eleven sealant materials supplied by four different vendors and six sealing techniques were considered in the investigation.

Both transverse and longitudinal cracks were evaluated at all test sites over a two year period. During evaluation, material failures and superficial sealant distress were measured and recorded. After two years of performance monitoring of the test sites, the study stated routing transverse cracks improved the performance of sealants, but routing did not appear to be necessary for longitudinal cracks. The author stated that cracks in control sections were in good condition, but that no analysis or conclusions were made for the control section pavement performance.

2.3.4 Techniques for Pavement Rehabilitation - Reference Manual (Six Edition), Federal Highway Administration, FHWA HI-98-033, August, 1998.

The FHWA "*Techniques for Pavement Rehabilitation Reference Manual*" states that in flexible pavements, non-sealed or poorly sealed joints allow moisture and debris to enter the pavement structures contributing to asphalt stripping, secondary cracking, cupping and lipping at transverse joints, and spalling [16]. The manual includes a section entitled, “Limitations and Effectiveness” in which it is stated, “In the past, the effectiveness of joint sealing has been questioned by some agencies. For example one agency contends that the purported benefits derived from joint sealing do not offset the costs of sealing and resealing operations. While this debate might never be completely resolved, those efforts should go a long way toward identifying whether sealing activities were effective and under what conditions they should be applied. Nonetheless, the overwhelming majority of States’ experiences support the contention that sealing cracks and resealing joints was a meaningful rehabilitation activity.”

3. Survey of Practice

With the objective of obtaining better knowledge of the current joint/sealing sealing practices in the US, a survey regarding joint/crack sealing was conducted by Galal and Ward of InDOT in June, 1999. All 50 States in the US were polled in June, 1999. The survey included eleven questionnaire on joint/crack sealing, which are shown in Appendix A. The eleven concise questions resulted in quick responses from 42 of 50 States. California, Connecticut, Idaho, Kentucky, Massachusetts, Ohio, Tennessee and West Virginia did not respond. The eight states that did not respond to the survey were considered as the no-response group in the survey statistical analysis. A summary of survey results is presented in Appendix B. The statistical analysis of the responses to each of the eleven questions are shown in the following subjects in the form of pie charts and tabulated answers.

3.1 Question 1: "Do you seal concrete pavements?"

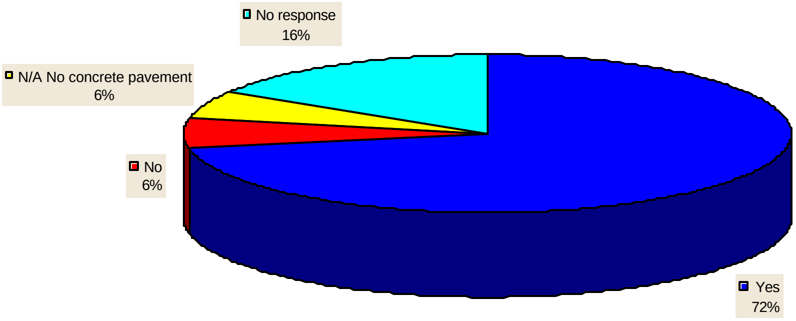

Figure 3-1 Responses to Question 1

Table 3-1 Summary Responses to Question 1

Response	Number of States Responding
Yes	36
No	3
N/A No concrete pavement	3
No response	8

As shown in Figure 3-1 and Table 3-1, almost three-fourths of the states surveyed seal concrete pavements. The responses of the states to question 1 coincide with the common belief that joint sealing will extend pavement life or improve pavement performance. Only three states surveyed, Alaska, Hawaii, and Wisconsin, do not seal concrete pavements. However, only Wisconsin stated the reason for not seal, which because sealing is not cost-effective.

3.2 Question 2: "How wide is your saw cut for joints on new concrete pavements (transverse)?"

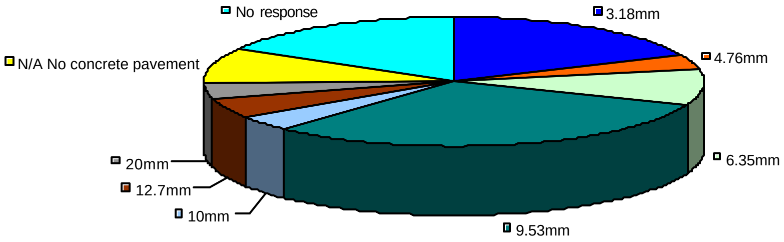

Figure 3-2 Responses to Question 2

Table 3-2 Summary Respnses to Question 2

Response	Number of States Responding
3.18mm	10
4.76mm	2
6.35mm	5
9.53mm	17
10mm	2
12.7mm	3
20mm	2
N/A No concrete pavement	5
No response	9

As shown in Figure 3-2 and Table 3-2, thirty-one percent of surveyed states specify transverse joint widths less than or equal to 6.35mm. An additional thirty-one percent employ 9.5 mm joint widths. Thirteen percent specify joint widths greater than 10mm. Wide saw cut joints(>10mm) are not commonly applied in US.

3.3 Question 2b: "How wide is your saw cut for joints on new concrete pavements? (longitudinal)"

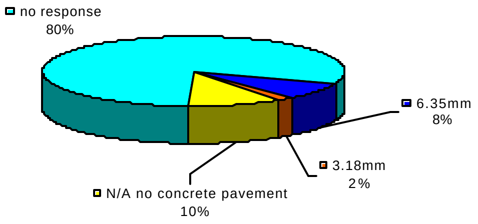

Figure 3-3 Responses to Question 2b

Table 3-3 Summary Responses to Question 2b

Response	Number of States Responding
6.35mm	4
3.18mm	1
N/A no concrete pavement	5
no response	40

Figure 3-3 and Table 3-3 show that eight percent of the states surveyed specify a longitudinal joint width of 6.35mm. Two percent specify 3.18mm joint width. Unfortunately, eighty percent of the states did not respond the question. Therefore, it is nor possible to any meaningful conclusions from the responses obtained.

3.4 Question 3: “Do you reseal older concrete pavements?

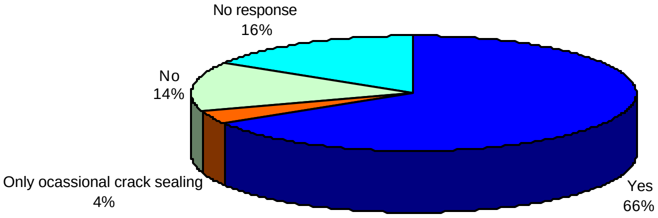

Figure 3-4 Responses to Question 3

Table 3-4 Summary Responses to Question 3

Response	Number of States Responding
Yes	33
No	7
N/A	2
No response	8

As Shown in Figure 3-4 and Table 3-4, more than half of states surveyed reseal older concrete pavements. Fourteen percent of the states surveyed do not seal joints in older concrete pavements. This is significantly higher than the percentage of the states that do not seal on new pavements. It indicates that some states believe resealing older pavements may not provide benefit or be as cost-effective as sealing new pavements.

3.5 Question 4: “Do you reseal bituminous pavements?”

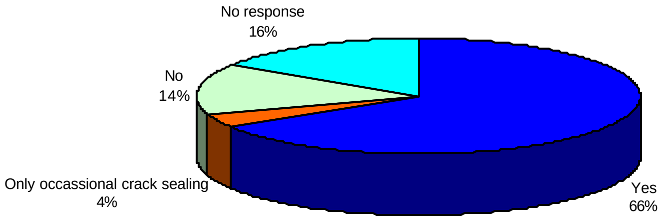

Figure 3-5 Responses to Question 4

Table 3-5 Summary Responses to Question 4

Response	Number of States Responding
Yes	33
Only occasional crack sealing	2
No	7
No response	8

Figure 3-5 and Figure 3-5 indicate that more than half of the states surveyed reseal older bituminous pavements, but fourteen percent of the states surveyed do not reseal. It suggests that some states do not believe that resealing the bituminous pavement is cost- effectiveness.

3.6 Question 5: "How was the decision made to conduct joint or crack sealing?"

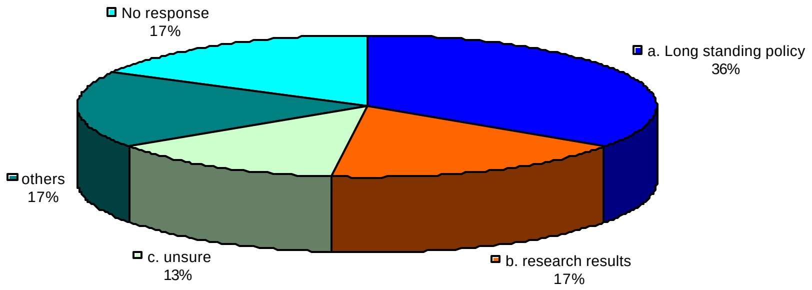

Figure 3-6 Responses to Question 5

Table 3-6 Summary Responses to Question 5

Response	Number of States Responding
a. Long standing policy	18
b. research results	9
c. unsure	7
Others	9
No response	9

As shown in Figure 3-6 and Table 3-6, nearly half of states surveyed declared that their decisions to conduct joint/crack sealing are based on long standing policy or they were unsure of the reason for sealing. Only seventeen percent of the states surveyed declared that their decisions were based on research, which included both supporters and non-supporters of sealing. The responses suggest that many states have not justified the benefit or cost-effectiveness of joint/crack sealing.

3.7 Question 6: "Do you install subsurface drains on new pavements?"

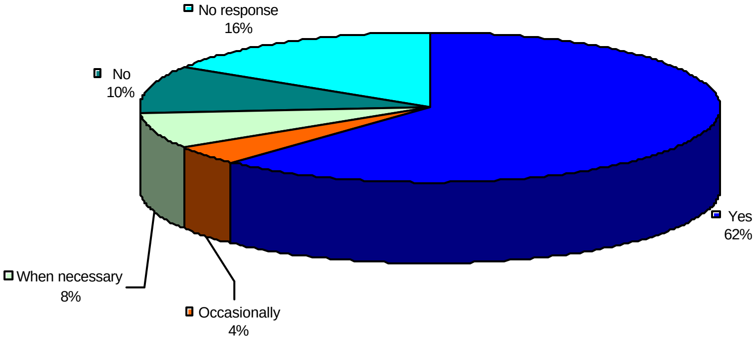

Figure 3-7 Responses to Question 6

Table 3-7 Summary Responses to Question 6

Response	Number of States Responding
Yes	31
Occasionally	2
When necessary	4
No	5
No response	8

The data presented in Figure 3-7 and Table 3-7 that more than sixty percent of the states surveyed install subsurface drainage on new pavements, and more than ten percent of the states install subsurface drains occasionally or when necessary. The results indicate that most of states believe the important subsurface drainage is important to pavement performance. Further research may be needed to investigate the function and cost-effectiveness of installing drainage.

3.8 Question 7: "Has your DOT studied the effect of joint and crack sealing with regard to the impact it has on the performance of your concrete, asphalt or composite pavements?"

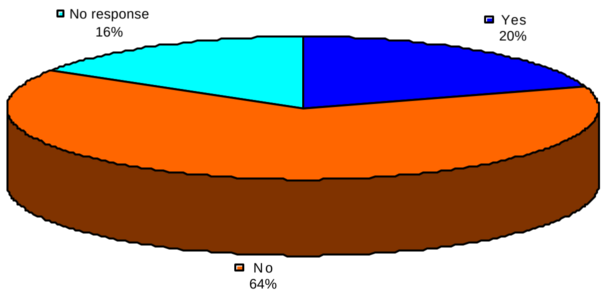

Figure 3-8 Responses to Question 7

Table 3-8 Summary Responses to Question

Response	Number of States Responds
Yes	10
No	32
No response	8

As shown in Figure 3-8 and Table 3-8, more than sixty of the states surveyed have not studied the effect of joint and crack sealing on the performance of your concrete, asphalt or composite pavements. Only twenty percent of the states surveyed have studied the effect. These results coincide with the result of question 5 that most states surveyed declared that their decisions on conducting joint/crack sealing are based on long standing policy or they are unsure of the reason for sealing.

3.9 Question 8a: "Does your DOT plan on investigating the cost-effectiveness of joint/crack sealing in the near future?"

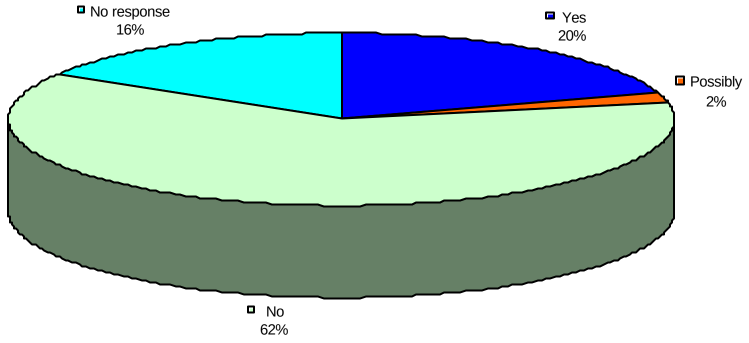

Figure 3-9 Responses to Question 8a

Table 3-9 Summary Responses to Question 8a

Response	Number of States Responding
Yes	10
Possibly	1
No	31
No response	8

Figure 3-9 and Table 3-9 show that more than sixty percent of the states surveyed do not plan on investigating the cost-effectiveness of joint/crack sealing in the near future. However, twenty percent do plan to investigate it. This suggests that the states do question the cost-effectiveness of joint/crack sealing. Whether or not the states were aware of the recent WDOT finding is unclear.

3. 10 Question 8b "If your DOT is planning on investigating the cost of joint/crack sealing in the near future, how?"

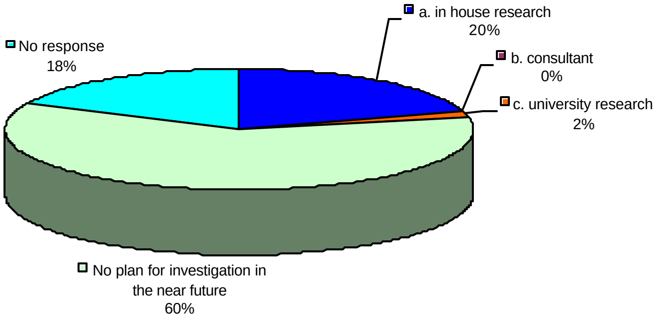

Figure 3-10 Responses to Question 8b

Table 3-10 Summary Responses to Question 8b.

Response	Number of States Responding
a. in house research	10
b. consultant	0
c. university research	1
No plan for investigation in the near future	30
No response	9

As indicated in Figure 3-10 and Table 3-10, sixty percent of the states surveyed do not plan on investigating the issue in the near future. However, twenty-two percent of the states suggest that they are planning on researching the issue on the near future. This indicates some states believe it is necessary to justify the benefits or cost effectiveness of their current sealing policies. Twenty percent plan to conduct in house research.

3.11 Question 9: "How do you define traffic level in terms of ESALs and/or truck count/truck factor?"

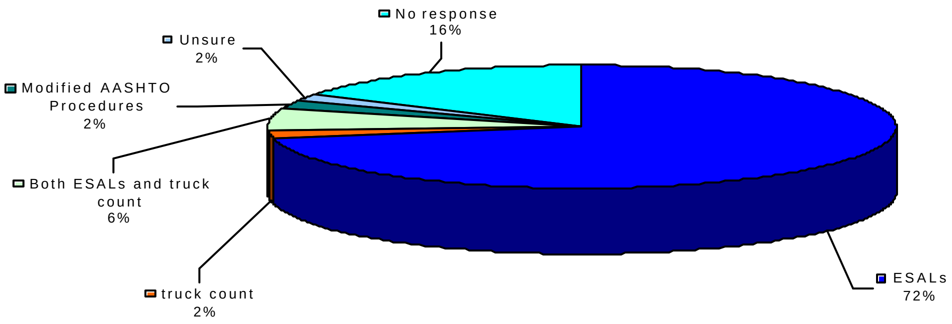

Figure 3-11 Responses to Question 9

Table 3-11 Summary Responses to Question 9

Response	Number of States Responding
ESALs	36
truck count	1
Both ESALs and truck count	3
Modified AASHTO Procedures	1
Unsure	1
No response	8

Figure 3-11 and Table 3-11 show that seventy percent of the states surveyed define traffic level in terms of ESAL. ESAL is commonly accepted as the standard traffic load definition for most states in US.

3.12 Question 10a: “Do you have criteria defining thick and thin pavements?”

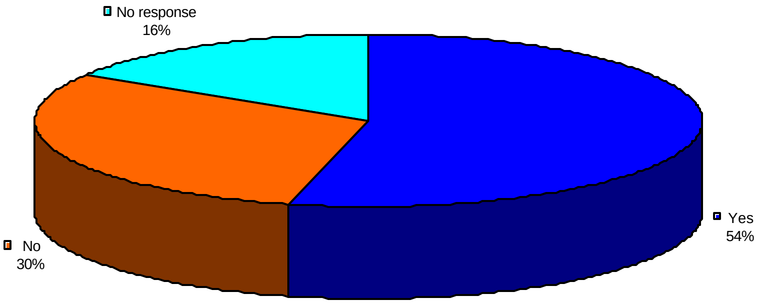

Figure 3-12 Responses to Question 10a

Table 3-12 Summary Responses to Question 10a

Response	Number of States Responding
Yes	27
No	15
No response	8

Figure 3-12 and Table 3-12 show that more than half of states surveyed have criteria defining thick and thin pavements. The criteria varied from state to state however.

3.13 Question 11a: "Do you have FWD criteria that define performing joints or cracks?"

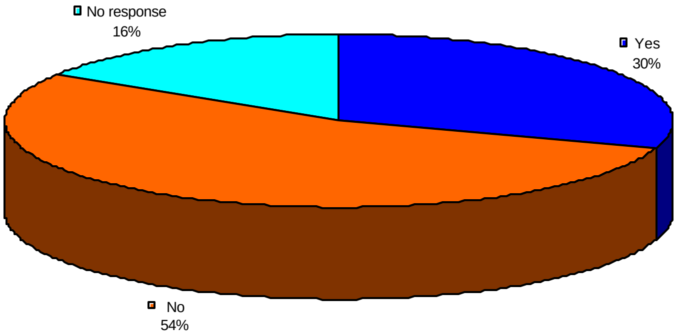

Figure 3-13 Responses to Question 11a

Table 3-13 Summary Responses to Question 11a

Response	Number of States Responding
Yes	15
No	27
No response	8

As shown in Figure 3-13 and Table 3-13, more than half of states surveyed do not have criteria defining performing joints or cracks. The FWD equipment is available to InDOT. The thirty percent that do have criteria use joint or load transfer efficiency criteria.

4. Conclusions Based on Literature Review and Survey of Practice

The objectives of sealing and resealing of joints and cracks in both PCC and AC pavements are to reduce the amount of moisture infiltration, and to prevent the intrusion of incompressibles into the joints and cracks. It has been a widespread belief that this will extend pavement life or improve serviceability and therefore will be cost effective. Since the common belief was challenged by Wisconsin DOT in the early 1950's, there has been growing pressure within highway maintenance agencies for further studies to determine if various construction and maintenance activities can be justified in terms of cost. A decision was made by InDOT to review all available literature and to contact individuals with regard to cost effectiveness issues as a first step, and then to determine whether it is necessary to conduct further research on the cost effectiveness of the joint/crack sealing on Indiana highways.

4.1 Summary of Literature Review and Practice Survey

Of over one hundred potential references reviewed in this study, only eighteen specifically discussed cost-effectiveness of joint/crack sealing, and of these only four provided useful quantitative information related to the cost-effectiveness of joint/crack sealing. Individuals who are recognized experts were also contacted and asked to comment on the merits of the proposed research. However, all these efforts revealed a little quantitative evidence to prove the cost-effectiveness of joint/crack sealing. Furthermore, some discrepancies exist among different research results. For example, Shober [1] concluded from his study that total pavement performance was not positively affected by joint sealing, and joint sealing was not cost-effective for PCC pavements. This conclusion was also supported by two other research efforts conducted in Wisconsin. However, the LTPP SPS-4 test section data analyzed by Morian and Epps [9] showed that test sections with unsealed joints showed more joint deterioration than sections with sealed joints. In addition to discrepancies in the literature, some ambiguous statements regarding joint sealing were identified. For instance, Morian and Stoffel [12] stated that after Wisconsin, California and Arizona are two other states having adopted a “no seal” rigid pavement joint policy. However, when those state DOTs were contacted by the authors of the current study via telephone, the use of a “no-seal” policy could not be verified. No publications regarding the issue from California or Arizona could be obtained. Morian and Stoffel also suggested that the relatively short span of available pavement performance associated with the Shober study was insufficient to support his conclusions.

With regard to crack sealing of flexible pavements, most available literature seems to support the idea that cracking sealing will retard the deterioration of cracks, which is detrimental to pavement serviceability and therefore extend pavement service life. However, the cost effectiveness of crack sealing in terms of pavement performance is not substantiated by a preponderance of evidence. Additionally, the review of flexible pavement crack sealing performance on LTPP SPS projects suggest that it is effective in specific climates. There are only some superficial suggestions and comments on the cost effectiveness of crack sealing on flexible pavements. For example, the FHWA Techniques for Pavement Rehabilitation Manual [16] suggests that crack sealing is most effective when conducted on pavements exhibiting little structural deterioration. However, flexible pavements displaying extensive alligator cracking or severe crack deterioration should not be treated by crack sealing. Chong

[5] also concluded that deferred maintenance particularly on transverse cracks was not an acceptable engineering or economical option.

In the literature review, it was found that only two studies ([10] and [13]) relative to joint/crack sealing have been carried out in the State of Indiana. One of studies, Sinha [10], showed that when more crack sealing was performed in the Fall, less patching was required after that Winter. Ward [13] in another study, concluded that there were significant differences in the performance of sealant/treatment combinations, and routing appeared to improve the performance of most of the sealants. However, neither of these two studies nor any other available research considered the overall pavement performance as influenced by sealing and the cost effectiveness for joint/crack sealing in Indiana. InDOT’s joint/crack sealing policy is based on long standing policy and there is not any available research to justify the policy. However, according to the survey of practice, InDOT’s policy is consistent with that of sixty-two percent of the states surveyed.

The statistical results of the survey show that seventy-two percent of the states seal concrete pavements. Sixty-six percent reseal both PCC and HMA pavements. However, only seventeen percent of the states surveyed declared that joint/crack sealing policy decision was based on research results, and almost fifty percent declared that their decision was based on long standing policy or they were not sure of the reasons for sealing. The results illustrate that most of states do not have quantitative justification for sealing policies nor do they know the cost-effectiveness of the operations.

4.2 Recommendations Based on Literature Review and Survey of Practice

Even though the State of Wisconsin has adopted the “no-seal” policy based on research results, it is apparent that different climatic, subgrade, and drainage conditions may all have effects on the performance of pavements with and without sealed joints and cracks. Furthermore, there are even some controversial and ambiguous research results in literature regarding the cost-effectiveness of joint/cracking sealing both flexible and rigid pavements. Therefore it would be inappropriate for InDOT or any other states for that matter to simply adopt a "no seal" policy. However, without sound research to justify current sealing practices, they too can be questioned. InDOT currently spends approximately four million dollars annually to accomplish crack and joint sealing, but unfortunately, it is realized that there is no any quantitative evidence to justify this expenditure. Further research is strongly recommended to investigate the cost-effectiveness of joint/crack sealing in relation to pavement performance in Indiana. Research results would then formulated into a set of guidelines for InDOT implementation by maintenance and design personnel. The potential savings associated with this research could very well amount to a significant portion of the four million dollars now spent annually on joint and crack sealing by InDOT.

The following recommendations are made based on this study:

1. Further research is strongly suggested to investigate the cost-effectiveness of joint/crack sealing in relation to pavement performance in Indiana via field studies;
2. Overall pavement performance, as influenced by sealing, and the cost effectiveness of joint/crack sealing would be the focus of the suggested future research.
3. A two to three year field study incorporating pavement representing a large range in age should be considered;
4. Pavement type, thickness, base type, pavement drainage, site-specific environment and traffic loading conditions should be considered as factors in the experiment design; and

5. Highway agencies and researchers should be contacted to request input on the experimental design.

5. Experimental Design

The literature review revealed that there is a lack of quantitative evidence to establish the cost-effectiveness of joint/crack sealing, and furthermore, some discrepancies existed among research results. The statistical analysis of the survey of practice also showed that most of states, including Indiana, did not have quantitative justification for sealing policies nor did they know the cost-effectiveness of the operations. Hence, a field study is needed to determine whether joint/crack sealing is cost-effective relative to pavement performance in Indiana. The design of a field experiment is presented in this section, the objective of which is to provide adequate evidence to answer the age old question of whether joint/crack sealing is cost effective.

The greatest challenge associated with the experimental design revolved around the fact that pavement lives typically range from ten to thirty or more years and for all practical purposes a field experiment with a maximum duration of twenty to twenty-four months for field data collection was permitted. Therefore, the need to obtain representative pavement performance data representative of extended time periods needed to be obtained in a twenty to twenty-four month period. The twenty to twenty-four month field data collection period allows for the collection of performance data through two each Spring and Fall seasons if the data collection is initiated in Spring. The proposed experimental design overcomes this challenge through the selection of field sites that represent similar pavement types, but of differing ages. The reality is that even though pavement lives may range from ten to thirty or more years, joint and crack seals typically have much shorter lives. Therefore, pavement performance data over a large portion of typical joint and crack seal lives is actually what is needed. The methodology proposed to capture this data is illustrated in Figure 5-1, with present serviceability index (PSI) used as an example measure of pavement performance.

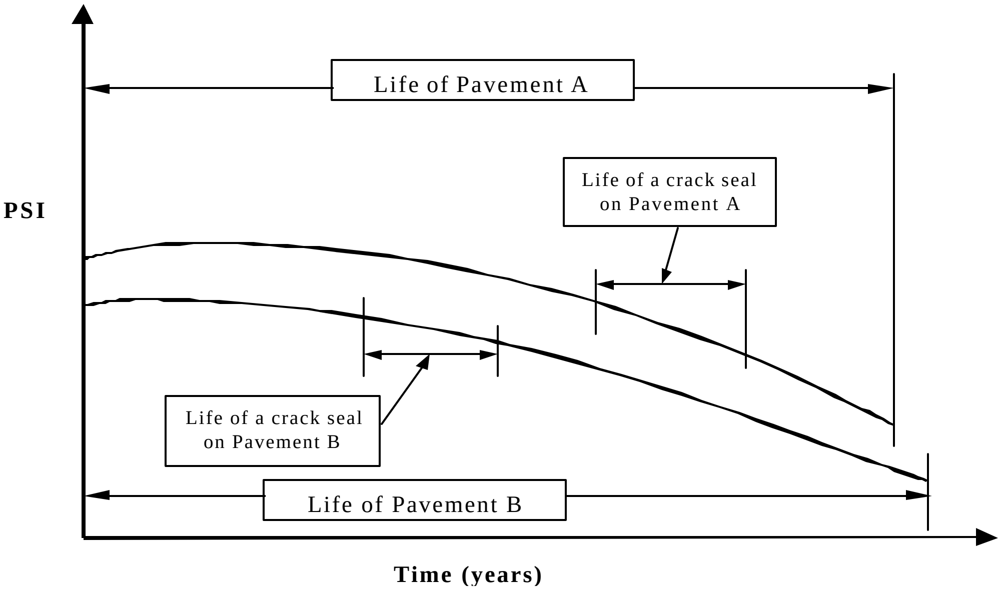

Figure 5-1 Pavement Life, Seal Life, Age Concepts of Experimental Design

Typical lives of a particular pavement type, for example a composite pavement (asphalt overlay on concrete), are depicted in the figure (Life of Pavement A and Life of Pavement B). The lives of crack seals applied to that pavement type are also depicted (Pavement A and Pavement B crack seal lives). It is important to understand that the depicted crack seal lives would be associated with different pavement sections or physical locations (Pavement A and Pavement B). The obvious reason for this is that the allowable duration for field data collection must be limited to a maximum of twenty-four months. Using this technique, performance data may be obtained from different pavement sections with similar composition and pooled for statistical analysis. It must be noted that the performance data will be rigorously analyzed after the two year performance monitoring period to ensure adequate data exists to meet the project objectives. Based on this analysis, a determination will be made as to the need to collect another years worth of performance data.

5.1 Preliminary Experiment Design

A preliminary experimental design, summarized in Table 5-1, was presented in the original project proposal. The design was developed through a series of meeting with pavement technologists and a statistician. Recognize that at that point in time, the rigorous literature search/review and survey of practice, presented in Sections 2 and 3 respectively of this report, had not yet been conducted.

Table 5-1 Preliminary Experiment Design

Climate	Traffic	Pavement Thickness	New Pavement				Existing Pavement					
			Concrete		Asphalt		Concrete		Asphalt		Composite	
			Drainage				Drainage					
			Yes	No	Yes	No	Yes	No	Yes	No	Yes	No
North	High	Thick	**1**	▨	**5**	▨	▨	**9**	**13**	▨	▨	**17**
	Med		**2**	▨	**6**	▨	▨	**10**	**14**	▨	▨	**18**
	Low		▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
	High	Thin	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
	Med		**3**	▨	**7**	▨	▨	**11**	**15**	▨	▨	**19**
	Low		**4**	▨	**8**	▨	▨	**12**	**16**	▨	▨	**20**
South	High	Thick										
	Med											
	Low											
	High	Thin										
	Med											
	Low											

The experimental design incorporated six factors, with levels of each factor ranging from two to three, which were expected to have the greatest impact on sealing effectiveness. The six factors were:

1. climate (two levels-north and south);
2. traffic (three levels-high, medium, and low);
3. pavement thickness (two levels-thick and thin);
4. pavement age (two levels-new pavement and existing pavement);
5. pavement type (three levels-concrete, asphalt, and composite); and

6. subsurface drainage (two levels- yes and no).

For the purposes of this project the following pavement type definitions will be used:

1. concrete – a Portland cement concrete pavement or in other words a rigid pavement;
2. asphalt – full depth asphalt concrete pavement or in other words a flexible pavement; and
3. composite – an asphalt concrete layer resting on an old concrete pavement.

Based on the fact that each cell in Table 5-1 would require an associated amount of fieldwork and data collection/analysis, several were eliminated to keep these efforts to a manageable level. The shaded and cross-hatched cells were acknowledged as potentially important, but were deemed non-essential based on the time and expense that would be associated with filling them. The two levels (north and south) for the climate factor were reduced to one level (north only). The reduction was made based on the fact that field locations had not yet been identified and the decision that climatic (precipitation, freeze-thaw cycles, etc.) data would simply be collected at each field location where ever they may be located within the state. The shaded cells were eliminated based on illogical combinations and historical InDOT practices. An example of an illogical combination would be a thin pavement exposed to high traffic because pavement thickness is determined as a function of expected traffic in the structural design process. An example of a historical InDOT practice might be that drainage is routinely incorporated into concrete pavement structures.

A refined experimental design was developed based on several factors. They included:

1. a critical review of the preliminary experimental design;
2. recommendations of other researchers identified in the literature review process;
3. suggestions of SAC members;

4. distribution of pavement types in Indiana; and
5. time, physical data collection, and monetary constraints of the project.

The refined design of experiment is described in the following section.

5.2 Refined Experimental Design

Based on the critical review of the preliminary experimental design, the research team felt that pavement type, traffic, pavement thickness, and drainage had to be included as factors in the experiment design as they are excepted to have the greatest influence on pavement performance related to joint/crack sealing effectiveness. The consideration of these factors is consistent with recommendations found in the previously discussed literature review and those extended by SAC members. SAC members with extensive field experience suggested that two very important factors specific to Indiana were drainage conditions and the inclusion of low volume facilities (eg. State Routes). This lead to the formulation of the experimental design presented in Table 5-2.

Table 5-2 Refined Experiment Design

Roadway Classification	Pavement Type					
	Concrete		Asphalt		Composite	
	Drainage		Drainage		Drainage	
	Yes	No	Yes	No	Yes	No
National	1	3	5	7	9	11
State	2	4	6	8	10	12

Note that the two factors, traffic and pavement thickness, were combined into the single factor roadway classification with two levels, National and State Routes. There were two reasons for combining traffic and pavement thickness. First of all, because pavement thickness is established in the structural design process as a function of expected traffic, including both traffic and thickness would be redundant. The second reason was to provide the greatest statistical inference space with the smallest number of field projects. This is achieved by using data that represent the higher and lower limits for a main factor. In the case of the design presented in Table 5-2 the National routes represent the high traffic volume, thick pavements while the State routes represent the lower volume, thinner pavements. The refinements led to an experimental design (Table 5-2) with twelve cells. Within each cell, two projects of different ages with two test sections per project are planned. Details of these items are further discussed in subsequent sections.

It should be noted that one additional refinement was attempted. An attempt was made to determine the distribution of roadway miles in Indiana by pavement type (concrete, asphalt, and composite) as well as the distribution of drainage conditions within each pavement type. The objective was to determine whether efforts should be focused within specific cells and/or if others should be deleted based on the percentage of the roadway network each cell represented in Indiana. Unfortunately this information was not readily available from INDOT. However, research currently underway at Purdue University, under the directions of Professor Kumares Sinha, incorporates the development of a database with must of the required information. The database is in the developmental stage, so information extracted from it will ultimately need to be verified, but it does provide for an estimate of the distribution of pavement types within Indiana. Estimates of the percentage of each pavement type, extracted from the database, are presented in Table 5-3. Unfortunately, the distribution of drained versus undrained pavements is not available at this time. Table 5-3 shows that the combination of composite and asphalt pavements represents approximately eighty-five percent of the Indiana network, which suggests that the field experiment should focus on these pavement types. However, the literature suggests that joint/crack sealing of concrete pavements may be the least cost effective. For these reasons it is recommended that the experimental design incorporate all three pavement types as depicted in Table 5-3.

Table 5-3 Pavement Type and Drainage Distributions

Pavement Type	Percentage of Total Indiana Network	Percentage of Drained and Undrained by Pavement Type	
		Drained	Undrained
Concrete	10		
Asphalt	25		
Composite	59		
Other(unknown)	6		

It is anticipated that interviewing INDOT Division and District personnel in the project selection process, as well as records available at the Materials and Test Division will assist in obtaining more refined estimates of the distributions discussed above. Based on this information and field inspections it is anticipated that it may not be possible or practical to fill some of the cells currently included in the experimental design. For example it may be difficult to find undrained concrete pavements in the state route functional dassification. This can only be determined after the project selection process is initiated.

5.3 Project Selection, Description, and Treatment

The methodology proposed for selection of field projects is presented in this section along with a physical description of a typical project identify in both sealed and unsealed sections. This will be followed by a description of how the individual sections will be treated or maintained.

5.3.1 Project Selection

Field projects will be selected to conform as closely as possible to the proposed experimental design. The site selection process will be a cooperative effort between InDOT Division of Roadway Management and Purdue University personnel. Candidate sites will initially be identified based on classification, pavement type and age. This will be done using the Roadway Management database. Unfortunately, the database does not include include pavement structural layer thickness or drainage condition data. If the projects are young enough (constructed within the last ten years) structural composition and possibly even drainage conditions may be obtained from design records at the INDOT Division of Materials and Test. If the pavements are older than approximately ten years, the assistance of INDOT District personnel will be requested to assist in compiling structural composition and drainage condition information. Finally, once candidate sites are identified as described above, field inspections will be conducted to establish/verify structural composition and drainage condition information.

5.3.2 Physical Test Section Description

For each cell in the experimental design, two projects are needed. The two projects associated with each cell will need to be of considerably different age in order to be consistent with the methodology described in the beginning of this section of the report and depicted in Figure 5-1. Within each project there will be two test sections, one will be sealed and the other will be unsealed (control). Each test section will be approximately two hundred fifty meters in length. This length was established based on typical concrete pavement slab lengths and transverse crack spacings in asphalt pavements in Indiana. The proposed test section length will likely provide for up to ten or more individual joints/cracks within each test section.

Both test sections at each project will be located in the same lane and they will have a two hundred fifty meter section between them (transition zoen) to ensure that the performance of each section is not influenced by the adjacent unsealed or sealed section. A plan view of a pair of test sections at a particular project is presented in Figure 5-2.

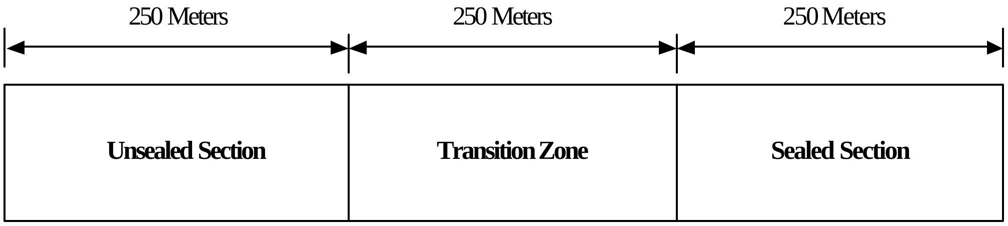

Figure 5-2 Plan View of Typical Project Location With Test Sections Identified

5.3.3 Section Treatment

An extremely important component of the field experiment will be the maintenance of the individual test sections. Once a project is identified, the unsealed section, transition zone, and sealed section will be marked on the pavement. The following descriptions will be used to define “sealed” sections:

1. For concrete pavements all joints surrounding as well as any cracks within individual slabs or panels (eg. mid panel transverse cracks) will be sealed;
2. For asphalt and composite pavements any and all cracks and joints regardless of their nature (thermal, reflective, construction, etc.) will be sealed.

All of the joint/crack sealer within the entire project length (750m) will then be removed. The joints/cracks in the transition and sealed sections will then be consciously sealed using typical quality materials and practices. The joint/crack sealer in the transition zone and sealed section will then be rigorously maintained throughout the duration of the approximately two year performance monitoring period. This will require regular inspection of the projects on a monthly basis. Mr. Chuanxin Fang will be responsible for conducting the inspections and immediately notifying INDOT Maintenance Forces of any deterioration that will have to be repaired as quickly as possible. This will maintain the integrity of the joint/crack sealing to the maximum degree possible.

5.4 Data Collection and Analysis

Three pavement types, concrete, asphalt, and composite, are included in the experimental design as shown in Table 5-2. Pavement thickness (thick versus thin) and traffic volume (high versus low) factors are incorporated through functional classification termed “Roadway Classification,” with two levels, specifically the national highway system and the state route system. Drainage is the other main factor included in the design. Other factors such as subgrade conditions and pavement locations (climate) are indirectly incorporated as co-variants.

Several performance measures will be used to evaluate the effects of joint/crack sealing as well as the absence of sealing on pavement performance. The performance measures that will be employed differ somewhat depending on pavement type. A description of the specific performance measures that will be used for each pavement type is presented below and this is followed by a discussion/outline of the techniques that will he used to analyze the data.

5.4.1 Concrete Pavements

Ride quality as measured by the international roughness index (IRI), falling weight deflectometer (FWD) deflections to measure load transfer at joints and/or mid slab cracks, and pavement serviceability index (AASHTO PSI) and/or pavement condition rating (PCR) will all be measured on both sealed and unsealed sections. The PSI and/or PCR data will actually be extracted from the INDOT Roadway Management database. Visual condition surveys (distress surveys) will also be conducted to assess the severity and extent of individual distresses such as faulting and mid slab cracking. Cores will be collected at and/or near the joints and/or cracks to investigate both physical and mechanical properties of the pavement. The IRI, PSI and/or PCR, and core measurements will be conducted annually. The visual distress surveys and deflection testing will be conducted bi-annually.

5.4.2 Asphalt Pavements

The same performance measures will be collected for asphalt pavements, with the exception that the visual condition surveys will focus on a different set of individual distresses. For example, the severity and extent of longitudinal and transverse cracking, as well as potholes and patching will be monitored. Crack cupping and lipping will also be monitored. Coring will also be collected at or near cracks for physical and mechanical property assessment. The frequency of data collection will be the same as that defined for concrete pavements.

5.4.3 Composite Pavements

The data collection outlined in Section 5.4.2 for asphalt pavements will also apply to composite pavements.

5.5 Data Analysis

The following discussion provides a description of the techniques that will be used to analyze the performance measures described in the previous section.

5.5.1 Ride Quality (IRI)

The ride quality of pavement sections considered in this experiment will be documented by IRI measurements. This index will be collected at the beginning of this study and annually thereafter. The measurements will be used to document the difference in ride quality between sealed and unsealed sections. Statistical analyses (t-tests) will also be performed to determine whether significant differences are observed in ride quality between sealed and unsealed sections. Multiple analyses will actually be performed. For example, as a first step a test will be conducted with the data pooled for all pavement types and roadway classifications. Then it will be subdivided by pavement type, followed by subdivision by pavement type and roadway classification, and finally subdivision by pavement type, roadway classification, and drainage condition. The first test would determine the effectiveness of sealing in general. The second set of tests would determine the effectiveness of sealing for the specific pavement types regardless of roadway classification. The third set of tests would be used to determine the effectiveness of sealing for specific pavement types and roadway classifications. The four sets of tests would be used to assess the effectiveness of sealing for specific pavement types, roadway classifications and drainage conditions. Applying this technique to all the performance measures collected will not only provide the answer to whether sealing is effective, but specifically for individual pavement types exposed to different loading and drainage conditions. This is consistent with the project objective of determining whether joint/crack sealing is effective and under what conditions.

5.5.2 FWD Deflections

FWD deflection measurements for all the cells included in the experimental design will be attempted bi-annually. Once in early spring, the end of March through April, when spring thaw is expected to take place leaving subgrades saturated and a second time in late summer or early fall, the end of August through early October, when subgrade conditions should be relatively dry. Figure 5-3 illustrates the FWD testing geometry and the spacing of the deflection sensors during measurements. The deflection at the first (D_o) and second (D_1) sensors will be utilized for the analysis of the FWD measurements. The normalized deflection ratio D_1/D_0 will be used to measure load transfer at the joints and cracks for the different pavement types. Because pavement serviceability deteriorates over pavement life it is expected that this deflection ratio will deteriorate with the pavement life and as illustrated by the thin line in Figure 5-4.

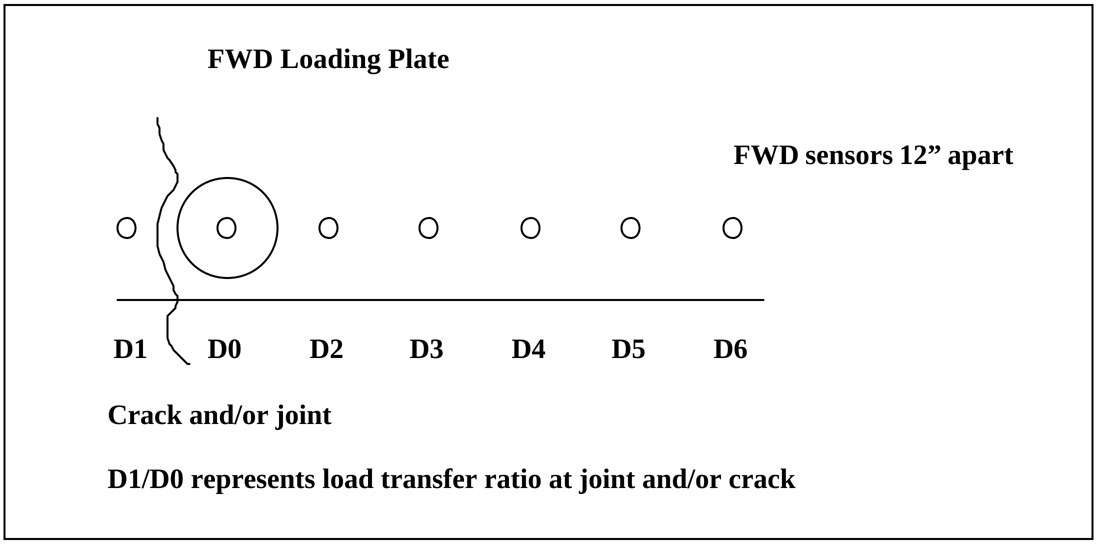

Figure 5-3 FWD Sensor Spacing and Geometry of Test

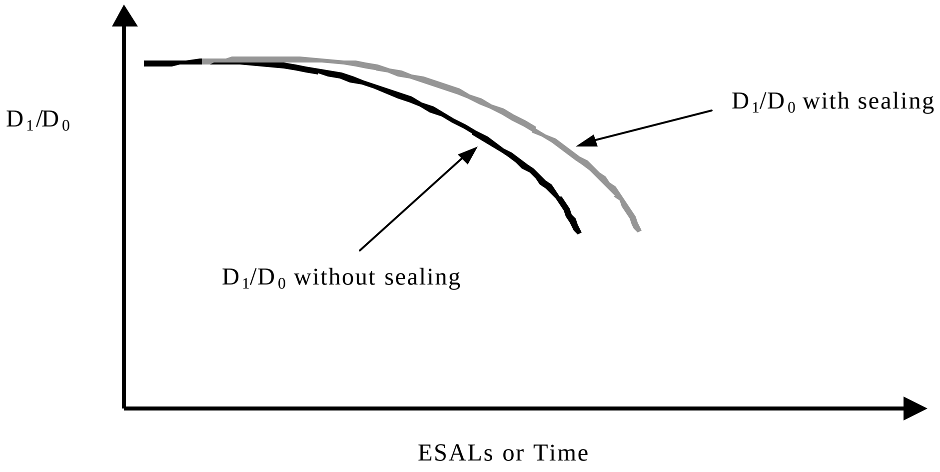

Figure 5-4 FWD Ratio (D_1/D_0) for sealed and unsealed Sections Versus Time and/or ESAL's.

It is hypothesized that sealing joints and/or cracks will retard the deterioration of the pavement. Consequently, the deflection ratio would be greater for a sealed pavement as a function of time as illustrated by the thick line in Figure 5-4.

From a statistical standpoint, if the difference between the thin and thick lines or their slopes is significant, sealing of joints and/or cracks would have an effect on performance. On the other hand, if the differences were not significant, sealing of joints and/or cracks would not have an effect on performance. Quantifying the difference between the two lines would result in the cost effectiveness of sealing joints and/or cracks.

During the coarse of this study traffic data will be collected using the weigh-in-motion (WIM) stations and other conventional methods. These traffic data coupled with the deflection ratio (D_1/D_0) would provide quantification of the cost associated with sealing the joints and/or cracks in different pavement types. Consequently recommendations could be made as to the cost effectiveness of sealing on these types of pavements. A seal/no-seal policy could then be recommended based on this quantitative analysis as to the cost effective of sealing in Indiana.

5.5.3 Condition Survey Data

The Long-Term Pavement Performance (LTPP) Distress Identification Manual and/or the INDOT condition survey manual will be used to conduct condition surveys throughout the duration of this study. Condition surveys will be performed bi-annually to monitor overall pavement conditions and to provide input for PSI and/or PCR determinations. The pavement type specific individual distresses outlined in previous sections will be closely monitored. The individual distress and combined index (PSI and/or PCR) data will be analyzed in a manner similar that described for pavement ride quality.

5.5.4 Pavement Cores

The physical properties of cores extracted at or near joints and cracks will be evaluated by visual inspection and documented with photographs. The cores will provide insight to the condition of sealants, bonds, and depth of sealant penetration. Mechanical properties may be used to assess the effect of sealing on the durability of the pavement.

The data collection and data analysis effort associated with this study may also include limited investigations of subgrade conditions during the spring and summer FWD testing. Additionally, investigations of a general nature may be conducted to determine pavement locations that have been successfully or unsuccessfully sealed over extended periods of time. Testing at these pavement locations may include IRI trends or FWD testing.

6. Summary and Recommendations

The literature search and review that considered over one hundred potential references revealed that only eighteen specifically discussed cost-effectiveness of joint/crack sealing. Of these only four provided useful quantitative information related to the cost-effectiveness of joint/crack sealing. This in itself suggests the need for the proposed research. In addition to the literature search, individuals who are recognized experts on this topic were contacted and asked to comment on the merits of the proposed research. Both of these efforts revealed little quantitative evidence to prove the cost-effectiveness of joint/crack sealing and suggested the need for the research. The literature review showed that only two studies relative to joint/crack sealing have been conducted in the State of Indiana. However, neither of these two studies nor any other available research considered the overall pavement performance as influenced by sealing and the cost effectiveness of joint/crack sealing in Indiana.

A survey of practice was also conducted which included responses to eleven questions by forty-two of the fifty state highway agencies polled. The survey revealed that like most other agencies, InDOT's joint/crack sealing policy is based on long standing policy rather than research. The statistical results of the survey also showed that most of states, including Indiana, do not have quantitative justification for sealing policies nor do they know the cost-effectiveness of the operations. InDOT currently spends approximately four million dollars annually to accomplish joint/crack sealing even though there is no quantitative evidence to justify this expenditure. Thus, a well designed field experiment is strongly recommended to investigate the cost-effectiveness of joint/crack sealing in relation to pavement performance in Indiana. The potential savings associated with the research could very well amount to a significant portion of the four million dollars now spent annually on joint/crack sealing by InDOT.

An experimental design for a field study was developed through a series of meetings with pavement technologists and a statistician. Three main factors, specifically roadway classification (national and state routes), pavement type (concrete, asphalt, and composite), and drainage (drained and undrained) are included in the experiment design as they are expected to have the greatest influence on pavement performance relative to joint/crack sealing effectiveness. The objective of the experiment is to provide adequate evidence to answer the age old question of whether joint/crack sealing is cost effective and under what conditions. The experimental design incorporates twelve cells. For each cell in the design, two projects each with two test sections (one sealed and one unsealed) are recommended. The sealed sections will then be rigorously maintained throughout the duration of the field performance monitoring period.

Pavement performance will be monitored periodically throughout the duration of the field study. Performance response variables will include ride quality (IRI), seasonal pavement deflection (FWD), composite performance indices PSI and PCR, individual pavement distresses, and physical and mechanical properties of in-service pavement cores. The performance data will be analyzed statistically to determine the effectiveness of joint/crack sealing. It will also be coupled with remaining life predictions to evaluate the cost effective of sealing. These analyses will provide the basis for formulating a joint/crack sealing policy for INDOT.

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10. *Energy Saving from Increased Preventive Maintenance on Indiana highways*. E.A. Sharaf and K.C. Sinha, Transportation Research Record 1102, TRB, National Research Council, Washington, D.C., 1986.

11. *Improved Preventive Maintenance: Sealing Cracks in Flexible Pavements in Cold Regions*. Chong, G.J. and W.A. Phang, Transportation Research Record 1205, TRB, National Research Council, Washington, D.C., 1988.

12. *Joint Seal Practices in the United States Observation and Consideration*, D.A. Morian and S. Stoffels, Transportation Research Record 1627, TRB, National Research Council, Washington, D.C., 1998.

13. *Evaluation of Crack Sealing Performance on Indiana's Asphalt Concrete Surfaced Pavements*, D. R. Ward, Indiana Department of Transportation, October, 1993.

14. *Value Engineering Study of Crack and Joint Sealing*, Blais, E.J., FHWA-TS-84-221, Federal Highway Administration, December, 1984.

15. *Cost – Effectiveness of Crack Sealing Materials and Techniques for Asphalt Pavements*, R.B. Freeman and D. Johnson, Montana State University, February, 1999.

16. *Techniques for Pavement Rehabilitation - Reference Manual, 6th Edition*, Federal Highway Administration, FHWA HI-98-033, Washington, D.C., August, 1998.

17. *Concrete Pavement Maintenance Treatment Performance Review: SPS-4 5 Year Data Analysis*, D.A. Morian, S.D. Gibson, J.A. Epps. Federal Highway Administration, FHWA-RD-97-155, Washington, D.C., July, 1998.

Appendix A

Joint and Crack Sealing Questionnaire

1. Do you seal new concrete pavements?

   Yes No

2. How wide is your saw cut for joints on new concrete pavements?

3. Do you reseal older concrete pavements?

   Yes No

   If yes, a. When do you perform the first resealing (as needed)?

   b. How often do you reseal? (For Example, every 5 years)

4. Do you reseal bituminous pavements?

   Yes No

   If yes, a. When do you perform the first resealing (as needed)?

   b. How often do you reseal? (For Example, every 5 years)

5. How was the decision made to conduct joint or crack sealing?

   a. long standing policy

   b. research results

   c. unsure

6. Do you install subsurface drains on new pavements?

   Yes No

7. Has your DOT studied the effect of joint and crack sealing with regard to the impact it has on the performance of your concrete, asphalt or composite pavement? If yes, please give the title of the project, name of the principal investigators and how we can get a copy of this research?
   a. Title of the project:
   b. Principal investigators:
   c. Availability of the report:

8. Does your DOT plan on investigating the cost of joint/crack sealing in the near future?

   Yes No

   If so, how?
   a. in house research (name)
   b. consultant (name)
   c. university research (name)
9. How do you define traffic level in terms of ESALS and/or truck count/truck factor?

10. How do you define thick vs. thin pavement (concrete, flexible or composite)?

    For example: concrete pavement less than 6" thin, greater than 6" thick…etc.

11. Do you have FWD criteria that define performing joints or cracks? If so, please state the criteria? For example: ratio between any sensors or difference between any sensors.

Appendix B

Survey Results of Questionnaire on joint and Crack Sealing

Table B-1 Survey Responses

State	1. Do you seal new concrete pavements?	2. How wide is your saw cut for joints on new concrete pavements?	3. Do you reseal older concrete pavements? If yes,a. When do you perform the first resealing (as needed)? b. How often do you reseal? (For Example, every 5 years)	4. Do you reseal bituminous pavements?	5. How was the decision made to conduct joint or crack sealing? a. long standing policy b. research results c. Unsure	6. Do you install subsurface drains on new pavements?
Alabama	Yes	3/8" (9.53mm)	Yes a. No uniform criteria. Resealing is performed when deemed necessary by the division maintenance Engineer or a District Engineer b. No set time interval.	Yes a. same as question 3a b. Same as question 3b.	c.	Yes
Alaska	No, we don't use concrete pavement	N/A	No a. N/A b. N/A	Yes, sometimes a. Chip seal + 8 yr old pavements without ruting or IRI problems b. No criteria set, depends on condition.	b.	Yes A Few
Arkansas	Yes	Standard drawing attached	Yes a. When the joint sealer begins to lose adhesion to joint surfaces b. 5-8 years.	Yes a. When enough cracks or joints open to justify b. 3-5 years.	a.	Some
Arizona	Yes	nominal 1/8"(3.18mm) (width of saw Blade)	Yes a. Generally after 10 years of service b. Approximate 10 year cycle	Yes a. 7-10 years cycle b. As needed-generally 3 year cycle	a.	No
California						
Colorado	Yes	Single cut, 1/8" (3.18mm) wide.	Yes a. As needed	Yes a. as needed b. Unsure	a.	No. However, through LTPP we have installed edge drains with permeable asphalt treated base (PATB).
Connecticut						
Delaware	Yes	3/8"(9.53mm) Joint - Neoprene seals	Yes a. When Moderate to severe failure of Joint material is observed b. As needed	Yes a. When moderate failure of crack sealant is observed b. ~5 years as need	a. -also, pavement managemnet road raters note sealant condition during annual road rating.	Yes

Table B-1 Survey Responses (Cont.)

Florida	Yes	3/8"(9.53mm)	Yes a. When minor CPR needed (3% slab replacement) b. ~10 years, when CPR needed	No	b.	Yes - Rigid only
Georgia	Yes	3/8" (9.53mm) transverse joint; 1/4"(6.35mm) longitudinal joint	Yes a. Based on annual inspections of PCC pavement condition. No written criteria b. 7 to 10 years	occasional crack sealing	a.	Yes - only on an as-needed basis
Hawaii	No We use permeable bases and draw our pavements.	N/A	No Our older pavements were never sealed.	No	N/A	Yes, with permeable bases.
Idaho						
Illinois	Yes	3/8"(9.53mm)	Yes a. We reseal concrete pavements when deemed necessary. We do not have any set policy on resealing concrete pavements. Resealing is decided based on the appearance of the joint and/or the surrounding pavement b. When necessary.	Illinois Department of Transportation does not seal bituminous pavements initially. Bituminous pavements are sealed after cracks appear a. The first sealing of bituminous pavements is done about three to five years after construction b. Usually bituminous pavements are overlaid or replaced before cracks are sealed a second time.	a.	Yes
Indiana	Yes	initial 1/8"(3.18mm)	No	No	a.	Yes
Iowa	Yes	1/4"(6.35mm)	Yes.(Infrequently) a. age b. Should be every 7 years but is not that frequent. (Once the maintenance management system is in place we should be able to better determine when these activities are being done.)	Yes a. age b. should be every 10 years. (Once the maintenance management system is in place we should be able to better determine when these activities are being done.)	a.	Yes

Table B-1 Survey Responses (Cont.)

Kansas	Yes	3/8"(9.53mm) (15' Plain PCCP w Dowels)	Yes a. as needed b. Usually once in life of a pavement	Yes a. When cracks (unsealed) reach 1/4" or wider and do not exhibit roughness (noticable). b. As needed	b. (SHPP SPS-3 results)	Yes
Kentucky						
Louisiana	Yes	3/8"(9.53mm)	No	Yes as determined by the maintenance engineer.	This is also determined by the maintenance egineer, if the cracking is extensive and it is associated with raveling and pitting (about 20% of the area), a seal coat may be applied.	Yes, for interstate highways
Maine	N/A Do not construct PCC Pavement	N/A	N/A	No Not much if any resealing has been done to my knowledge a. We do have a fairly aggregate under sealing program along interstate. Also Bureau of Maintenance & operations has crack sealing program.	c. Decision to crack seal is made based on concensus approach with planning, project development and maintenance team members.	Yes, install under drain systems where needed. Do not use edgedrain systems.
Maryland	Yes	1/8"(3.18mm) - contraction joints	Yes a. When seals are demaged and to be replaced b. Varies - not a routine preventive measure	Yes a. No criteria is established although we are developing guidelines this summer. Typically seal tight environment or joint reflection cracks b. Varies - not routine	currently based on local expertise - will become part of our pavement management decision process.	Yes - not all pavements - those that require outlets for drainage.
Massachusetts						

Table B-1 Survey Responses (Cont.)

Michigan	Yes	3mm relief cut 10mm final width for neoprene (compression) seal	Yes a. MDOT will look at resealing concrete joints at approximate 12-15 year of pavement life b. A second cycle of resealing may or may not occur depending on the deterioration of the pavement at the time of consideration	Yes, both flexible and rigid Flexible - MDOT will crack seal at year 5 to year 10 depending on the pavement condition. A second cycle of resealing may or may not occur depending on the rate of pavement deterioration of the pavement at the time of consideration Composite - MDOT will crack seal at year 2 to year 3 depending on the pavement condition. A second cycle of resealing may or may not occur depending on the rate of pavement deterioration of the pavement at the time of consideration	Recent policy directive, research and informal field observations of the benefits obtained from joint and crack sealing.	Yes, 100mm and 140mm circular
Minnesota	Yes	3/8"(9.53mm)	Yes a. When sealant fails b. Varies with life of sealant (3yrs-25yrs)	Yes a. 1) Reseal joints when sealant fails. 2) Seal cracks when new transverse cracks develop b. Reseal varies, we typically seal new transverse cracks two years after paving.	b.	Yes On high volume and highways with non granular subgrade.
Mississippi	Yes	1/2"(12.7mm)	Yes a. No timetable; when needed b. N/A	No	a.	Yes
Missouri	Yes	3/8"(9.53mm)	No	Yes a. Seal cracks as they occur on an annual basis b. Seal cracks as they occur on an annual basis	a.	Yes Heavy Duty PVMT - Longitudinal edge drains on both sides of dual PVMT. Medium Duty PVMT - longitudinal edge drains on outside of dual PVMT. Light Duty PVMT - No longitudinal edge drains.

Table B-1 Survey Responses (Cont.)

Montana	Yes	1/4"(6.35mm)	Yes a. Hot Pour = 5 to 10 yrs b. Silicone = longer 8 to 14 yrs	Yes a. 2 to 3 years b. 2 to 3 years	b.	No
Nebraska	Yes	3/16"(4.76mm)	Yes a. District engineer's judgement b. A 5-year cycle has been proposed for the interstate	Yes a. District Engineer's judgement b. A 3-year cycle is being used for the Interstate	Engineering judgement.	Yes
Nevada	Yes	3/8"(9.53mm)for transverse joints, 1/4"(6.35mm)for logitudinal joints.	Yes	Yes	a.	Yes,under PCCP only
New Hampshire	NH has not placed a concrete pavement in 50 years		No	Yes b. 5-8 years	b. & c.	Yes
New Jersey	Yes	Formed Expansion Joint - 3/4" (19.05mm)	Yes a. As needed b. 5-6 years; Depends on funding.	Yes a. As needed b. 5-6 years; Depends on funding.	c.	1. Pavement Drainage system for concrete pavement 2. Subsurface, cross-drains every 250' +/- for bituminous pavement
New Mexico	Yes	20mm	Yes a. Our District Maintenance Engineers decide when this is necessary based on in-field reviews. b. Same as 3(a) - no set average interval.	see answer to question 3	see answer to question 3	No
New York	Yes	First Stage: 3-6mm Second Stage: 10mm+/-1 mm Bevel (Transverse Joints only): 3mm x 3mm	Yes a. Between years 8-12. After sealer sidewall adhesion starts to fall as determined by field Inspection b. 8-12 years	See attached	a.	Yes

Table B-1 Survey Responses (Cont.)

North Carolina	Yes	Currently we use two saw cuts. (see figure) But are considering using a single 1/8" (3.18mm) cut.	Yes. a & b. this varies greatly depending on the area of the state.	Yes. a & b. this varies greatly depending on the area of the state.	No response---	Yes
North Dakota	Yes	For joints we use both silcone and preformed. Saw cuts for silicone is 3/8" (9.53mm) wide and for preformed is 1/4" (6.35mm) wide.	Yes a. When doing a concrete pavement repair or dowel bar retrofit project on a section of highway the joints will be resealed.	Yes a. After the appearance of the initial crock pattern b. Varies, normally be the appearance of the pavement.	c.	Yes, only in concrete pavements
Ohio						
Oklahoma	Yes	1/4"(6.35mm)	Yes a. Usually as part of a AC rehab. Project b. 10-15 years	Yes a. severe cracking is usually seal by state Maintenance forces b. 5 to 20 years, as needed.	a.	Yes - only on very high type facilities (Interstate Hwys.)
Oregon	Yes	3-6mm	Yes, only on rare ocassions	Yes, a. when crack become a problem.	c.	Yes, most new pavements.
Pennsylvania	Yes Neoprene Transverse Joints Seals For Interstate Highways	1/8" (3.18mm) initial reservoir 1/2"(12.7mm)~5/8"(15.9mm)	Yes Joints and Cracks a. As needed b. As needed	Yes a. 3-5 years b. usually every 5 years.	a.	Yes
Rhode Island	N/A	N/A	N/A	Yes a. Please see additional information b. see additional information	Experience and judgement	occasionally
South Carolina	Yes	3/8" (9.53mm)	Yes a. Resealing is performed as part of general rehabilitation. These projects are generally driven by other distresses such as faulting or broken slabs rather than by seal condition. The first rehabilitation is generally at 18-30 years after construction, so the seals are generally gone by the time we get to them. (This is not a good practice, but this is what we do.) b. No set period.	No	a.	Yes, for rigid. No, for flexible

Table B-1 Survey Responses (Cont.)

South Dakota	Yes	Contraction Joints - 3/8"(9.53mm)	Yes a. Approximate 15 years b. After the first reseal it is about 10-15 year intervals.	Yes a.Based on inspection - the 1st seal is at 2 years b. As required.	b.- informal research test site results	Yes - very limited in number and location of any new installations we would do.
Tennessee						
Texas	Yes	Contraction Joints - 3/8"(9.53mm) Logitudinal Joints - 1/4"(6.35mm)	Yes a. Local decision b. No scehedule, judgement	Yes a. Generally 8 to 15 years for seal coats b. Generally 5 to 10 years for seal coats	Local engineering judgement	No
Utah	Yes	1/8" (3.18mm)	Yes a. Scheduled every ten years	Yes a. As needed	a & b	Yes Not used in the past. They are starting to be used now.
Vermont	Yes	1/2"(12.7mm)	Yes a. 5 years b. every 5 years	Yes a. 2-3 years b. every 5 years	c.	As necessary.
Virginia	Yes	See the attached Standard PR-2	Yes a. 8th year b. 10 years	Yes a. 8th year b. 10 years	a.	Yes
Washington	Yes	3/16"(4.76mm) - 5/16"(7.94mm)	Yes a. As part of other rehabilitation - Dowel Bar Retrofit, Diamond Grinding.	No In general, some maintenance areas are sealing cracks as part of maintenance work a. No specific criteria has been established.	Engineering judgement - Minimize Ability of incompressibles & Moisture into Joint - Minimize spalling/faulting/cracking Potential. (new pavements) still investigating resealing of existing Joints/cracks.	Yes Only when part of larger drainage plan - Typically in Urban Areas.
West Virginia						

Table B-1 Survey Responses (Cont.)

Wisconsin	No	1/8"(3.18mm) - 3/16"(4.76mm)	Not generally - If it had a wide saw cut, we may a. Hit or miss	Yes a. Counties do work for us - in first 5 years b. every 5 years +/-	b. -50 years of research o PCC says it is not cost-effective. AC research says it may be cost-effective.	Yes - PCC only
Wyoming	Yes	Transverse-3/8"(9.53mm) use preformed seals Longitudinal-1/8"(3.18mm) use hot pour seal	Yes a. usually not until other CPR is being performed, such as grinding b. Propably 15 years	Yes a. Propably 5 to 10 years after construction b. Only when sealant and crack is in poor condition	a.	Yes, On most concrete pavements. On some flexible sections where earth widing will create a bath tub.

Table B-1 Survey Responses (Cont.)

7. Has your DOT studied the effect of joint and crack sealing with regard to the impact it has on the performance of your concrete, asphalt or composite pavement? If yes, please give the title of the project, name of the principal investigators and how we can get a copy of this research?	8. Does your DOT plan on investigating the cost of joint/crack sealing in the near future?If so, how? a. in house research b. consultant c. university research	9. How do you define traffic level in terms of ESALS and/or truck count/truck factor?	10. How do you define thick vs. thin pavement (concrete, flexible or composite)?	11. Do you have FWD criteria that define performing joints or cracks? If so, please state the criteria? For example: ratio between any sensors or difference between any sensors.	Additional information
No	No	Low traffic level < 1,000,000 ESALs over 20 years <= medium traffic Level < 10,000,000 over 20 year ESALs<= High traffic level	Thin PCC <8" Thick PCC >10" Thin HMA <6" Thick HMA >8" Thin AC/PCC <10" Thick AC/PCC >12"	No	
No	No, it costs approximately $0.27/SY	ESALs	Flexible: Thin <= 2" (50.8mm) Thick > 2" (50.8mm)	No	
No	Currently have data to compute cost in house.	ESALs	No criteria	No	A drawing of Transverse & longitudinal Joints for Concrete Pavement is attached.
Ongoing LTPP Studies of Test Sections	Yes a. Larry Scofield. Research ongoing as part of LTPP study.	ESALs	Concrete - thin less than 10"(254mm) Flexible - thin less than 5"(127mm)	No criteria.	
NO	No	ESAL's	For concrete 0-4"(101.6mm) =ultra thin 4-7"(77.8mm) =Thin & anything over 8" (203.2mm) is full depth	Yes, CDOT uses FWD to examine load transfer efficiency (LTE) between slabs & shoulders. FWD is also used as an indicator of load carrying capacity of rigid pavements.(AA). No stated criteria (GL)	(AA)=Ahmad Ardani (GL)=Greg Lowery

Table B-1 Survey Responses (Cont.)

No	No	ESALS	Don't Define thick vs. thin. Classify by PCC, flexible and composite.	Have no FWD equipment. Use a consultant on as-needed basis (very infrequently)	
Yes a. Evaluation of Surface Sealing Techniques b. Jim Musselman, Gale Page c. FDOT Materials Office	No	Total ESALs in design period.	Flexible, thick>4"(101.6mm) Rigid, thick>9"(228.6mm), Ultrathin<=4"(101.6mm)	No	
No formal studies since there are many interacting factors which affect performance	No	Use ESALs in design, AADT and percent trucks in studies which use existing traffic levels - Depends on what tpye of study	Do not use such definitions	None	Questionnaire completed by Wouter Gulden Georgia DOT State Material and Research Engineer 404 363-7512
No	No	ESALs and Truck count	We don't have a difinition. All of our PCC pavements are greater than 6".	No	We don't seal joints because we believe they require high maintenance and our maintenance crew won't maintain them. We believe draining the pavement is the best alternative. We are interested in your study if available.

Table B-1 Survey Responses (Cont.)

Yes a. Repair of longitudinal Cracks in CRPCC Pavement, February 1984 b. John L. Saner, Illinois Department of Transportation, Bureau of Materials and Physical Research c. Please request a copy, if one is desired. Contact: Tessa Volle, IDOT-Bureau of Materials & physical Research 126E. Ash street, Springfeild, Illinois 62704 (217)782-7200	Possibly. Illinois DOT just began a study that is similar to Wisconcin DOT's seal?no seal study. Cost may be one of the topics of study. a. For more information on the study. Please contact Mark Gawedzinski, P.E. IDOT-Bureau of Materials and Physical Research 126 E. Ash St, Springfield, Illinois 62704 (217)782-7200	Illinois Department of Transportation defines traffic levels in terms of ESALs.	IDOT does not label pavements "thick" or "thin". Bituminous pavements are at least 6"(152.4mm) thick. Concrete pavements are at least 6.5"(165.1mm) thick. Design thicknesses greater than the minimums are based on traffic that exceeds the minimum design traffic.	The FWD criteria that defines performing joints or cracks is load transfer efficiency: the ratio between deflection under load and deflection of the sensor on the other side of the joint or crack. IDOT does not have any absolute criteria, but follows the following guidelines: Below 50% Failed 50%-65% Poor 65%-85% Moderate 85%-100% Good	
See Dave Ward INDOT Research---No	a.	ESALs	All thick 12"(304.8mm) or greater	No	
No	Yes a. We plan on trying to use the maintenance management system to get information on frequency and costs.	ESALs and Truck count/axle loadings	PCC thin 8" (203.2mm)and less, thick >10" (254mm) ACC thin 11" (279.4mm)and less, thick >13" (330.2mm)	No	
Yes a. "Final Report of North Central Region Tour of SPS-3 Projects-1995" b. Ron Shuberg, Engr. Of Maint.; KDOT (Retired) c. Report may be available through FHWA; Summary of all regions pulished as "Pavement Treatment Effectiveness, 1995 SPS-3 and SPS-4 Site Evaluations, National Report". Pub. No. FHWA-RD-96-208 May 1997	No - satisfied with SHRP findings	ESALs/ day in design lane	PCCP>=8"(203.2mm) - thick Bit.>=5.5"(139.7mm) - thick Comp>2"(50.8mm) - thick	AASHTO Guide criteria - "Performing" joints have deflection load transfer (^LT)>70% where:^LT=100*(^uI / ^I)*B ^uI=unloaded side deflection (in.) ^I=loaded side deflection (in.) B=slab bending & AC compression correction factor	Tessa Volle's e-mail: VolleTH@nt.dot,state.il.us

Table B-1 Survey Responses (Cont.)

Although, we have done research on the joint material performance, we have not look at the effect of joint sealing on the performance of the pavements.	We are initiating to look at performance of sealed and unsealed narrow joints in concrete pavements. LTRC in-house research.	Modified AASHTO procedures.	For concrete pavements, our concrete overlays are arround 4"(101.6mm) thick, that can be considered thin. For our concrete pavements, the minimum is 10"(254mm) thick. For flexible pavements, the minimum hot mix overlay is about 1.5"(38.1mm), a typical value for our AC overlay is 3.5"(88.9mm), any thickness greater than this will be considered a thick pavement.	We have used the FWD to determine the load carrying efficiency of load transfer devices at concrete pavement joints, please refer to the attached diagram for information.	Diagram attached.
No	No	18K equivalents, ESALs	Don't really have definitions. Generally speaking use 6"(152.4mm) hot mix asphalt on new construction, 3"(76.2mm) HMA over full depth reclaim on highway improvements, and use 1.5(38.1mm) to 3"(76.2mm) HMA overlays.	N/A	
No	No	We calculate ESALs based on traffic counts, truck counts and truck weights.	Only define Flexible: Thick - >4"(101.6mm) overlay Med - 2.5"(63.5mm)-4"(101.6mm) overlay Thin - <2.5"(63.5mm) overlay	Load transfer <70% requires load transfer repair. Load transfer <70% on concrete/composite pavement requires PCC repair instead of Full depth AC repair.	
Yes, enclosed is a study titled "Bituminous Crack Filling - Test Section on US-10 Near Evart" Please contact Mr. Mike Eacker, Pavement Rehabilitation Engieer, 517-322-5673 for information on this report or additional informal research on joint /crack sealing.	The department continually track cost of various sealants. Please contact Mr. Mike Eacker, Pavement Rehabilitation Engineer, 517-322-5673 for information on this report or additional informal research on joint/crack sealing.	Ambiguous	Composite & Flexible - A thin overlay is considered a one course overlay (40 to 50mm). Rigid - thin overlay is considered less than 100mm thick.	Yes, a performing joint or crack is defined by MDOT to have a load transfer efficiency of 70% or greater. If efficiency is lower, we consider a joint/crack retrofit to restore joint/crack integrity.	

Table B-1 Survey Responses (Cont.)

Yes a. 1) Sawing and Sealing Joints in Bituminous Pavements to Control Cracking #96-27 2) Joint and Crack Filler #93-11 3) Evaluation of Materials and Methods for Bituminous Pavement Crack Sealing and Filling #89-19 b. 1) David W. Janisch and Cutis M. Turgeon 2) Mark Hagen 3) Curtis M. Turgeon c. Contact Mn/DOT Office of Materials & Road Research, Lisa Bilotta (651) 779-5500	Yes a. Roger Olson (651)779-5517 Monitor and evaluate pavement performace of test sections and pavements.	No criteria for joint & crack sealing. Mn/DOT uses ESALs for Pavement Design and Rehab, ie Superpave Levels 1-7.	No criteria for joint & Crack sealing Asphalt Pavements: Thin<2"(50.8mm), Medium =2"(50.8mm)-4"(101.6mm), Thick>4"(101.6mm)	No criteria.	
No	No	ESALs for design life.	MDOT makes no such determination.	No	
No	Yes We currently have research underway (in our Northwest District) evaluating the effectiveness of unsealed joints in PCCP. At this time, the study has not been under investigation long enough to draw any conclusions. a. Patricia Lemongelli - Director/Research	ESALs	PCCP < 8"(203.2mm) - thin	No	
Yes a. Crack sealing Cost Effectiveness b. Dave Johnson, Montana State c. Progress report is available. Last progress report is attached. Final report due March 2002.	Yes. It is currently ongoing, see #7 above c. Montana State University	ESALs	concrete = our new standard is 9"(228.6mm). Flexible = Interstate minimum = 4.6"(116.84mm). Primary = 3.6"(91.44mm). Composite = White on top = 2"(50.8mm) to 4"(101.6mm) = Ultra-thin. 4"(101.6mm) to 6"(152.4mm) = whitetopping	Yes, load transfer, ratio of deflections on each side of the joint.	
No	No	ESALs	8"(203.2mm) or less - thin greater than 8"(203.2mm) - thick	No	

Table B-1 Survey Responses (Cont.)

No	No	ESALs	Concrete Pavement less than 10"(254mm) is thin, Flexible less than 4"(101.6mm) is thin	Use FWD to measure load transfer at the conc. Joint. Less than 70% load transfer is considered poor joint.	
No	No	ESALs	Flexible thin: 4"(101.6mm) or less	No	
No	No	ESALs for pavement design as determined from traffic/Truck %/Truck Factor	Don't Define	1. 60% load transfer for joint replacement 2. Slab intercept angle for sub sealing	
No	No	ESALs based on a minimum of a 48 hour continuous traffic count	We have no formal definition. Our minimum PCCP thickness is 180mm. For asphalt pavements, our minimum are based on the AASHTO 1993 design guide recommendations supplemented by actual minimum construction requirements (I.e. a 19mm Superpave minimum constructed thickness would be 65 mm). In general, we build what is required, regardless if it is a construction or maintenance project, to support a given design life need.	No.	New Mexico is basically an asphalt state with only 2% of our system being PCCP. If you should have any questions concerning this response, please contact me. John Tenison, P.E. Section Head Pavement, Investigation and Design Section, New Mexico State Highway Department, State Materials Bureau, P.O. Box 1149, Santa Fe, New Mexico 87504 (505)827-87504
No	No	We use ESALs in thickness desion and superpave mix design	We do not define "Thin". We define pavement later thickness based on ESALs.	We have used our FWD to determine tranverse joint load transfer efficiency.	

Table B-1 Survey Responses (Cont.)

No	No	ESALs (Two classes of trucks: Single unit and tractor-Trailor, each with a truck factor)	>=8" (203.2mm)concrete is think	No	
No	No	ESALs	Concrete - greater than 6" (152.4mm) is thick Flexible - greater than 3" (76.2mm) is thick	We test joints with a FWD to determine load transfer efficiency using the ratio between sensors that are a foot apart.	
No	No	Simple ADT's are evolving into ESAL counts.	AC- Thin less than 6"(152.4mm), Thick 6"(152.4mm) or Greater PC- Thin less than 8"(203.2mm), Thick 8"(203.2mm) or Greater	Joint efficiency = 75-100% - good 50-75% - fair 0-50% - very poor	New Pavement Engineer is Masoud Pajoh.
No	No	We compute ESALs for all projects.	We don't have that definition.	None	
No	No, we currently are using Neoprene Joints on Interstate Highways.	Volume? Or Loading 18KIPS/ESALs	Thin : Asphalt ~3.5"(88.9) or less Concrete ~4" or less Thick: Asphalt 8" = Full Depth Concrete Full Depth 6"-14"	If deflection is acceptable if it is 0.02 IN or less or JT effection *see attachment (For Ultra Thin Whitetopping)	With Attachment
No	No`	Both	Asphalt concrete: less than 4"(101.6mm) thin	No	Accompanying this is your completed questionnaire. In Rhode Island, we rarely construct concrete pavements. However, last year we began a pavement preservation program which includes the crack-sealing of many roads and state Highways.

					Those to be crack-sealed were selected based on their condition. (i.e., a moderate amount of cracking), not their age. We plan to continue our crack sealing program, but have not yet determine an interval at which we will seal or reseal pavements.
No	No	Our Planning office makes traffic counts and uses the estimated truck percentage and a truck load factor determined from previous weight studies to calculate future ESALs for 10 and 20 year periods.	We don't use thick and thin as descriptive factors in our pavement design and analysis. Consequently, we do not have formal definitions for these terms. However, w hat follows are my own rules of thumb for South Carolina. Concrete-Thin, less than 9" (228.6mm). Thick, more than 12"(304.8mm) Asphalt-Thin, less than 3"(76.2mm) over base; Thick, more than 12" (304.8mm) over base Composite-Thin, less than 4"(101.6mm) overlay on existing PCC, thinck, more than 6"(152.4mm) on existing PCC.	No	

Table B-1 Survey Responses (Cont.)

Yes a.1. (SD 90-13) PCC/AC Shoulder Joint Sealants 2. (SD96-10) Evaluation of PCC/AC Joint Sealant 3.(SD 92-03) Evaluation of silicone Joint Sealant Performance b. 1.Hal Rumpca (SD96-10) 2. Dan Johnston (SD90-13) 3. Arial Soriano(SD92-03) c. SDDOT	No	ESALs	PCC Concrete: <8"(203.2mm) thin >8"(203.2mm) thick Asphalt concrete: <4"(101.6mm) thin >8"(203.2mm) thick	PCC Pavement - Testing is done 4" on either side of the joint to deermine load transfer efficiency and inplace concrete strength at the joint.	
No	No	18kip ESALs	Define surfacing thickness ACP: thin<=2", thick ACP>=7". Do not defined thick/thin for PCC. But thickness of most PCC lies between 10" (254mm) and 13" (330.2mm). Some extreme thickness of PCC may lies between 8"(203.2mm) to 15"(381mm).	No criteria - Project judgement decision	
Sort of. An engineer working for UDOT write his thesis on this subject. a. Field Performance Study of Selected Potland Cement Concrete joint Sealants in Utah. b. Tim Biel c. He can send a copy. ph.(801) 975-4928.	No Also, Lynn Evans from ERES is monitoring our LTPP sealant sites. We have not seen a report from them.	ESALs	We don't distinguish between thick and thin.	Ratio of deflection of the average of 1st and 3rd sensors across the joint and 1 st sensor.	
No	No	ESALs	PCC > 8"(203.2mm) BCP > 6"(152.4mm) BCP/PCC > 12"(304.8mm)	No	
No, but conventional wisdom told us that this is the best practice. We may not have the exact number, but we know the benefit is there.	No	For 30 year life: 20 million low 21-50 million medium 51-100million heavy	Concrete 8"(203.2mm) thin, 11"(279.4mm) thick Asphalt 4"(101.6mm)-5"(127mm) thin, 13"(330.2mm) thick (this is asphalt courses only) Composite (only asphalt overlaying concrete) 2"(50.8mm) thin, 6"(152.4mm) thick	The load transfer criteria is: 0-50% poor Require full depth patching and dowel bars replacement 51-75% fair-good (no action taking, but will watch for future faulting) 76-100% excellent	Sent by Mike Jennings for Mohamed Elfino

Table B-1 Survey Responses (Cont.)

No	Yes a. Linda Pierce	Primarily use ESALs, however the pavement mansgement systems contain all terms.	ACP<4"(101.6mm) Thin, >4"(101.6mm) Thick PCCP - Not Defined. Typical Range 8"(203.2mm)-12"(304.8mm).	Load transfer less than ~70% Faulting greater than 1/8"(3.18mm)	
Yes a. 1. The Great Unsealing-TRR 1597 2. Evaluation of AC Crack Sealing b. S.F. Shober & Terry Rutkouski c. 1. TRR 1597 2. From WISDOT	No, It is done in WI. NCHRP is doing it	ESALs		No. Just evaluate Actual performance (not a surrogate like FWD) in terms of ride and distress!	
No	No	Daily ESALs	Do not make a distinction.	No	