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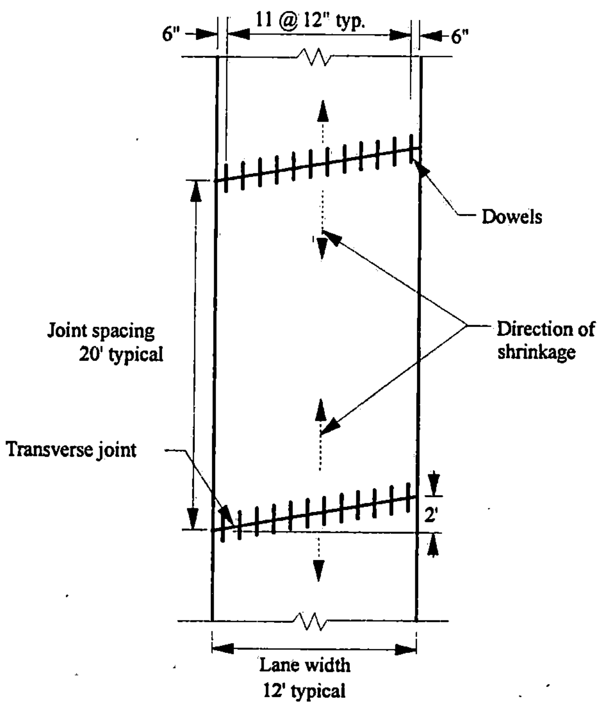

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College of Engineering Iowa State University

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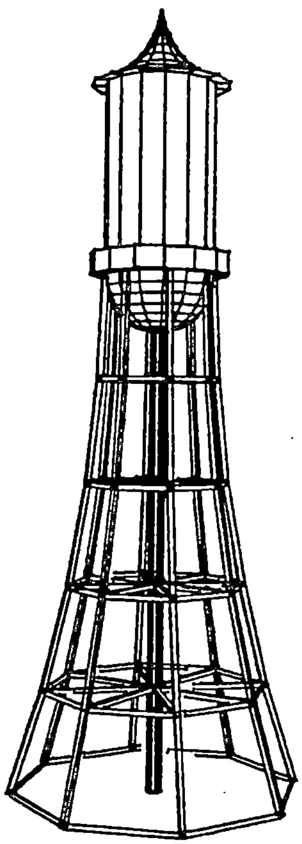

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List of Acronym Definitions

AASHTO	American Association of State Highway and Transportation Officials
ACPA	American Concrete Pavement Association
ADOT	Alabama Department of Transportation
AkDOT	Alaska Department of Transportation
ATRC	Arizona Transportation Research Center
Caltrans	California Department of Transportation
CDOT	Colorado Department of Transportation
CERF	Civil Engineering Research Foundation
CFRP	carbon fiber reinforced plastic
CRP	continuous rigid pavement
CtDOT	Connecticut Department of Transportation
DCDPW	District of Columbia Department of Public Works
DOT	Department of Transportation
FCD	fiber composite dowel
FDOT	Florida Department of Transportation
FHWA	Federal Highway Administration
FRP	fiber reinforced plastic
GDOT	Georgia Department of Transportation
GFRP	glass fiber reinforced plastic
HITEC	Highway Innovative Technology Evaluation Center
ICPA	Iowa Concrete Paving Association
IdDOT	Idaho Department of Transportation
IDOT	Iowa Department of Transportation
IlDOT	Illinois Department of Transportation
InDOT	Indiana Department of Transportation
ISU	Iowa State University
JRP	jointed rigid pavement
KDOT	Kansas Department of Transportation
LTD	load-transfer device
LTR	Load-Transfer Restoration
LTRC	Louisiana Transportation Research Center
MaDOT	Maine Department of Transportation
MDOT	Michigan Department of Transportation
MiDOT	Mississippi Department of Transportation
MoDOT	Missouri Department of Transportation
MSHA	Maryland State Highway Administration
NCDOT	North Carolina Department of Transportation
NDDOT	North Dakota Department of Transportation
NDOT	Nevada Department of Transportation
NeDOT	Nebraska Department of Roads

NHDOT	New Hampshire Department of Transportation
NMSHTD	New Mexico State Highway and Transportation Department
NSF	National Science Foundation
NYSDOT	New York State Department of Transportation
ODOT	Ohio Department of Transportation
OkDOT	Oklahoma Department of Transportation
PCA	Portland Cement Association
PCC	Portland Cement Concrete
SCDOT	South Carolina Department of Transportation
SDDOT	South Dakota Department of Transportation
SHRP	Strategic Highway Research Program
SS	stainless-steel
UDOT	Utah Department of Transportation
US	United States
VTRC	Virginia Transportation Research Council
WisDOT	Wisconsin Department of Transportation
WVDOT	West Virginia Department of Transportation
WSDOT	Washington State Department of Transportation

Chapter 1 Introduction

1.1 Background

HITEC, the Highway Innovative Technology Evaluation Center, has noted the increase in interest for the use of alternative materials for use in concrete highway pavement joints by representatives from industry, academia, and the highway design field. As a result, HITEC distributed a questionnaire, a copy of which is found in Appendix A, to representatives of the 51 Departments of Transportation (50 states plus the District of Columbia) to survey their thoughts about and experiences with alternative materials and concrete pavement joints. In December of 1996, Kathleen Almand of HITEC contacted Dr. Max L. Porter, a Professor of Civil Engineering at Iowa State University, to compile and interpret the results of the survey in the form of a concise paper. She included an additional list of topics that were deemed vital by HITEC in the assessment of alternative dowel materials, the review of which were to be included in the paper as a review of the literature available to and the knowledge of contacts made by Dr. Porter and his staff. Dr. Porter and Randall Braun subsequently accepted the task and have compiled the information contained herein.

Dr. Max L. Porter, and Randall L. Braun, hereafter referred to as the authors, have also noted the increasing interest in alternative materials. The authors have conducted several projects, given many presentations and lectures, attended numerous conferences, and made hundreds of contacts involving the use of alternative materials as reinforcement in concrete structures. Dr. Porter has also served on and chaired several committees formed to establish materials, such as fiber composites, as viable structural alternatives to concrete, steel, and timber.

1.2 Objective

The overall objective of the work contained in this paper is to identify background information on the use of load-transfer devices in highway pavement joints and to provide a preliminary assessment of the market potential for use of alternative materials in that capacity. The intent of the authors is to provide a concise compilation of information upon which HITEC personnel may judge whether or not the use of alternative materials for concrete highway pavement joints is worth a more thorough and rigorous evaluation.

1.3 Scope

To accomplish the stated objective, the paper is divided into four sections, Chapters 2, 3, 4, and 5, each containing information deemed vital to the preliminary assessment of alternative load-transfer devices. In Chapter 2, a compilation of the information provided by state organizations in the form of responses to the HITEC survey is presented in a textual format. The tabulated responses to the surveys are contained in Appendix B at the end of the paper. Chapter 3 presents a brief review of topics deemed vital by HITEC personnel to the evaluation of alternative material for concrete highway pavement joints. The contained information is the result of an extensive search of highway literature and expert knowledge. Recent findings of research investigations and field applications of alternative load-transfer devices are discussed in Chapter 4 to provide the most recent evaluations of performance of some of the currently available alternative products. Finally, in Chapter 5, the overall conclusions are discussed along with the major points resulting from the completed work. These conclusions are solely the interpretation by the authors of the information compiled in this paper and should not be considered that of HITEC personnel.

The authors stress the fact that the scope of this paper is limited to a largely qualitative analysis of the information and should be treated as the first step in the complete evaluation of the use of alternative materials in concrete highway pavement joints. No attempt was made to perform a rigorous statistical analysis of the survey information, nor was an "in-depth" assessment of the dowel market undertaken.

Chapter 2 Compilation of HITEC Survey Information

2.1 Responder Information

Of the 51 DOT's solicited for feedback about the use of alternative materials for concrete highway pavement joints, a total of 36 (71 %) responded by filling out the prepared survey. Many of the responders provided additional information and/or rationale for their response to the survey. Overall, the response by the various DOT's was quite favorable, with a vast majority indicating they would consider alternative materials for use in concrete pavement joints if proper justification were provided.

As a means of summarizing information provided on each returned survey, the authors of this paper compiled a table for each of the five major categories included on the surveys. **Table B1**, found in Appendix B, lists the 36 organizations who responded to the HITEC survey. Each responder was given a label ("ISU Label") by the authors so identification of individual responses would be more convenient. Throughout the remainder of the paper, reference will be made to specific organizations through the use of these labels.

Although most of the responders indicated they would consider alternative materials, four didn't completely fill out the survey because they haven't used PCC pavement for 15-20 years, or don't use enough to justify any additional expense with new materials. These four responders are NMSHTD[1], MaDOT, AkDOT, and NHDOT, which are not related by geography other than none are located in the Midwest, or central United States. The four responders who did not provide much information will not be included in the remainder of the paper.

On the other end of the spectrum, six of the responders, NYSDOT, KDOT, WVDOT, ODOT, IDOT, and NDDOT, indicated much interest in the use of alternative materials for concrete pavement joints. Responses from these organizations included supplemental information regarding past experiences and indications of both monetary, field, and personnel

[1] See Table B1 in Appendix B for identification of acronyms which are not spelled out in the text.

interest. Several references are made to reports written and data available regarding applications of alternative materials as load-transfer devices.

Overall, midwestern states appear to be the most interested in the use of alternative materials in concrete pavement joints due to corrosion problems caused by harmful chemicals such as deicing salts and freeze/thaw conditions which cause cracking of the pavement. Many of the states with moderate to dry climates indicated less interest in the alternative materials.

2.2 Background in PCC Joints

In Section 2.2, the second major category covered by the HITEC survey, background in PCC joints, is summarized and discussed. In the survey, responders were inquired about three main items: PCC joints currently used, load-transfer devices currently used, and the problems that are currently encountered in existing highway pavements. The responses to each item are discussed below..

Three types of standard joints are currently used in PCC highway pavements, as will be discussed in Chapter 3. Of the three joints, contraction joints are most commonly used as indicated by **Table B2**, located in Appendix B. Thirty-one of the 36 (86%) responders stated they use load-transfer devices in contraction joints, while 18 of 36 (50%) responded that expansion joints are specified. Of those 18, most said that expansion joints are rarely specified, normally in bridge abutment locations and other expansion areas.

Several types of load-transfer devices were listed by the responders as being currently used in their state. As anticipated by the authors, most of the responders indicated that round steel dowels are specified for transverse PCC pavement joints. However, many of the responses were quite vague, providing answers such as "Dowel Bars", "Dowels", and "Uncoated Steel", so interpretation of the responses had to be considered by the authors. Since the majority of the responders indicated using round steel dowels, the vague responses were interpreted the same as the majority. Specific responses included 13 state organizations that use epoxy-coated round steel dowel bars and 16 states that use round steel dowel bars.

Of the latter 16, only one specifically stated using uncoated steel dowels, therefore, the remaining fifteen could be interpreted as epoxy-coated steel dowel users. However, the authors are aware that, in some states, where epoxy coating is used, a bituminous or greasing agent is added on top of the epoxy coating as an additional coating material. Two states, NYSDOT and CtDOT, indicated using steel I-beams greased on one end as load-transfer devices. Only one state, NMSHTD, indicated use of stainless-steel round dowels, however, only sparingly. The only other load-transfer type mentioned was aggregate interlock, which was specifically mentioned by two states, however, the authors believe most of the states use this form of load-transfer but failed to indicate that on the surveys. Caltrans indicated exclusive use of aggregate interlock in the past, but future designs will specify dowels.

Although it wasn't specifically asked for, several of the state organizations indicated the dowel placement methods normally used in their states. As expected by the authors, all eight who specifically stated their chosen placement method indicated they normally specify baskets. However, three also stated they specify dowel inserters on rare occasions. If placement methods were specifically asked for on the surveys, the authors would anticipate the use of baskets by most of the states.

In response to the third question of the survey, many of the states indicated a large variety of problems encountered in PCC joint systems. Although many of the responses were quite vague, and included problems not associated with the load-transfer devices, a few problems were clearly identified by several of the states, most being corrosion related. The most common identified problem was the alignment/placement of the dowels, reported by eight of the responders. Equally encountered was joint faulting and cracking as indicated by eight of the responders. The other problems repeatedly mentioned were problems with dowels "seizing" due to poor bond breakers and corrosion and joint spalling. All of the major encountered problems, along with the number of responders reporting them, are listed in **Table 1**. Of particular interest in this category are eight of the states who reported little or no problems associated with pavement joints. Of these eight, four did not fully respond to the survey because they rarely use PCC pavements.

Table 1: Reported PCC Joint Problems

Problem Encountered	# Reported
Dowel misalignment/placement	8
Joint faulting/cracking	8
Joint spalling	5
Joint "seizing", "frozen" (bond problem)	4
Care for epoxy-coated dowels	2
Joint sealer cracking	4
Too much grease (air voids)	1
PCC consolidation	1
Non-durable aggregate	1
No reported problems	8

2.3 Required Performance Criteria

In Section 2.3, information is summarized regarding the performance characteristics required by the states for a dowel bar joint system. Responders were asked to rate the most important performance characteristics of a dowel bar joint system based on six criteria set forth by HITEC, namely, *ductility/toughness*, *corrosion resistance*, *availability*, *fatigue resistance*, *strength*, and *ease of installation.* The responders could also list any other characteristics they felt were important. All seven (six by HITEC plus one other listed by responder) were numbered in order of importance from 1 to 7, with 1 being the most important, 7 being the least important. Since the objective of the authors was to qualitatively summarize the results of the survey (i.e. no rigorous statistical analysis) a method was devised to analyze and present the responses of the state organizations.

As seen in **Table B3**, found in Appendix B, all six of the criteria are listed as column heads where numbers assigned by the responders are listed. These numbers are then totaled at the bottom of each column where the lowest total indicates the most important characteristic according to the state organizations. To put the overall response pattern in a chart form, the characteristic with the lowest total was normalized to 1.00, and the other characteristics factored accordingly. Since strength resulted in the lowest total of 88, all other totals were inversed and multiplied by 88 to give a qualitative measure. As seen in **Figure 1**, the results of this analysis shows that the criteria of strength was selected as the most important performance characteristic of the dowel bar joint system with a close second being corrosion resistance. The third, fourth, fifth, and sixth most important characteristics were

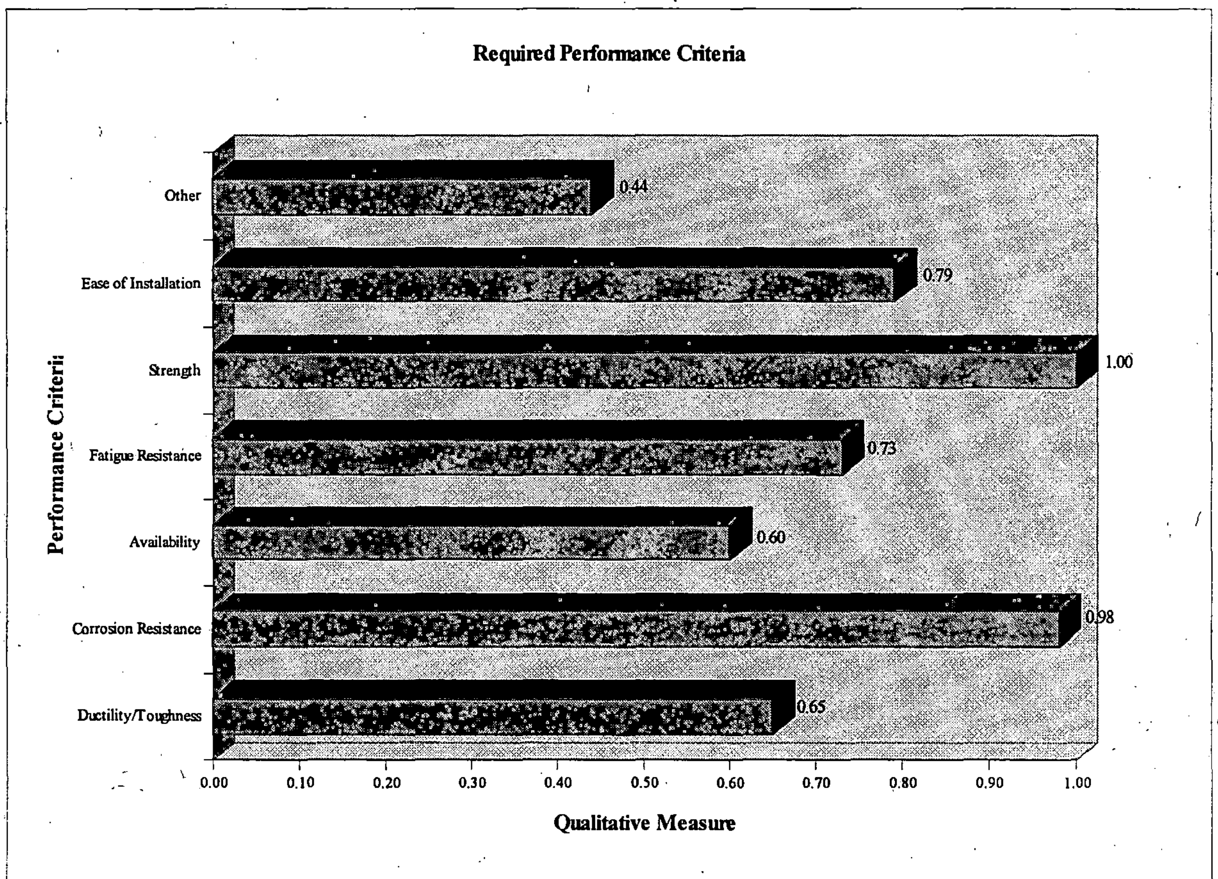

Figure 1: Required performance criteria

ease of installation, fatigue resistance, ductility/toughness, and availability, respectively. All four were very close to each other and considered significantly less important by the responders than the top two characteristics.

Several other characteristics were identified by the responders as being somewhat important in the performance of a dowel bar joint system. Two of the responders indicated that the *long-term durability* was an important characteristic, which could easily be related to corrosion resistance, strength, fatigue resistance, or ductility/toughness. One other responder indicated that the *ability to break the bond* with concrete is important. *Load-transfer* was listed by three responders which is more of a function than a characteristic, however, it could be considered a measure of strength for the purposes of this paper. The only other characteristic listed was *abrasion resistance*, related to ductility/toughness.

As a follow-up question, the HITEC survey asked the responders how much of a first-cost premium they would incur to achieve the required performance characteristics of the dowel bar joint system. Response to this question was somewhat vague with different responders interpreting the question differently. Of the 36 responders, 12 (33%) stated they would pay little or no more of a premium above the current standards for an alternative product, 8 (22%) were unsure of their financial commitment to alternative materials, 4 (11%) stated they would pay more, and 3 (8%) said they would consider the life cycle costs associated with a new product. Seven of the responders did not complete an answer to the question, while two of the responders answered with "ball-park" dollar amounts or percentages which were interpreted as "none" or "more" at the authors' discretion.

2.4 Consideration of Alternative Materials

In the fourth major informational category, the HITEC survey questioned the responders about their consideration of alternative materials for use in dowel bars. Section 2.4 summarizes the response of the state organizations based on two areas: their experiences, if any, with alternative materials, and their future consideration of using alternative materials.

The background information provided by the responders regarding the use of alternative materials is included in **Table B4** (Part 1 of 2), located in Appendix B. Of the 36 responders, 14 (39%) stated they have considered alternative materials for dowel bars, while 22 (61%) stated they had not considered alternative materials. When prompted to list the materials considered, 11 of 14 (79%) stated that they had either considered or implemented fiber composite materials, while only 4 (29%) listed the consideration of stainless-steel as a dowel bar alternative material. Other responses included "non-corrosive", interpreted as either stainless-steel or fiber composite, and a 2-component iron-malleable load-transfer device briefly used by NYSDOT. Additionally, a patented dowel system called X-Flex™ was mentioned by KDOT as an alternative considered by their designers.

Similar to the responses to the required performance criteria, corrosion resistance was the primary reason listed by 8 of the 14 (57%) state organizations who stated they have considered alternative materials. The second most popular reason listed for alternative material consideration was the low pullout strength exhibited by both the fiber composite and stainless-steel bars, listed by 3 responders. A low pullout strength is a significant advantage of the alternative material dowels in that it allows the pavement slab to move freely without the addition of bond breakers. Other reasons listed included the need to analyze the cost/benefit ratio, the ease with which fiber composite dowels can be manufactured in different shapes to ease PCC stresses, easier installation (probably low weight consideration), and research.

As a result of alternative material consideration, several of the responders indicated that they had implemented test pavement sections with the new dowels. Although most (5) indicated that evaluation of the new materials was "too-soon-to-tell", implementation has appeared to be met with mixed results. Personnel from the ODOT came to the conclusion that stainless-steel doubles the cost of construction while not really improving performance, and fiber composites cost approximately the same with adequate performance. Additionally, the GDOT indicated that installation of the fiber composite dowels went smoothly, even though it's too soon to evaluate their long term performance. On the other hand, KDOT indicates that the cost/benefit ratio of the new materials is far from proven. The NDOT goes one step further, stating that by using the fiber composite dowels, the strength of the joint is reduced while the cost goes up. As a whole, the response from the state organizations is that it is too soon to completely evaluate the effectiveness of the alternative materials.

The future consideration of alternative materials, given certain criteria are met, was asked of each state organization, the responses of which are summarized in **Table B4** (Part 2 of 2). As seen, 31 of the 36 (86%) responders indicated they would consider alternative materials for dowel bars, and of the five who said they wouldn't consider alternative materials, 4 don't use PCC pavements. When prompted for the improvements expected by the new materials, a great majority of the responders indicated increased corrosion resistance as a major factor in their consideration of the alternative material. A smaller portion indicated that no performance improvement would be needed as long as the cost (immediate or long-term) would be reduced. Others expect improvements including lighter weight dowels, less care in handling, ease and accuracy of installation, reduced maintenance, and lower pullout strength, possibly to eliminate the need for a bond breaking agent. The locations identified as the most probable for placement of the alternative material dowels included rehabilitation/retrofit sites (3), corrosive environments (2) and research sites (2). However most of the state organizations (10) indicated that no special location would be designated for alternative dowel placement, which was interpreted as meaning that, if approved, they would specify dowels in any joint that would require them.

Before any of the state organizations would consider using alternative materials for PCC highway pavements, HITEC anticipated that they would require information regarding their performance. Accordingly, responders were asked to rank the four most important performance information types required for acceptance of the new materials. Similar to required performance criteria of Section 2.2, four types of performance information, labeled *AASHTO specification*, *long-term demo. project*, *non-propriety joint system*, and *cost data*, were ranked from 1 (highest) to 5 (lowest). The results were qualitatively analyzed in a similar manner as the required joint performance criteria by adding up each column and selecting the information type with the lowest total as the most important. As indicated in **Figure 2**, by a large majority, the most important type of information required by the state organizations is the completion of a long term demonstration project showing the adequacy and advantages of alternative materials in a dowel joint system. Coming in a distant second and third are the requirements of an approved AASHTO specification and complete cost data, respectively. The fourth, and least important required information is a non-propriety joint system. Four of the responders indicated other required information types, including *laboratory and/or test track data*, *abrasion and corrosion data*, and other engineering data regarding the performance of the alternate materials as dowels. The NYSDOT representative indicated that alternative material dowels would only have to meet the current specifications for dowels in their state, details of which are included in Appendix C.

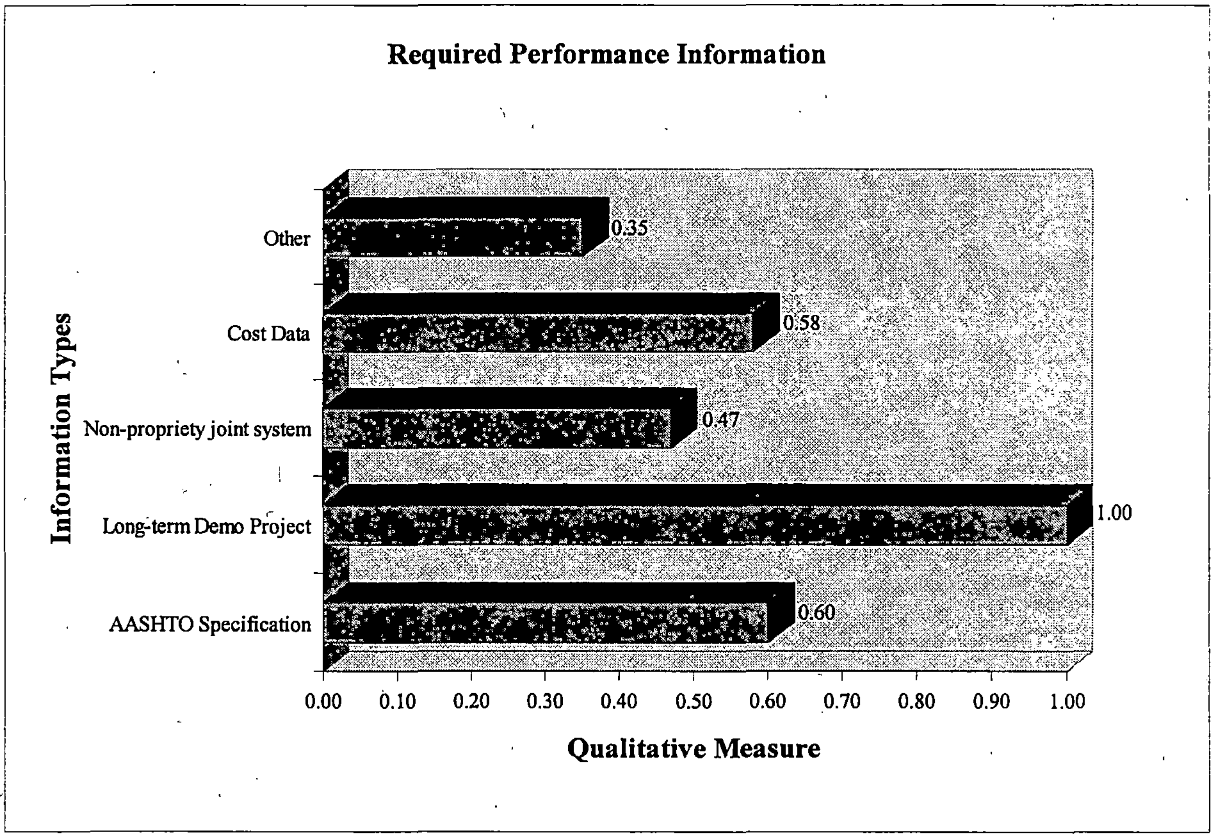

Figure 2: Required performance criteria

2.5 Interest in HITEC Participation

In the fifth, and final category of information, HITEC asked the state agencies about their interest in participating in future HITEC activities related to the use of alternative materials in highway pavements. Similar to the other four categories, the interest in HITEC participation information was summarized by the authors in **Table B5**, located in Appendix B. The overall response by the state organizations appears encouraging for the future of alternative material dowels.

Of the 34 responders who answered the questions posed by HITEC in this final category, 14 (41%) stated they would be interested in participating on a HITEC evaluation panel that would be established to evaluate alternate materials for dowel bar joints. As anticipated, most of the interested responders were from midwestern states who are already involved in alternative materials for dowel bars. Of the 14 interested responders, 9 (64%) stated they would consider serving as a test-bed site for a demonstration of bar performance. Two other organizations, FDOT and IDOT, also stated they would be interested in a test-bed site, even though they are not interested in serving on a HITEC panel. Therefore, a total of 11of 32 (32%) responders were interested in providing locations for bar performance evaluation.

Several of the responders included additional information regarding their experiences involving alternative materials for dowel bars. A one-sentence summary of the supplemental information is included in **Table B5**, however, the fully detailed information is included in the original surveys. Most of the information supplied by the responders was in the form of references to reports written by researchers associated with or funded by the state organizations. In particular, the WVDOT, ODOT, NDDOT, WisDOT, MDOT, IDOT, and the MoDOT indicated they had either completed reports or have data available about recently implemented projects. The NYSDOT included a packet of information about their experiences with alternative materials and an extensive list of reference materials including research reports and value engineering proposals.

Some of the supplemental information provided by certain responders is included in Appendix C. Included is the actual materials sent by the NYSDOT to HITEC which includes an index of research publications and the state specifications for transverse joint supports. Also included is a more detailed summary of the supplemental information provided by certain responders, including research report titles and contact person information. Further discussion of the supplemental materials provided by the responders is found in Chapter 4.

Chapter 3 Review of HITEC's Major Topics

3.1 Introduction

The intent of the following section is to provide HITEC with an idea of what is being done with transverse joints as far as design and the failures occurring at those joints. Additionally, estimates of the current and potential use of dowels are made so HITEC personnel can assess whether or not to go ahead with further evaluation of alternative materials for concrete highway pavement joints. The topics are split into three categories identified as the most important by HITEC: (1) *marketing information*, (2) *design specifications*, and (3) *performance issues*.

3.2 Marketing Information

The following section outlines research completed by ISU personnel on the potential market of alternative materials in the manufacture of dowel bars. As mentioned in Chapter 2, the objective of the market assessment is to provide HITEC with a "light" overview of the pavement quantities, both existing and anticipated, for jointed rigid pavement (JRP). Several other topics are covered including possible target areas or "hot spots", relative market shares of concrete paving, and estimates of future quantities of JRP. The expected result of this section is to give HITEC an indication whether or not to proceed with a more thorough and rigorous analysis of the potential market for alternate materials for dowels.

3.2.1 Existing Jointed Rigid Pavements (JRP)

To assess the amount of JRP that exists in the continental United States, the main source used was the yearly compilation by the Federal Highway Administration (FHWA) titled Highway Statistics 1994 [1][2]. In this document, mileage of public roads are split into many categories, such as jurisdiction/functional system, surface type, and pavement condition. For this paper, the most applicable category was the surface type which was in

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[2]Numbers in brackets [ ] indicate references found at the end of the report.

turn split into many categories such as several unpaved road types, three flexible pavement types, composite pavements, and rigid pavements. However, the rigid pavement category was not split between JRP and continuous rigid pavement (CRP), which was required to satisfactorily complete the objective of this section. Therefore, estimation of the relative amounts of JRP and CRP had to be considered by the authors.

In order to accomplish this task, the authors conducted several telephone interviews with knowledgeable people from organizations such as the Portland Cement Association (PCA), the American Concrete Pavement Association (ACPA), the Iowa Concrete Paving Association (ICPA), and the Iowa Department of Transportation (IDOT). Additionally, face-to-face interviews with members of the Iowa State University (ISU) faculty provided valuable information. The basic approach taken in these interviews was to retrieve any information from these individuals that related to the current use of concrete and dowels in JRP and CRP, and the future use of concrete and dowels in JRP and CRP in both rehabilitation/restoration and new pavement applications. Although all of the contacted persons stated that estimation of future use of concrete, especially in rehabilitation/restoration projects, is very difficult to accurately determine, the results of the interviews yielded much information regarding the use of concrete in JRP and CRP.

The overall consensus by the interviewees and subsequent literature points to the fact that JRP comprises a very large percentage of the total amount of rigid pavements that exist in the U.S. According to Dr. James Cable, professor of Civil Engineering at ISU, most upper level rigid pavements, such as principal arterial roads, are JRP while the minor arterial rigid pavements could be anywhere from 50% to 90% JRP [2]. Further, Mr. Clint Solberg of the ACPA estimates that approximately 90% of all rigid pavements are JRP, with that number rising every year. For example, the state of Wisconsin has approximately 90-95% JRP of existing pavement and all planned rigid pavement is JRP [3]. Similarly, Mr. Brian McWaters of the IDOT estimates that only 4% of all new rigid pavement in the next five years will be CRP, which reflects the percentage of existing rigid pavement [4]. These large percentages of JRP are supported by materials sent to the authors by Mr Jerry Voight of the ACPA. Included in the information sent by Mr Voight were three maps indicating the relative use of

JRP and CRP for each state. As seen in Appendix D, only Texas, Oklahoma, Oregon, and Maryland predominately use CRP on major highways, while the remaining states primarily use either plain or reinforced JRP. These maps qualitatively support the large percentages of JRP reported by Dr. Cable, Mr. Solberg, and Mr. McWaters. ~~As a result of this investigation, the authors made the assumption that 90% of all existing and future rigid pavements are JRP.~~

Using the information contained in the FHWA statistical compilation [1] and the interviews, a table of the total mileage of JRP was compiled. **Table 2** contains the results of this investigation including the total mileage of unpaved, flexible, and composite roads, as well as the rigid pavements. As seen, the total number of JRP is dwarfed by the relatively large number of unpaved roads and flexible pavements that currently exist. Although not indicated, some percentage of the composite pavement does include the use of dowels to transfer load. However, a much more rigorous search would have to be conducted to even estimate that percentage.

Table 2: Existing Public Road and Street Mileage[3]

Jurisdiction	Surface Type					
	Unpaved	Flexible	Composite*	Rigid	Total	JRP (90% Rigid)
Total Rural	1,537,469	1,424,237	78,391	52,856	3,092,953	47,570
% Rural	49.7	46	2.6	1.7	100.0	1.5
Total Urban	33,395	655,361	49,464	75,371	813,591	67,834
% Urban	4.1	80.5	6.1	9.3	100.0	8.4
Total Rural and Urban	1,570,864	2,079,598	127,855	128,227	3,906,544	115,404
% Total	40.2	53.2	3.3	3.3	100.0	3.0

*Composite roads are defined as those with a bituminous (flexible) layer of 1 inch or greater above a rigid pavement base.

[3]**Table 2** was adapted from Table HM-12, Page V-6 of Reference 1.

3.2.2 Estimation of New JRP and Dowel Use

The estimation of the amount of new JRP and the number of dowels that will be specified for the entire U.S. in the next five years was a somewhat arduous task that required several assumptions to be made on the part of the authors. To more accurately accomplish this task, the time consuming job of obtaining estimates of total paving from each state would be required. Due to the preliminary nature and limited scope of this paper, a simpler approach was taken which used data compiled by PCA personnel that tracked and analyzed the general trend of national concrete used in highway pavements [5]. Additionally, quite accurate data was obtained from Mr. Gordon L. Smith of the ICPA which included past and future estimated annual PCC paving quantities for the State of Iowa [6]. The basic approach used by the authors was a two step process: (1) determine the number of dowels required yearly by the State of Iowa and (2) extrapolate that data based on national trends of concrete usage identified in Reference 25 to result in a national yearly dowel requirement. The results of this approach are considered preliminary estimates and should only be considered as "ball-park" figures.

The first step in the estimation process was to determine the use of PCC pavement and dowels in the State of Iowa. **Table 3** lists the estimated square yardage of PCC pavement for the State of Iowa in 1997 as compiled by the ICPA [6]. According to Mr. Gordon L. Smith, all of the primary paving and 20% of the secondary and airport paving will require the placement of dowels [7]. Therefore, only 20% of the secondary and airport while 100 % of primary PCC paving quantities are summed for a total of 2,425,660 square yards of PCC. Assuming a lane width of 12 feet, slab length of 20 feet, 1 joint per slab, and 12 dowels per joint, the total calculated number of dowels required in the State of Iowa equals approximately 1,100,000 for 1997. This quantity is indicated in **Table 4**.

Table 3: Estimated State of Iowa Required Doweled PCC Paving Quantities [6]

	Functional System			
	Primary	Secondary (20%)	Airport (20%)	Total
1997 Estimate (yd^2)	2,130,600	245,060	50,000	2,425,660

The second step in the estimate of required quantities of PCC pavement and dowels was to relate the calculated Iowa quantities to the entire U.S. The approach used by the authors was to first determine which states use a significant amount of PCC pavement and which do not. Then the users of PCC pavement were compared to the State of Iowa based on the existing rigid pavement mileage in each state, as tabulated in Reference 1. The comparison was quantified in the form of a ratio in which the mileage of rigid pavements existing in Iowa was divided by the average mileage of rigid pavements existing in the other states which regularly specify PCC pavement. The resulting ratio was then applied to the calculated number of dowels required yearly by Iowa to result in the calculated number of required dowels per state, and subsequently, the entire U.S., per year.

According to a compilation of national trends by PCA, the six states of Alaska, Massachusetts, Montana, New Hampshire, New Mexico, and Vermont specify no significant amounts of PCC pavement [5, p. 3]. Therefore, these six states were not considered in the determination of the calculated ratio. Further, PCA identified Iowa as among the top ten states which specify PCC pavements [5, p. 3], which suggested the calculated ratio would be considerably less than one (i.e. Iowa requires significantly more PCC pavement and dowels than the national average). Using **Table HM-31** of Reference 1, Iowa has 2,112 miles of existing rigid pavement in principal arterial roads. Additionally, the average for the other 43 states and the District of Columbia is calculated to be 753 miles of existing rigid pavement per state in principal arterial roads [1, p. V-15]. As anticipated, the resulting ratio is then 753/2,112 = 0.36, far less than 1.0. The ratio of 0.36 was then applied to the Iowa quantities for required PCC pavement and dowels. **Table 4** lists the estimated quantities for Iowa and the U.S. based on the preceding approach. As seen the considerable quantity of 18,500,000 dowels per year is estimated to be required by the entire U.S., definitely a potential market for prospective suppliers.

Although the large numbers indicated by **Table 4** are probably conservative estimates for the entire U.S., many factors would effect the need for non-corrosive bars. For instance, several of the states located in dry, warm climates, indicated on the surveys that they do not experience corrosion problems with their current steel dowels. Also, a few states such as

Texas, do not specify much JRP as supported by the maps in Appendix B, and would not require as many dowels as assumed in the preceding calculations. Overall, however, the values in **Table 4** are good "ball-park" estimates.

Table 4: Estimated PCC Paving and Dowels Required for Iowa and U.S.

Geographic Area	Estimated Doweled PCC Paving (yd^2 per year)	Estimated Required Dowels (number per year)
Iowa	2,425,660	1,100,000
United States*	40,850,000	18,500,000

*Assumes 44 states (including the District of Columbia) and a reduction factor of 0.36 from the Iowa quantities.

In addition to quantity estimations, the authors obtained information regarding the general trends of the PCC share in the paving market and characteristics of decision making for road paving. The two main sources cited for this discussion are the FHWA Material Use Factor Share Analysis [5] and the Road Paving Decisionmaker Study [8], both compiled by the Portland Cement Association Market Research Division.

Nationally, the PCC market share of overall pavements has declined by approximately 1.5% every three years since its peak of 35.1% from 1967-1969. Since 1987, however, PCC paving has remained very steady at 22% of the total market share of pavements in the U.S. The remaining market for paving is comprised of flexible pavements, such as asphalt, or bituminous concrete. The theory for this trend of PCC paving, as theorized by PCA, is that new highway construction has also declined considerably since the 1960's, while overlays of the older deteriorating highways have increased, resulting in decline of PCC and subsequent growth of flexible pavements. The recent steadiness of PCC paving may be attributed to the increasing need for complete reconstruction after several overlays have been applied [5, p. 2].

According to the PCA, the top ten states utilizing concrete paving in the past five years are Utah, Kansas, West Virginia, Iowa, Nevada, Wisconsin, Nebraska, Michigan, Louisiana, and Texas. As mentioned in Chapter 2, several of these states were also very interested in the use of alternative materials in dowels. The bottom-ten states , or those specifying the least PCC compared to flexible pavement, are identified as Alaska, Massachusetts, Montana, New Hampshire, New Mexico, Vermont, Delaware, New Jersey, New York, and Alabama. In support of these rankings, New Hampshire, Alaska, New Jersey, Vermont, and New Mexico did not complete a survey, nor indicate any real interest in alternative materials for use in dowels, as noted in Section 2.4 [5, p. 2].

In an evaluation of current decisionmaker attitudes and material usage patterns conducted by PCA in 1991, the attitudes and decisions of highway designers were assessed with regard to the use of PCC in pavements. The two factors perceived as the most important when deciding which pavement materials to use are *initial cost* and *maintenance cost*, with life-cycle cost not mentioned very often. Since life-cycle costs are vital to the future use of PCC pavements, the PCA has since implemented several approaches to emphasize this material evaluation technique [8, p. 12]. The consideration of life-cycle costs is also vital for the future use of alternative materials due to their generally high initial costs.

3.2.3 Rehabilitation and Dowel Use

Prediction of future use of dowels in rehabilitation applications is even more difficult than the estimation of new pavement quantities due to the lack of comprehensive data. However, given the limited scope of this paper, the need for actual quantity estimation was deemed unnecessary after discussion with experts in the field.

According to Larry Mosher, head of the Restoration Division of the ACPA, all of the rehabilitation efforts that have required dowels in the last ten years have used a relatively insignificant amount of dowels compared to the total required by new paving. He supports his argument by remarking that only 5% of all existing doweled joints have required full-depth repairs, usually using 20 dowels per repair. Additionally, Load-Transfer Restoration (LTR), a process described in Section 3.4.2, uses only 6 dowels per repair and is far less specified than full-depth repair, a process requiring pavement replacement. Since LTR is a relatively new repair process (≤5 years), he estimates that a total of one million bars have been used for this application in that time, usually with jobs requiring 5,000-10,000 total bars. Mr. Mosher adds that the practice of rehabilitation of transverse joints in existing pavement, especially LTR, probably has a finite life of 4-5 years before all old pavement has been restored, with the remaining pavements all designed according to the improved standards. Mr. Mosher did not have any summary statistics of total amounts of PCC or dowels used in rehabilitation efforts, adding that such a summary would be very difficult to obtain due to the sporadic nature of such jobs [9].

The sentiments of Mr Mosher were supported with testimony by Mr. Brian McWaters of the IDOT who stated that not much rehabilitation is specified that requires dowels. Generally this lack of rehabilitation is due to economic reasons because the placement of new pavement is generally less expensive than repair, or retrofit, of a transverse joint [4]. Dr. James Cable of ISU states that 20%-40% of all pavements in service are beyond their original design life of 20 years, however he did not know how much of these would require dowel placement. He did go on to mention that the use of LTR does have merit if used in the correct situation, such as the presence of strong pavement and access to the correct construction equipment. Without these elements, the cost and performance effectiveness of LTR decreases rapidly and the use of pavement replacement is recommended [2].

Overall, the total potential market for dowels in rehabilitation applications appears to be quite small compared to potential in new pavements. This trend is supported by the opinions of experts with first hand knowledge of rehabilitation of rigid pavements. Since the total market is small for rehabilitation dowels, a rigorous statistical estimate of the quantity of dowels was not attempted by the authors. However, since only a ballpark figure is desired, the percentage of all existing transverse joints that require full-depth repairs, estimated by Mr. Mosher as 5% of new pavements [9], was considered directly proportional to the required number of dowels used in repair situations. Using this logic, the potential market for dowels in rehabilitation applications is assumed to be 5% of that for new pavements. For the U.S., according to the approach used in Section 3.1.2, a total of 925,000 dowels (18,500,000 * 5%) would be required yearly in rehabilitation projects.

3.3 Current Joint Design and Materials

The intent of the following section is to provide HITEC with information related to transverse joint design, construction, and performance as it currently exists in the field. A brief discussion is presented of the current dowel material types, geometry, and coating techniques.

3.3.1 Jointed Rigid Pavement (JRP) Design and Specifications

Due to the limited scope of this paper, a complete review of all aspects of jointed rigid pavement (JRP) design was not attempted. However the following section outlines the aspects of JRP design which are most important in the assessment of market potential for alternative material dowel bars, namely, a description of basic design values for joint spacings, dowels spacings, and slab thicknesses. Additionally, three transverse joints typically specified for JRP, contraction, expansion, and construction, are discussed from the perspective of their purpose, where they are used, and their relative amount of use in JRP.

One of the most important aspects of JRP design is the spacing of transverse joints because the shorter the spacing, the higher the number of joints, and therefore the more load-transfer devices (LTD's) are required. In general, the spacing of transverse joints depends on local conditions of materials and environment, construction capabilities, and the layout of the road, depending on the type of joint specified. According to the AASHTO Guide for Design of Pavement Structures 1993, transverse joint spacing (in feet) should not greatly exceed twice the slab thickness (in inches) [10, p. II-48]. For example, the transverse joint spacing for an 8-inch slab should not exceed 16 feet. In a typical Iowa Department of Transportation (IDOT) highway pavement design, 20-foot transverse joint spacings are specified. In several states, transverse joints are spaced in a random pattern to prevent rhythmic or resonant responses in vehicles traveling over the pavements. The standard in California calls for a joint spacing pattern of 13-19-18-12 feet, while Michigan has specified spacings of 13-17-16-12 feet [10, p. 121]. Overall, a wide variety of joint spacings are found across the country, anywhere from 7.5 feet to 60 feet.

Determination of slab thickness is a very important part in the design of a JRP, and it also effects the need for dowels to transfer the load from one slab to the next. Design of the slab thickness is dependent on several variables such as the geometrical and mechanical properties of the base, the amount of vehicle travel anticipated over the design life of the pavement, and the local environmental conditions. A typical highway pavement design calls for a slab thickness of 8-12 inches with extreme conditions requiring slabs up to 14 inches thick.

The amount of dowels required for each transverse joint is dependent on the diameter of each dowel and the Modulus of Elasticity of their constituent material. According to AASHTO's Guide Specifications For Highway Construction 1988, dowels shall be spaced in one-foot centers and held in position with a wire basket or mechanically implanted [12, p. 139]. Additionally, most local specifications require dowels to be placed no closer than six inches from the edge of the pavement slab. A typical lane width is shown in **Figure 3**, where the dowels are spaced at 12 inches on-center over a 13-foot lane width, for a total of 13 dowels per joint per lane width. The one-foot spacing required by AASHTO assumes that steel (typically 60-80 grade) is used for the dowels, however, if other materials such as glass fiber-reinforced plastic (GFRP) is used, the spacing may have to be considerably less due to GFRP's much lower Modulus of Elasticity. In a study conducted by Dr. Max Porter, a spacing of 8 inches was required for 1.75 inch diameter GFRP dowels to perform equivalent to 1.5 inch steel dowels spaced at 12 inches on center [13].

Lane widths, also very important to pavement design and dowel bar assessments, are generally 12-13 feet for U.S. highways. However, various functional categories such as interstate, arterial, or local roads may vary considerably in width.

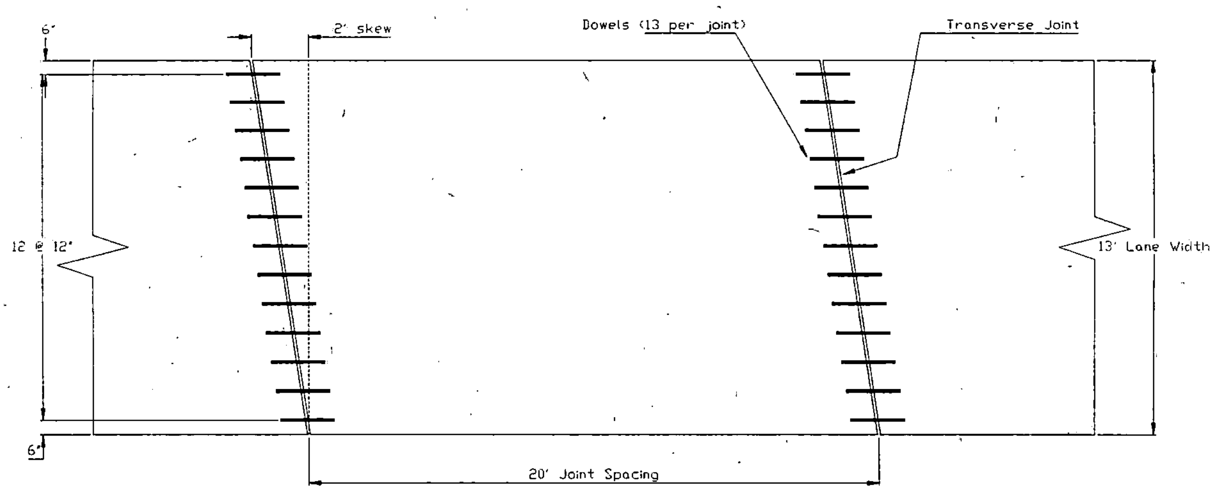

Figure 3: Typical joint and dowel placement, single traffic lane

Three types of transverse joints are generally specified for JRP that may or may not require the use of LTD's: *contraction, expansion,* and *construction.* Contraction and expansion joints were available as options on the survey sent out to state DOT's, however, several of the responders indicated the use of construction joints as well.

Undoubtedly, the most common type of joint in JRP is the contraction joint, this fact being supported by both the available literature and the responses on the survey. Sometimes called "dummy" or weakened-plane joints, contraction joints are provided to relieve the tensile stresses induced in the concrete as a result of its shrinkage caused by temperature and moisture fluctuations [10, p. II-49]. Without contraction joints, random cracking would occur on the surface of the pavement allowing harmful chemicals and water to reach the reinforcement below. Additionally, contraction joints impede the progress of longitudinal cracks, allowing repair to correct a problematic situation instead of total pavement replacement. A typical doweled contraction joint is shown as type "CD" on the IDOT Standard Road Plan RH-50, found in Appendix E. Also shown on this road plan is the details of a typical joint seal approach. Joint sealants are provided to minimize the infiltration of surface water and incompressible material into the joint system. Joint sealants also protect the dowel bar from de-icing chemicals, thus reducing their potential for corrosion [14].

Another transverse joint commonly found in highway pavements is the expansion joint. The primary function of expansion joints is to allow the concrete to expand from thermal changes and prevent high compressive stresses from forming [10, p. II-49]. These compressive stresses may result in pavement buckling and blowups [15]. Expansion joints are generally much wider openings than contraction joints and are far less specified due to cost, complexity, and performance problems. Typically, expansion joints are specified where pavement types change, such as near prestressed pavements and highway structures, and at intersections.

Construction joints, also very common in the U.S. highway system, are basically contraction joints that are placed to facilitate construction [10, p. II-49]. These types of joints are placed at the end of a day's work or where equipment breaks down. There isn't much difference between construction joints and contraction joints, only the placement of construction joints is dictated by field placement and equipment capabilities while contraction joint placement depends more on local conditions of materials and environment.

3.3.2 Dowel Types and Coatings

Since the onset of corrosion, and its subsequent distress on U.S. pavements, numerous methods of coating the standard carbon steel dowels have been attempted. Going one step further, complete replacements for the carbon steel dowels have been studied, such as stainless-steel and fiber composites. In the following section, numerous methods of coating or replacing steel are briefly described.

By far the most widely used type of dowel in the United States is the round carbon steel dowel, typically 1.5 inches in diameter by 18 inches long. To prevent corrosion, the use of some sort of epoxy coating predominates. Several methods of epoxy coating have been attempted including powder coating [16], organic coating [17], and many propriety coatings such as Tarset, Adipene L-167, and RC-70 [18]. The relative differences between types and methods of epoxy coating have been quite varied. However, the overall effectiveness of epoxy is good if proper care is taken prior to and during placement. The most common failure of an epoxy-coated dowel is the presence of an imperfection of the coating, or "holiday", which may be caused by nicking or general mishandling during construction. The imperfection acts as an access location for water and harmful chemicals to begin the corrosion process on the unprotected steel. Several other non-metallic coatings have been attempted to protect steel dowels including the use of bituminous materials [19].

In addition to non-metallic coating, several attempts have been made to apply inert metallic coatings to the vulnerable carbon steel. Attempts have included the use of Zinc and Nickel plating and hot-dip galvanization, both exhibiting poor corrosion resistance at a high cost [18]. The use of plasma spraying metallic microcomposite powders onto the dowels has proven to work satisfactorily [19].

In a more successful attempt at thwarting the corrosion process, stainless-steel, or Monel steel, has been used in replacement of the conventional carbon steel used in dowels. Although the performance of the stainless-steel has proven satisfactory in regards to corrosion resistance, the initial cost of such dowels has stood in the way of this technology's progress. In an attempt to offset this high initial cost, a study conducted by the FHWA, hollow stainless-steel dowels filled with concrete were subjected to rigorous lab testing and directly compared to similar solid bars [20]. The performance of the 1.66 inch outside diameter pipe with 0.109 inch wall thickness and filled with concrete proved to be significantly better than its 1.25 inch diameter solid stainless-steel counterpart [20, p. 42]. Additional evidence of the use of stainless-steel dowels was indicated by the responder from the NMSHTD survey, as mentioned in Section 2.2; however, their use was quite limited.

Of the steel alternatives, glass fiber-reinforced plastic (GFRP) appears to be gaining the most recent popularity in the highway industry. However, GFRP dowels appear to have a similar disadvantage to the stainless-steel dowels in that their initial cost can be significantly higher than the conventional steel dowels. This fact may be short-lived, however, with the larger number of dowels produced and the cost of glass-fibers and resin decreasing.

In a study conducted by the University of Ohio, E-glass fibers longitudinally set in a modified epoxy resin with a clay filler were pultruded and cut-off to form dowels [21]. Similarly, in another study, continuous aligned glass fibers, called *rovings*, were used to construct Fiber Composite Dowels (FCD) [22]. Further, in several studies conducted at Iowa State University, the use of E-glass in a vinyl ester resin was employed to construct GFRP dowels [13,23,24]. Overall, the use of glass fibers encapsulated in resin has proven to meet or exceed the performance of conventional carbon steel when the correct dowel dimensions and spacings are employed. However, in a study conducted at Iowa State University, some off-the-shelf GFRP products exhibited corrosive behavior when subjected to highly alkaline environments, which are found in the porewater of PCC. The results of this investigation, and several other field and laboratory studies are discussed in more detail in Chapter 4.

3.4 Performance Issues

Essential to the assessment of the use of alternative materials as dowel bars is the identification of the failures, or distresses, of pavements currently in use in the United States. Since the scope of this paper is limited to the discussion of load-transfer devices, only distresses associated with LTD performance and other transfer joint problems will be discussed in the following section. However, if more detailed information concerning all of the distresses occurring in highway pavements is desired, the reader is directed to Reference 25 and additional references contained therein.

3.4.1 Common Failures of Transverse Joints in Rigid Pavements

A highway pavement can fail in numerous ways, including blowups, pumping, map cracking and scaling, polished aggregate, popouts, corner breaks, longitudinal and transverse cracking, and bleeding [25]. However, the three typical failures, or distresses, that can be directly associated with transverse joints and load-transfer devices are (1) *transverse joint seal damage*, (2) *spalling of transverse joints*, and (3) *faulting of transverse joints* [25, p. 47]. All three, indirectly and directly referred to as the main modes of failure by survey responders in Section 2.2, are briefly discussed below.

Transverse joint seal damage is "any condition which enables incompressible materials, or a significant amount of water to infiltrate the joint from the surface" as defined by the Strategic Highway Research Program [25, p. 48]. Such a failure, probably the most common type found on highway pavements, may result in total corrosion of the dowels and other reinforcement and high compressive stresses in the joint face due to the incompressibles preventing the movement of the slabs. The compressive stresses ultimately result in spalling of the joint face, as seen in **Figure 4** [14, p. 11]. Additionally, the dowel corrosion may prevent the necessary movement of the slabs causing additional cracking and spalling, and also, corrosion may result in full or partial loss of load-transfer strength in the dowel. The most common reason for the failure of a sealant is its improper installation [14, p. 2]. Great care must be taken to prepare the joint reservoir prior to sealant placement.

The second major distress occurring at transverse doweled joints is *spalling*, one of the results of the joint seal failure. Spalling is defined as "cracking, breaking, chipping, or

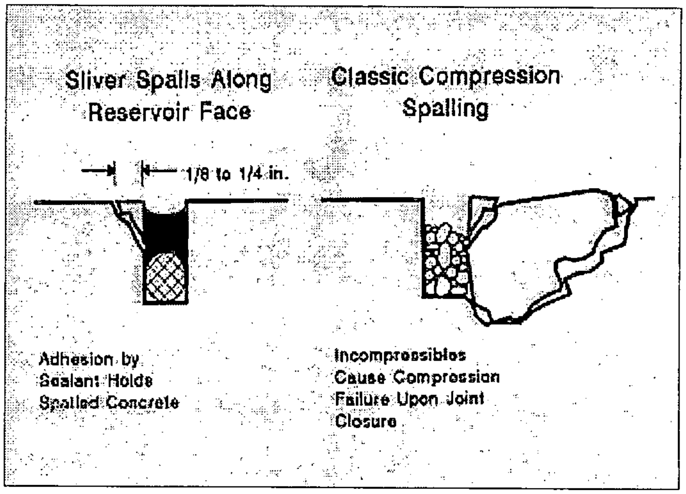

Figure 4: Typical joint seal failure

fraying of slab edge within 0.6 m (2 ft) of transverse joint" [25, p. 50]. Spalling, as pictured in **Figure 5** below, results in very "bumpy" road conditions and allows the infiltration of water to increase causing more pavement distress. The major causes of spalling include the misalignment of dowels during construction, the corrosion of dowels and subsequent joint lockup, and the high bearing stresses of the small, round dowels on the surrounding concrete. These causes were referred to emphatically by survey responders in Section 2.2.

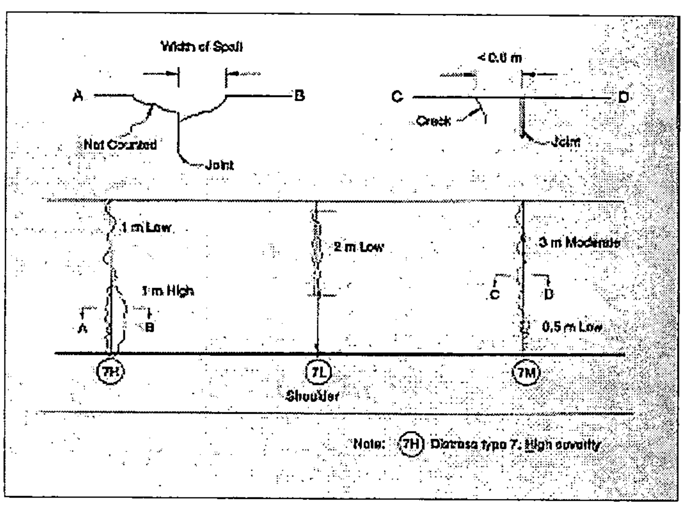

Figure 5: Typical joint spalling

The third, and final, major joint distress is *faulting*, or the "difference in elevation across a crack or joint" [25, p. 57]. When faulting is encountered, a more serious level of "roughness" occurs on the pavement, and may reach the point of unsafe driving conditions. Although many causes may result in joint faulting, such as loss of subgrade support and frost heave, the cause most applicable to the content of this paper is the loss of load-transfer strength in the joint system. Loss of load-transfer strength may be the result of dowel bar corrosion, yielding of the steel dowel bar, spalling of the concrete around the bar due to improper placement, or the inclusion of air voids in the surrounding concrete due to a poor bond breaker applied during construction. A typical joint faulting situation is depicted in **Figure 6** [25, pg. 57].

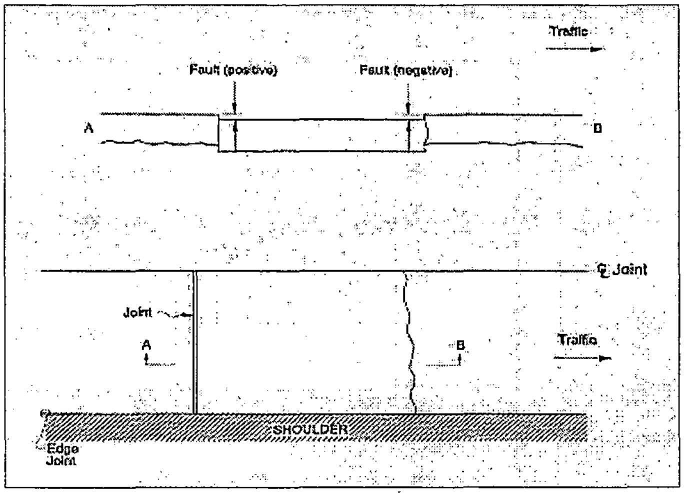

Figure 6: Typical joint faulting

3.4.2 Steps Taken To Combat Transverse Joint Failures

Since the deterioration of the nation's highways has become a major issue to highway engineers, both the rehabilitation of existing joint failures and the development of new joints designed to prevent future failures have been considered. Both approaches are discussed in relation to the three main failures identified in Section 3.4.1.

One of the most common rehabilitation efforts has been directed at fixing the problems associated with transverse joint seal damage. Five steps are identified for the rehabilitation of joint seals: (1) old sealant removal, (2) shaping the reservoir, (3) cleaning the reservoir, (4) installing the backer rod, and (5) installing the sealant [14, p. 15]. In addition to rehabilitation, the performance of sealants placed in new pavements has been greatly improved by recent technological advances in sealant elasticity and adhesion, and more accurate anticipation of maximum joint movements [14, p. 7]. These improvements have allowed designers to specify better sealants and develop better joint sealant practices.

Since spalling at the face of a joint is mainly caused by dowel corrosion and misalignment, most attempts at correcting such failures have been concentrated on prevention instead of replacement. As discussed in Section 3.3.2, many coatings of the conventional carbon steel dowels and replacement of the steel with inert alternatives have focused on the prevention of corrosion in newly placed concrete. The problems associated with dowel misalignment have been addressed by AASHTO, which specifies a tolerance for alignment with the pavement edge and surface of ±1/4 inch per dowel and that placement be accomplished with a wire basket or by mechanical implantation (i.e. inserter) [12, p. 139]. However, placement conforming to these tolerances can be hard to accomplish and even harder to monitor after the concrete has been placed. Currently there are no known methods of placement that guarantee accurate, consistent, and economical placement of dowels. Therefore, as identified by responders in Section 2.2, misalignment continues to be a major cause of spalling in highway pavements.

An additional cause of spalling, the high bearing stresses of the dowels on surrounding concrete, has been addressed by many highway researchers and designers. Prevention of spalling due to high bearing stresses can be accomplished through the use of larger diameter dowels due to the increased surface area over which the dowel reacts with the concrete. Additionally, completely new cross-sectional shapes are being studied which would use the geometrical properties of the dowel in a more efficient manner [26].

Attempts at preventing faults from forming at transverse joints have included all those outlined in the prevention of spalling, including coating of dowels and replacement with non-corrosive materials. In addition to prevention of faulting, rehabilitation efforts have been attempted using a process called Load-Transfer Restoration (LTR) [14, p. 22]. LTR is a process where slots are cut into the pavement across failed joints and new dowels are placed with either a high strength grout or epoxy. **Figure 7** shows a typical joint subjected to the LTR process prior to backfilling. Situations commonly suited for LTR are where aggregate interlock alone was relied on for load transfer or where the load-transfer device has either degraded or totally lost its strength.

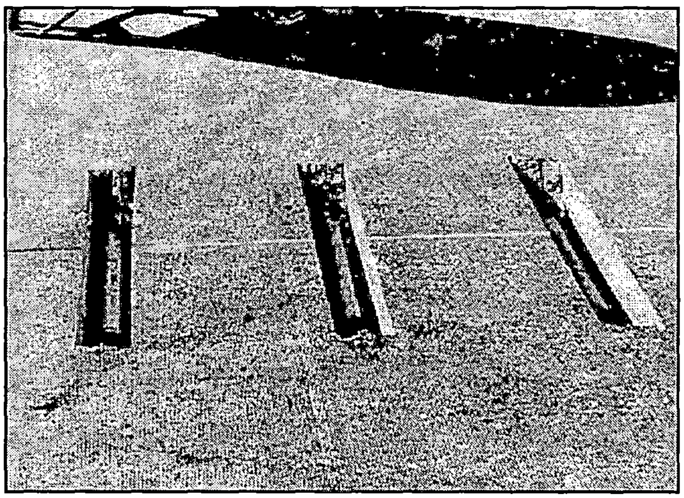

Figure 7: Load-Transfer Restoration (LTR)

Overall, rehabilitation of failed pavements represents a short term solution to a long term problem of highway pavement deterioration. Most efforts are now being focused on the prevention of future distress with the development of more durable joint designs. One of the major steps is inclusion of alternative materials for LTD's.

Chapter 4 Applications and Research

4.1 Introduction

The following section is composed primarily from research conducted at Iowa State University (ISU) under the direction of Dr. Max L. Porter. Information from research conducted by other researchers is limited due to the relatively new developments in alternative materials. The intent of this section is to provide HITEC with recent findings of research investigations and field applications of alternative materials, both as load-transfer devices and as primary tension load-carrying members in concrete, and to make available a valuable list of references for more detailed study.

4.2 Laboratory Investigations

Under the direction of Dr. Max L. Porter, ISU researchers have conducted many laboratory investigations involving the use of alternative materials as reinforcement for concrete structures. The majority of these projects have involved study of the behavior of Fiber Reinforced Plastic (FRP) concrete reinforcing components such as FRP rebar, prestressing strands, sandwich wall ties, and dowels bars. Dr. Porter's background in Highway pavement joint reinforcement is primarily based on two research projects conducted through funding by the Iowa Department of Transportation (IDOT). In the first study, a theoretical model of the dowel/pavement system was developed, a method for accurately determining the shear strength of the dowel/pavement system was developed, and an accelerated aging procedure was implemented to study the effects of aging on the FRP dowels [23,24]. The direct shear testing revealed that the moment of inertia of the FRP dowels must be increased to provide a stiffness equivalent to that of their steel counterparts, mainly due to FRP's low modulus of elasticity [24, p. 67]. The FRP materials used in this investigation, E-glass encapsulated in a vinyl ester resin, exhibited little or no adverse effects after being subjected to the accelerated aging solutions of water, lime, and salt [24, p. 86].

In the second study conducted at ISU, fatigue and static tests were performed on full-scale concrete pavement slabs supported by a simulated subgrade, including a single transverse joint. Single dowels cast in concrete underwent static shear testing using the test method developed in the previous study [23, 24], and test results from elemental and full-scale tests were compared and related. The behavior of full-scale specimens with both steel and FRP dowels placed at test joints was monitored during several million load cycles, which simulated truck traffic at a transverse joint. Performance of the FRP dowels indicated that they are at least as effective as steel dowels in resisting degradation of load transfer efficiency under cyclical loading [13, p. 198]. However, FRP dowels were required to be larger (1.75 inch diameter) than the steel dowels (1.5 inch diameter). When spaced at 12 inches on center, the FRP dowels performed similar to the steel dowels, at an 8 inch spacing, the FRP dowels outperformed the steel dowels spaced at 12 inches [13, p.199].

In a research project recently finished through the joint sponsorship of the U.S Army Corps of Engineers Waterways Experiment Station and the U.S. Navy's Naval Facilities Service Center, the effects of aging and corrosion on the structural behavior of glass fiber-reinforced plastic (GFRP) rebars and GFRP and carbon fiber-reinforced plastic (CFRP) prestressing tendons was investigated. The effects of corrosion on rebars under constant load and prestress losses in concrete beams reinforced with FRP prestressing tendons was studied. The results indicated that several of the GFRP products lost substantial strength (up to 68%) due to the breakdown of the protective resins in a highly alkaline environment. The CFRP specimens exhibited no adverse behavior after aging [27]. This "corrosion" due to alkalinity exhibited by certain GFRP products has raised concern among engineers because the porewater in PCC is highly alkaline and could present exposure problems to some GFRP resins. A more in depth study into the behavior of GFRP products subjected to accelerated aging is scheduled to begin at ISU in the spring of 1997 through funding by the National Science Foundation (NSF).

4.3 Field Applications

Information and data resulting from field applications of FRP and other alternative material dowels is difficult to obtain due to the relatively recent emergence of alternative materials for use in infrastructure. However, after review of the returned HITEC surveys, a few references to reports and data concerning field placement of alternative material dowels were included. Overall, 12 of the responding state DOT's said they have had experience with alternative materials, while only two listed actual report references. MDOT looked at the field performance of several coatings and materials for dowel bars, including stainless steel (SS) and FRP, although no report was written. They stated that corrosion was evident only at the joint and the epoxy coating was working fine. The NYSDOT used a 2-component iron-malleable LTD for a brief period in the 1960's. There were no other field applications of alternative materials. KDOT and WiDOT stated that they have placed, or will place, FRP and SS dowels in test bed sites but did not include any references to available literature in those regards. Representatives of CtDOT, NDDOT, and GDOT indicated they have placed FRP dowels in short PCC slab replacement sections but also did not list any specific references. The State of Ohio (ODOT) constructed 5 projects containing FRP dowels and 2 sections with SS dowels. They found that SS dowels approximately double the cost of the joint with no apparent improvement in performance. The FRP dowels cost approximately the same as the steel dowels although the FRP dowels have to be larger than their steel counterparts due to low modulus [28]. The MoDOT have not placed alternative material dowels, but they have investigated the use of other FRP products [29].

In the second IDOT study conducted at ISU, FRP dowels were place in two pavement joints on U.S. 30, east of Ames, Iowa. Two transverse contraction joints in the construction of a new highway pavement had the standard 1.5-inch steel dowels at a 12-inch spacing replaced with 1.75-inch FRP dowels spaced at eight inches. A program was developed for monitoring and evaluating the performance of the test joints, including visual inspections and experimental evaluations of the joints. The two FRP test joints and four adjacent steel joints were evaluated by IDOT personnel and equipment, which included the Road Rater™. Load testing was performed on the two FRP test joints and two adjacent steel joints using a loaded truck. Results of the investigation show that the performance of the FRP joints is equivalent to that of the joints with steel dowels. No significant deflection differences were measure and no difference in appearance was detected after one year of service. Additionally, the FRP dowels allowed the pavement to crack at the joint locations [13, p. 203].

Chapter 5 Conclusions

5.1 Conclusions Resulting From HITEC Survey

The following conclusions represent actual responses provided by state organizations and interpretations of those responses on the part of the authors:

- The six states most interested in alternative material dowels are New York, Kansas, West Virginia, Ohio, Iowa, and North Dakota.
- Circular, epoxy-coated carbon steel bars predominate the existing use of load-transfer devices.
- The most common reported problems with load-transfer devices are placement/misalignment of the dowels during construction and "seizing" of the dowels due to corrosion during the service life of the pavement.
- Strength and corrosion resistance appear to be the most important performance characteristics of a joint system according to state organizations.
- A majority of the state organizations are either unsure of their financial commitment or would pay little or no more of a first-cost premium over their present systems for alternative materials.
- 40% of the responders indicated they had considered alternative materials, with the majority (79%) considering fiber composites.
- Although many field applications of alternative material dowel bars have been implemented (9 states), the long-term performance of the new materials is too soon to be evaluated.
- 86% of the state organizations would consider alternative materials given certain criteria are met, the most important being long-term demonstration project data.
- Interest in future HITEC activities related to the use of alternative materials appears to

be quite high with 14 of the state organizations indicating interest in serving on a panel and 11 indicating interest in providing locations for field demonstrations.

5.2 Conclusions Resulting From HITEC Major Topic Review

The following conclusions represent the interpretations by the authors of the available literature on the use of load-transfer devices and expert knowledge of highway design:

- Jointed rigid pavements represent most (≥90%) of the rigid pavements in the United States.
- The estimated total mileage of jointed rigid pavements in the current United States highway system is 115,404 miles.
- The estimated amount of doweled PCC paving in the United States is 40,850,000 square yards per year.
- The estimated quantity of required dowels for the United States is 18,500,000 dowels per year.
- The states of Alaska, Massachusetts, Montana, New Hampshire, New Mexico, and Vermont specify no significant amount of PCC pavement, and are therefore potentially poor markets for alternative material dowels.
- The states of Texas, Oregon, Maryland, and Illinois predominately specify continuous rigid pavement and may be poor potential markets for alternative material dowels.
- Initial costs and maintenance costs appear to be the most important bases upon which highway designers choose materials; however, life-cycle costs appear to be increasing in importance.
- For the last ten years, PCC paving has accounted for approximately 22% of the total pavement market in the United States.
- The potential market for alternative material dowels in rehabilitation projects appears

to be quite small compared to new paving, accounting for only an estimated 925,000 dowels per year in the United States (estimated 5% of new pavement).

- Many metallic and non-metallic coatings of traditional carbon-steel dowels have been attempted and met with mixed results. Epoxy coating appears to predominate.
- Of the alternatives to traditional steel, glass fiber-reinforced plastic appears to be the most popular, with the use of E-glass encapsulated in vinyl-ester and epoxy resins predominate.
- The three most common failures in transverse joints are joint seal damage, spalling, and faulting.
- Research investigations into the use of alternate materials for highway dowels have determined that FRP may be used when correct diameters and spacings are specified and stainless-steel may be reliable and cost effective, however, many questions involving the optimal design and corrosion resistance of these materials have yet to be answered.

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Acknowledgments

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Appendix A Blank Questionnaire Sample

HITEC SURVEY

New Materials for Dowel Bar Pavement Joints

HITEC is considering a new evaluation project on the use of alternative materials for portland cement concrete highway pavement dowel bar joints; specifically composite materials and stainless steel. We would appreciate it if you took a few minutes to complete the following questionaire.

Background

What types of PCC joints do you use? ☐ expansion ☐ contraction ☐ mixed ☐ other ______________________

What types of load transfer devices do you use? ______________________

____

What problems have you encountered in pavement joint systems? ______________________

____

____

Performance

What are the performance characteristics you are seeking in a dowel bar joint system (place in order of importance from 1-the most important to 7-the least important)?

_______ ductility/fracture toughness
_______ corrosion resistance
_______ availability
_______ other (specify) ______________________
_______ fatigue resistance
_______ strength
_______ ease of installation

How much of a first-cost premium, if any, would you incur to achieve them?

____

Alternate Materials

Have you ever considered using alternative materials for dowel bars (circle)? Yes No

If yes, which materials? ______________________

what was the primary reason you considered using an alternate material? ______________________

____

what has been your experience, if any? ______________________

Would you consider using alternative materials in the future (circle)? Yes No

What improvements in performance would you expect from new materials?

____

Are there special pavement applications where you would consider using alternate materials?

____

What performance information if any would you need to see to justify specifying these materials in your state (rank 1=the highest, 5=the lowest)?

AASHTO specification for the material
______ Long-term demonstration performance data
______ Other (specify)
______ ______________________________
Non-proprietary joint system
______ Cost data
______

HITEC

Would you be interested in participating in a HITEC Evaluation Panel established to evaluate alternate materials for dowel bar joints (circle)? Yes No

If yes, would you consider serving as a test-bed site for a demonstration of bar performance (circle)? Yes No

Do you have any information that would be helpful to the HITEC Panel such as research, value engineering proposals, etc.?

____

____

____

____

THANK YOU

Your Name:

Organization: ____

Phone: ____

Fax: ____

____

Please fax your completed questionnaire to Maureen McAllister at (202) 789-5345

Appendix B Tabulated Survey Results

Table B1: Responder Information

#	ISU Label	Name/Title	Organization	Telephone #	Fax #
1	VTRC	Thomas E. Freeman	Virginia Transportation Research Council	(804) 293-1957	(804) 293-1990
2	NYSDOT	Rickey L. Morgan, CEI Dave Graves	Transportation Research & Development Bureau, New York State Department of Transportation	(518) 457-4662	(518) 457-7535
3	ATRC	Larry Scofield	Arizona Transportation Research Center, Arizona Department of Transportation	(602) 407-3131	(602) 256-6367
4	FDOT	Gregory T. Nottuno, P.E.	Florida Department of Transportation	(904) 381-8809	(904) 381-6082
5	KDOT	Andrew Gisi	Kansas Department of Transportation	(913) 296-3008	(913) 296-2526
6	WVDOT	Gary L. Robson	West Virginia Division of Highways West Virginia Department of Transportation	(304) 558-3160	(304) 558-0253
7	ODOT	Roger Green	Ohio Department of Transportation	(614) 752-5277	(614) 752-4835
8	NDDOT	Darcy Rosendahl	North Dakota Department of Transportation Materials & Research Division	(701) 328-6903	(701) 328-6913
9	IlDOT	Billy Wade	Illinois Department of Transportation	(217) 782-2921	(217) 782-2572
10	WisDOT	Robert B. Schmiedlin, P.E., Research Supervisor	Pavements Section Wisconsin Department of Transportation	(608) 246-7950 Email: rschmiel@mail.state.wi.us	(608) 246-4669
11	NDOT	Peter Booth, P.E.	Nevada Department of Transportation	(702) 888-7139	(702) 888-7501
12	LTRC	Masood Rasoulian	Louisiana Transportation Research Center	(504) 767-9112	(504) 767-9108
13	MSHA	Samual R. Miller, Jr.	Maryland State Highway Administration	(410) 321-3538	(410) 321-2208
14	Caltrans	Joseph Hannon	California Department of Transportation	(916) 227-7296	(916) 227-7242
15	MDOT	John F. Staton	Materials Research Group Michigan Department of Transportation	(517) 322-5701	(517) 322-5664
16	NeDOT	Marvin J. Volf	Nebraska Department of Roads	(402) 479-4756	(402) 479-3975
17	IdDOT	Dwayne Winn	Idaho Department of Transportation	(208) 334-8450	(208) 334-4411
18	CDOT	Greg Lowery	Colorado Department of Transportation	(303) 757-9449	(303) 757-9242
19	CtDOT	Charles E. Dougan, Ph.D, P.E.	Connecticut Department of Transportation Office of Research & Materials	(860) 258-0372	(860) 258-0399
20	ADOT	Larry Lockett	Alabama Department of Transportation	(334) 206-2201	(334) 264-6263
21	WSDOT	Dennis Jackson/Robyn Moore	Washington State Department of Transportation	(360) 709-5470	(360) 709-5588
22	GDOT	Mike Cown	Georgia Department of Transportation	(404) 363-7513	(404) 363-7684
23	UDOT	John Butterfield	Utah Department of Transportation	(801) 964-4468	(801) 965-4796
24	DCDPW	Wasi Khan	District of Columbia Department of Public Works	(202) 939-8077	(202) 939-7186
25	MoDOT	Jim Murray, Division Engineer Research, Development & Technology Division	Missouri Department of Transportation	(573) 751-3002	(573) 526-4337
26	NMSHTD	David Catanach	New Mexico State Highway and Trans. Dept. Materials Lab Bureau	(505) 827-5648	(505) 827-5649
27	SCDOT	Andrew Johnson Pavement Design Engineer	South Carolina Department of Transportation	(803) 737-1308	(803) 737-2389
28	MaDOT	Warren Spaulding Transportation Research Engineer	Maine Department of Transportation	(207) 287-2151	(207) 287-3292
29	MiDOT	Alfred Crawley	Mississippi Department of Transportation	(601) 359-7650	(601) 359-7634
30	AkDOT	Matt Reckard	Alaska Department of Transportation and Public Facilities, Division of Engineering and Operations	(907) 465-6956	(907) 465-2460
31	NHDOT	Alan Rawson	New Hampshire Department of Transportation	(603) 271-3151	(603) 271-1649
32	SDDOT	Ron McMahon	South Dakota Department of Transportation	(605) 773-3401	(605) 773-6608
33	INDOT	David Adrewski	Indiana Department of Transportation	(317) 232-5280	(317) 356-9351
34	OkDOT	Tim Borg	Oklahoma Department of Transportation	(405) 521-6773	(405) 521-6528
35	IDOT	Jim Grove	Iowa Department of Transportation	(515) 239-1226	(515) 239-1092
36	NCDOT	Jack Cowsert	North Carolina Department of Transportation Pavement Management Unit	(919) 250-4094	(919) 250-4098

Table B2: Background in PCC Joints

Responder	PCC Joints Currently Used			Load Transfer Devices Currently Used	Problems Encountered
	Expansion	Contraction	Mixed		
VTRC	1	1		Steel dowel bars	Joint faulting, pumping and joint spalling, bar alignment and concrete consolidation
NYSDOT	1	1		Epoxy-coated steels dowels, I-beams	Faulting, cracking around dowel due to corrosion
ARTC		1		Steel dowel bars, baskets and inserters	Construction quality
FDOT	1	1		Steel dowel bars	Impact spalling
KDOT		1		Epoxy-coated steel dowels	Reduction of cross-sectional area due to corrosion, non-durable aggregate problems
WVDOT	1	1		Epoxy-coated, baskets	Poor bond breakers
ODOT	1	1		Epoxy-coated, baskets and inserters	Corrosion, care for epoxy while hauling and placing, freeze/thaw of concrete
NDDOT		1		Steel dowel bars	Faulting of undoweled joints
IlDOT	1	1		Steel dowel bars	Rust siezing joints
WisDOT		1		Epoxy-coated steel	Placement of dowels
NDOT	1	1		Steel dowels	Placement of dowels, location
LTRC			1	Epoxy-coated steel, baskets	Cracking of concrete, not dowel material related
MSHA	1	1		Dowels, baskets	Deteriorated dowels, "frozen" dowels, faulting, cracking behind dowel cages
Caltrans	1	1		Aggregate interlock, dowels in future	Faulting and loss of load transfer
MDOT	1	1		Steel dowels, baskets and inserters	Joint lockup/blowup due to improper installation
NeDOT	1	1		Aggr. interlock, dowels at const. joints.	Faulting
IdDOT	1	1		Epoxy-coated steel	Joint sealer
CDOT		1		Epoxy-coated steel	Bar alignment, high costs
CtDOT		1		I-beams and round dowels	Joint siezure, misalignment, corrosion, cracking
ADOT	1	1		Epoxy-coated steel	Dowel misalignment
WSDOT		1		Dowel bars	Faulting
GDOT		1		Epoxy-coated steel, baskets	Misalignment with inserters, baskets ok
UDOT		1		Epoxy-coated steel	
DCDPW	1	1		Dowel bars	None
MoDOT		1		Epoxy-coated dowels, baskets	Corrosion, splitting of PCC at dowels
NMSHTD	1	1		Epoxy-coated and stainless steel dowels	None, don't use concrete pavements
SCDOT		1		Uncoated steel	None with dowels after 5-15 years of service
MaDOT					Did not respond to survey, haven't used PCC pavement in 20 years
MiDOT	1			Steel bars	Too much grease applied causing voids around bar
AkDOT					Did not respond to survey, don't use PCC pavement
NHDOT					Did not respond to survey, don't use PCC pavement
SDDOT		1		Dowel bars	Keeping joints sealed, faulting
INDOT		1		Steel dowels	"D" cracking and joint seal failure
OkDOT	1	1		Dowel bars, sleeper slabs	Joint seal reliability
IDOT	1	1		Steel dowels	Very little
NCDOT		1			Spalling due to dowel misplacement and poor bond breaker performance
SUMS:	**18**	**31**	**1**		

Table B3: Required Performance Criteria

Responder	Required Performance Characteristic								First-cost premium ?
	Ductility/ Toughness	Corrosion Resistance	Availability	Fatigue Resistance	Strength	Ease of Installation	Other		
VTRC	6	2	3	5	4	1	7		First cost of PCC not competitive with asphalt
NYSDOT	5	3	6	2	1	4	7	Abrasion	No first cost premium-just pass criteria
ATRC	5	6	1	3	2	4	7		Comparable to current methods
FDOT	1	5	6	2	4	3	7		<50% of total joint System cost
KDOT	3	2	6	4	5	1	7		Moderate ($1.00/S.Y.)
WVDOT	5	1	6	4	3	2	7		Not sure
ODOT	6	1	4	3	2	5	7		None--current is adequate
NDDOT	6	4	3	5	1	2	7		Don't know
IlDOT	3	4	6	7	2	5	1	Load transfer	Not determined
WisDOT	7	2	4	6	3	1	5	Long-term durability	5%-10% of pavement cost
NDOT	7	2	4	7	1	3	7		Very little
LTRC	5	3	2	6	4	1	7		Would pay high premium for superior product
MSHA	4	1	6	3	2	5	7		Not sure
Caltrans	4	5	7	2	3	6	1	Load transfer	$50+/- per dowel installed
MDOT	3	1	4	2	5	6	7		
NeDOT	3	1	2	3	4	1	7		None
IdDOT	3	2	6	4	1	7	5	Bond breaker	None
CDOT	2	3	5	1	4	6	7		None
CtDOT	5	1	4	6	3	2	7		Unknown
ADOT	4	2	6	1	3	5	7		None
WSDOT	1	3	6	2	4	5	7		Consider life cycle cost
GDOT	5	4	6	1	2	3	7		None
UDOT	6	1	4	3	2	5	7		Cheapest "Life Cycle" cost
DCDPW	1	1	3	1	1	2	7		
MoDOT	6	1	4	5	2	7	3	Durability	Competitive if justified by life cycle costs
NMSHTD	6	5	7	3	2	4	1	Load transfer	Unknown
SCDOT	4	3	5	7	6	6	7		None
MaDOT									
MiDOT	4	5	2	6	3	1	7		Unknown
AkDOT									
NHDOT									
SDDOT	4	3	5	6	1	2	7		Unknown
INDOT	6	4	3	5	1	2	7		None over present system
OkDOT	4	5	6	2	1	3	7		None
IDOT	Did Not	Complete	Survey						
NCDOT	2	4	5	3	6	1	7		Very small
SUMS:	**136**	**90**	**147**	**120**	**88**	**111**	**198**		

Table B4: Consideration of Alternative Materials (1 of 2)

Responder	Ever consider Alternative Matls. ?		Materials Considered	Primary Reasons	Experiences
	Yes	No			
VTRC		1			
NYSDOT	1		2-component iron-malleable LTD	Uncoated dowels corroded	New material worse
ATRC		1			
FDOT		1			
KDOT	1		Stainless-steel, plastics, fiberglass, X-flex	Decrease PCC stresses, installation	Cost/benefit not yet proven
WVDOT		1			
ODOT	1		FRP and Stainless-steel	Analyze cost/benefit	Stainless-steel doubles cost, no improvement FRP same cost, adequate performance
NDDOT	1		Composites	Supplier proposed, good data	Too soon for evaluation
ILDOT	1		Fiberglass	Corrosion resistance	Too soon for evaluation
WisDOT	1		Stainless steel, Fiberglass	Corrosion resistance	Too soon for evaluation
NDOT	1		Fiberglass	Corrosion resistance, low pullout strength	Reduced strength, high cost
LTRC		1			
MSHA		1			
Caltrans	1		FRP dowels	Corrosion resistance	Have not done any evaluation
MDOT	1		FRP and Stainless steel	Corrosion resistance, bond	Only corrosion at joint, can't tell if problem is dowel
NeDOT		1			
IdDOT		1			
CDOT		1			
CtDOT	1		FRP	Corrosion resistance, bond	Too soon to tell
ADOT		1			
WSDOT		1			
GDOT	1		Fiberglass	Supplier proposed	Too soon, no problems with installation
UDOT	1		Non-corrosive	Longevity problems	
DCDPW		1			
MoDOT	1		FRP (saw literature and samples)	Corrosion resistance	None
NMSHTD		1			
SCDOT		1			
MaDOT		1			
MiDOT		1			
AkDOT		1			
NHDOT		1			
SDDOT		1			
INDOT		1			
OkDOT		1			
IDOT	1		Fiber reinforced plastic	Research	Worked fine
NCDOT		1			
SUMS:	**14**	**22**			

Table B4: Consideration of Alternative Materials (2 of 2)

Responder	Would you consider Alternative Matls.?		Expected improvements ?	Where would you use them ?	Required performance criteria					
	Yes	No			AASHTO Specif.	Long-term Demonstration	Non-Propriety Joint System	Cost Data	Other	
VTRC	1		Corrosion resistance	corrosive environments	1	2	4	3	5	
NYSDOT	1		Corrosion resistance		3.	4	5	2	1	Meets NYSDOT current spec.
ATRC	1		None-as good as current		4	1	3	2	5	
FDOT	1		Ease of installation, maintenance	Rehab project	3	1	4	2	5	
KDOT	1		Corrosion resistance, decrease bearing stress	retrofit	5	1	3	4	2	Laboratory or test track data
WVDOT	1			need more info	2	1	3	4	5	
ODOT	1		Light weight, less handling care, versatility	none special	3	1	4	2	5	
NDDOT	1		Ease of intallation, more strength	dowel retrofit, new PCC	3	2	4	1	5	
IlDOT	1		extended life	none special	4	1	5	3	2	Engineering data
WisDOT	1		Extended life, corrosion resistance, load transfer	none special	5	1	5	2	5	
NDOT	1		Lower cost, lower pullout, less corrosion	all pavements	2	1	5	3	5	
LTRC	1		Reduced joint maintenance		2	1	4	3	5	
MSHA	1		Adequate strength, corrosion resistance	None special	2	1	4	3	5	
Caltrans	1		Corrosion resistance	corrosive environments	4	1	3	2	5	
MDOT	1		Corrosion resistance, bond	Urban sites, low vol. ramps	3	1	2	4	5	
NeDOT	1		Corrosion resistance, installation, availability	None special	3	1	4	2	5	
IdDOT	1		Pullout strength	Only research	4	3	1	2	5	
CDOT	1		Same performance, less cost		2	1	4	3	5	
CtDOT	1		Corrosion resistance, ease handling	none special	2	1	3	4	5	
ADOT	1			PCC intersection	1	2	3	4	5	
WSDOT	1		Equal to epoxy-coated steel	none special	1	3	2	4	5	
GDOT	1		Perform at current high level	none special	2	1	4	3	5	
UDOT	1		Longevity	none special	1	3	4	2	5	
DCDPW	1				1	1	2	1	5	
MoDOT	1		Corrosion resistance	only R&D purposes	1	4	5	3	2	Abrasion and corrosion data
NMSHTD		1			2	3	4	1	5	
SCDOT	1		Reduced cost for same performance	none	3	1	1	5	5	
MaDOT		1								
MiDOT		1		none	4	2	1	3	5	
AkDOT		1								
NHDOT		1								
SDDOT	1				3	1	4	2	5	
INDOT	1		Performance and cost similar to current level	none	4	1	3	2	5	
OkDOT	1		Corrosion resistance and elimination of bond breaker	none	1	2	3	4	5	
IDOT	1				Did Not	Complete	Survey			
NCDOT	1		Accurate placement and long-term performance	none	4	1	2	3	5	
SUMS:	31	5			85	51	108	88	147	

Table B5: Interest in HITEC Participation

Responder	Interested in participating on HITEC Panel ?		Interested in a Test Bed Site ?		Information you have for HITEC ?
	Yes	No	Yes	No	
VTRC	1			1	
NYSDOT	1		1		Full packet of information and person to serve on panel--see packet
ATRC		1		1	
FDOT		1	1		
KDOT	1		1		
WVDOT	1		1		Test data for FRP bars, from West Virginia University research project
ODOT	1		1		Research report available
NDDOT	1		1		Recently installed FRP dowels in rehab. proj., no data yet.
IlDOT	1			1	
WisDOT	1		1		Work plan governing new research project
NDOT	1		1		
LTRC	1		1		
MSHA	1		1		
Caltrans	1			1	
MDOT	1			1	Looked at field performance, no report written
NeDOT		1		1	
IdDOT	1			1	
CDOT		1		1	
CtDOT		1		1	Welcome to review their records
ADOT		1		1	
WSDOT		1		1	
GDOT		1		1	
UDOT		1		1	
DCDPW		1		1	
MoDOT	No Response		No	Response	Contract with Univ. of Missouri-Rolla , research report available
NMSHTD		1		1	
SCDOT		1		1	
MaDOT					
MiDOT		1		1	
AkDOT		1		1	
NHDOT		1		1	
SDDOT		1		1	
INDOT		1		1	
OkDOT		1		1	
IDOT		1	1		Referenced Dr. Max Porter's work, included in paper
NCDOT		1		1	
SUMS:	14	20	11	23	

Appendix C Supplemental Responder Information

The Quarterly R&D Digest

ENGINEERING RESEARCH AND DEVELOPMENT BUREAU
NEW YORK STATE DEPARTMENT OF TRANSPORTATION
Mario M. Cuomo, Governor/Franklin E. White, Commissioner

SPECIAL ISSUE | ALBANY, NEW YORK | SUMMER 1992

A SUBJECT INDEX OF RESEARCH PUBLICATIONS IN PRINT

Several times in the past, this Digest has included numerical listings of New York State engineering research publications in print. Because such a list would now total over 250 titles, we are providing a new compilation by subjects that may be useful to our readers. The index presented here is divided into the following eight areas (listed in alphabetical order):

1. Barriers and Roadside Appurtenances,
2. Flexible Pavement Design and Construction,
3. Highway Maintenance,
4. Materials and Testing,
5. Rigid Pavement Design and Construction,
6. Soils and Drainage,
7. Structures, and
8. Traffic and Safety.

Each entry includes full title, research report (RR) or special report (SR) number, and month of publication. Under each subject heading, titles are listed in reverse chronological order -- newest first, oldest last. All reports in this index are available without charge to interested readers (although a few are on the shelf in very limited quantity). Order by calling (518) 457-5826, or by writing the Engineering Research and Development Bureau, New York State Department of Transportation, State Campus, Albany, New York 12232. Additional copies of this index are also available on request.

NOTICE

Effective October 1, 1992, engineering research publications will be available for only 10 years after publication, as usual without charge -- after 10 years most, but not all, may be purchased in paper copy or microfiche from the National Technical Information Service, Springfield, Va 22161 -- for help in identifying a title for sale and its price, call (703) 487-4780. To assist readers in ordering reports that will be out-of-print after September 30, black vertical rulings appear by their titles in the left margin of each page in this listing; orders must be received by September 30.

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122 Design of Chip-Seal Surface Treatments Using An Expert System
123 Frictional Characteristics of Sand and Sand-Deicer Mixtures on Bare Ice

3. Longitudinal Joint Tie manufacturer's certification that the metal used conforms to the requirements of this specification. The ASTM Designation and Grade shall be included.

4. The appearance of the LJT system on the appropriate standard sheet or as approved by the Director, Materials Bureau.

5. The appearance of the name of the coating applicator and epoxy coating material on the Department's Approved List of Products.

705-15 TRANSVERSE JOINT SUPPORTS

SCOPE. This specification covers the requirements for load transfer devices in portland cement concrete pavement transverse joints.

GENERAL. All Transverse Joint Support systems not referenced on the Department's Approved List shall be subject to testing and approval before their use is allowed for Department work. Application for approval of such Transverse Joint Support systems shall be made to the Director, Materials Bureau, at least 120 days before their intended use. Systems found suitable shall be assigned a unique reference number, which shall be listed on the Department's Approved List. All requirements of this specification, those portions of referenced specifications, and the Materials Details referenced by the Approved List, shall apply. In case of conflict between the requirements of this specification and the referenced specifications, the requirements of this specification or the instructions of the Director, Materials Bureau, shall apply.

MATERIAL REQUIREMENTS

A. General Requirements. Dowels shall be made ~~of steel with 345 MPa minimum yield strength.~~ Materials other than steel may be proposed, but shall be subject to the prior approval of the Director, Materials Bureau. The free ends of dowels or bar type elements shall be saw cut and free of burrs or projections that would restrict movement.

Dowel coatings shall be continuous and undamaged for the full length of the element. Elements with perforated, cracked, damaged or improperly applied coatings will be rejected. Any damage which results from welding or mechanical fixation to achieve a fixed end condition shall not extend more than 25 mm in from the weld or point of fixation. All coatings will be tested and approved by the Materials Bureau in accordance with these specifications. The dowel coating thickness and material shall be as required by the Materials Details referenced by the Approved List or as approved by the Director, Materials Bureau.

Bond breaker material (when applicable) will be subject to approval by the Materials Bureau and shall be as required by the Materials Details referenced by the Approved List. The use of field applied bond breakers will not be allowed. Bond breaker (when required) shall completely coat the dowel element to within 150 mm of the fixed end.

Premoulded resilient joint filler shall meet the requirements of §705-07 of the Standard Specifications.

B. Physical Requirements. When tested in accordance with AASHTO T253, Standard Method of testing Corrosion Resistant Coated Dowel Bars~~, the dowel elements shall meet the requirements of AASHTO M254 for Load Deflection, Pull-out, Corrosion, and Abrasion~~.

OATING APPLICATION. Acceptable epoxy coating applicators shall be those found on the epartment's List of Approved Products titled "Epoxy Coatings For Longitudinal Joint Ties (705-14)" or "Epoxy Coatings and Applicators For Steel Reinforcing Bars (709-04)." Applicators of approved atings other than epoxy will be subject to approval by the Director, Materials Bureau.

GEOMETRIC REQUIREMENTS

A. Dowels. Joint support dowels shall be at least 460 mm and shall have a minimum bearing area of 10 300 mm^2. They shall have a uniform cross sectional shape for their entire length. Dowels with circular cross sections shall have a minimum diameter equal to 1/8 of the pavement design thickness exclusive of any coating(s).

B. Joint Support Assemblies. Transverse joint support assemblies shall meet the following general requirements as well as the applicable additional requirements given below for contraction, expansion, or construction joints:

1. General Requirements. Unless otherwise indicated by the plans or in the proposal, transverse joint support assemblies shall be constructed with one (1) dowel for each 300 mm of lane width. The locations of the dowels within the assemblies shall comply with the following geometry:

a. The axis of the two end dowels shall be located such that they are spaced 150 ± 13 mm from the lane edges after concrete is placed.

b. The axis of the intervening ten dowels shall be transversely spaced at 300 ± 13 mm centers relative to the axes of the two end dowels.

c. The axis of each dowel shall be held at the mid-depth of the concrete pavement slab ± 6 mm.

d. The assemblies shall be placed with each individual element's axis aligned and held parallel to the centerline horizontally and vertically to the profile, to 1 mm per 100 mm.

e. The dowels shall be longitudinally restrained such that the maximum longitudinal displacement of the midjoint of each dowel relative to the center of the joint is 25 mm.

2. Transverse Contraction Joints. Joint support assemblies used in contraction joints shall meet the general requirements shown in B1 above.

3. Transverse Expansion Joints. Joint support assemblies used in expansion joints shall meet the general requirements given in B1 above. In addition, a one piece premoulded resilient joint filler 19 mm thick shall be included in the assembly. The joint filler shall extend continuously across the lane width and shall extend from not less than 50 mm below the top of the pavement surface to the bottom of the pavement slab. The joint filler shall be protected on top by a metal finishing cap and supported to maintain a vertical position.

4. Transverse Construction Joints. Joint support assemblies used in construction joints shall meet the general requirements given in B1 above. In addition, a bulkhead device shown on the Materials Details referenced by the Approved List, or as approved by the DCEC, shall be used to form construction joints. The bulkhead device shall have a rigid center plate extending vertically downward from the pavement surface, through the joint support assembly, to the bottom of the pavement.

TESTS. When joint support assemblies are proposed for testing and approval, Materials Details (detailed shop drawings) for transverse contraction, construction and expansion joint assemblies, drawn by the manufacturer, shall be submitted for approval before any fabrication is started. These drawings shall be neat, clear, and legible and shall be in the manner and form required by the Director, Materials Bureau. The supplier shall also provide certification from the rolling mill as to the type and grade of steel used in the joint support elements.

The laboratory and field tests described below shall be conducted for transverse joint support elements and assemblies not referenced by the Department's Approved List.

A. Laboratory Tests. Transverse joint support elements and assemblies being considered for approval will be subjected to the LOAD-DEFLECTION, PULL-OUT, and CORROSION-ABRASION tests defined by AASHTO T253, Coated Dowel Bars. Only joint support assemblies, exhibiting satisfactory performance in these laboratory tests, will be considered for trial installation in the field test. For purposes of laboratory testing, two complete assemblies containing joint support elements and six (6) additional loose coated junior support elements shall be submitted to the Director, Materials Bureau. One assembly shall be fabricated to meet the requirements for a transverse contraction joint; the other shall meet the requirements of a transverse expansion joint. Samples shall be submitted at least 120 days prior to their intended use.

If the proposed assembly passes the laboratory tests and is considered acceptable to the Director, Materials Bureau, approval will be given to use the system in a field test at a project site on a trial basis.

B. Field Test. Materials Bureau personnel will observe the installation of transverse joint support assemblies being considered for approval. Specific attention will be given to the alignment of joint support elements before and during paving operations. Before approval can be given for the general use of a transverse joint support assembly, it must exhibit satisfactory performance in the field test. Transverse joint support assemblies that do not exhibit satisfactory performance during the field test will be rejected. All rejected assemblies shall be replaced with acceptable assemblies at no additional cost to the Department.

For approved transverse joint support assemblies, any proposed changes in materials and/or design will require review and approval by the Director, Materials Bureau.

BASIS OF ACCEPTANCE. Transverse joint support assemblies will be accepted based on the results of testing as described under TESTS of this specification. The Department requires the submission of Materials Details as defined in §101-34.1. The supplier shall prepare and submit the appropriate material in accordance with the procedural directives of the Materials Bureau. The supplier shall also provide certification that the elements and assemblies were manufactured in accordance with this specification and the submitted Materials Details. Upon approval by the Materials Bureau, the name of the product and/or the name and address of the reference number and date of the approved Materials Details will be placed on the Approved List.

Transverse joint support assemblies will be accepted at the contract site based on their name(s) appearing on the Approved list, conformance to the approved Materials Details, and the required certifications.

For each contract supplied, the following information shall be provided to the Engineer.

A. The supplier shall provide certification that the elements and assemblies were manufactured in accordance with this specification and the approved Materials Details.

B. The supplier shall provide certification from the rolling mill as to the type and grade of steel used in the joint support elements.

C. The supplier shall provide the following information:

1. The name of the bondbreaker (when applicable) and the name and address of the manufacturer.
2. The type of corrosion protection coating and name and address of the manufacturer.
3. The name and address of the corrosion protection coating applicator.
4. The name and address of the joint support assembly manufacturer.
5. The correlation between the rolling mill's certification and the supplier's certification.

D. Two (2) copies of the approved Materials Details, properly identified by reference number and date as shown on the Approved List.

705-16 CONCRETE PIPE JOINT SEALING COMPOUND

SCOPE. This specification covers a flexible/rubber sealer used for joints in elliptical pipe, cattle pass and drainage units.

MATERIAL REQUIREMENTS. Concrete pipe joint sealing compound shall conform to the requirements of either AASHTO M198 Type B or ASTM C990.

BASIS OF ACCEPTANCE. Label stating conformance to either AASHTO M198 Type B or ASTM C990. Labels shall be either attached directly to the sealing compound or to the packaging in which the compound arrives at the project site.

705-17 CONCRETE PIPE JOINT ELASTOMERIC GASKETS

SCOPE: This specification covers elastomeric gaskets used for joints in round pipe.

MATERIAL REQUIREMENTS. Concrete pipe joint elastomeric gaskets shall conform to the requirements of either ASTM C443 or ASTM C361.

BASIS OF ACCEPTANCE. Label stating conformance to either ASTM C443 or ASTM C361. Label shall be either stenciled on the elastomeric gaskets, attached directly to the gaskets or attached to the packaging in which the gaskets arrive at the project site.

705-18 AND 705-19 (VACANT)

705-20 MORTAR FOR STONE CURBS

SCOPE. This specification covers the material requirements for cement mortar used in filling stone curb joints and bedding stone curbs.

MATERIAL REQUIREMENTS. Mortar for filling stone curb joints shall consist of one part §701-01 Portland Cement, Type 2, with one part §703-03 Mortar Sand or §703-07 Concrete Sand, mixed as stiff as practicable and of such consistency that will require rodding when placed in joints.

Mortar for bedding the Types F1, G1, M, R1, R2, S and T curbs shall consist of one part §701-01 Portland Cement, Type 2, and two parts §703-03 Mortar Sand or §703-07 Concrete Sand, by volume.

BASIS OF ACCEPTANCE. The mortar shall be accepted on the basis of inspection and approved by the Engineer.

705-21 MORTAR FOR CONCRETE MASONRY

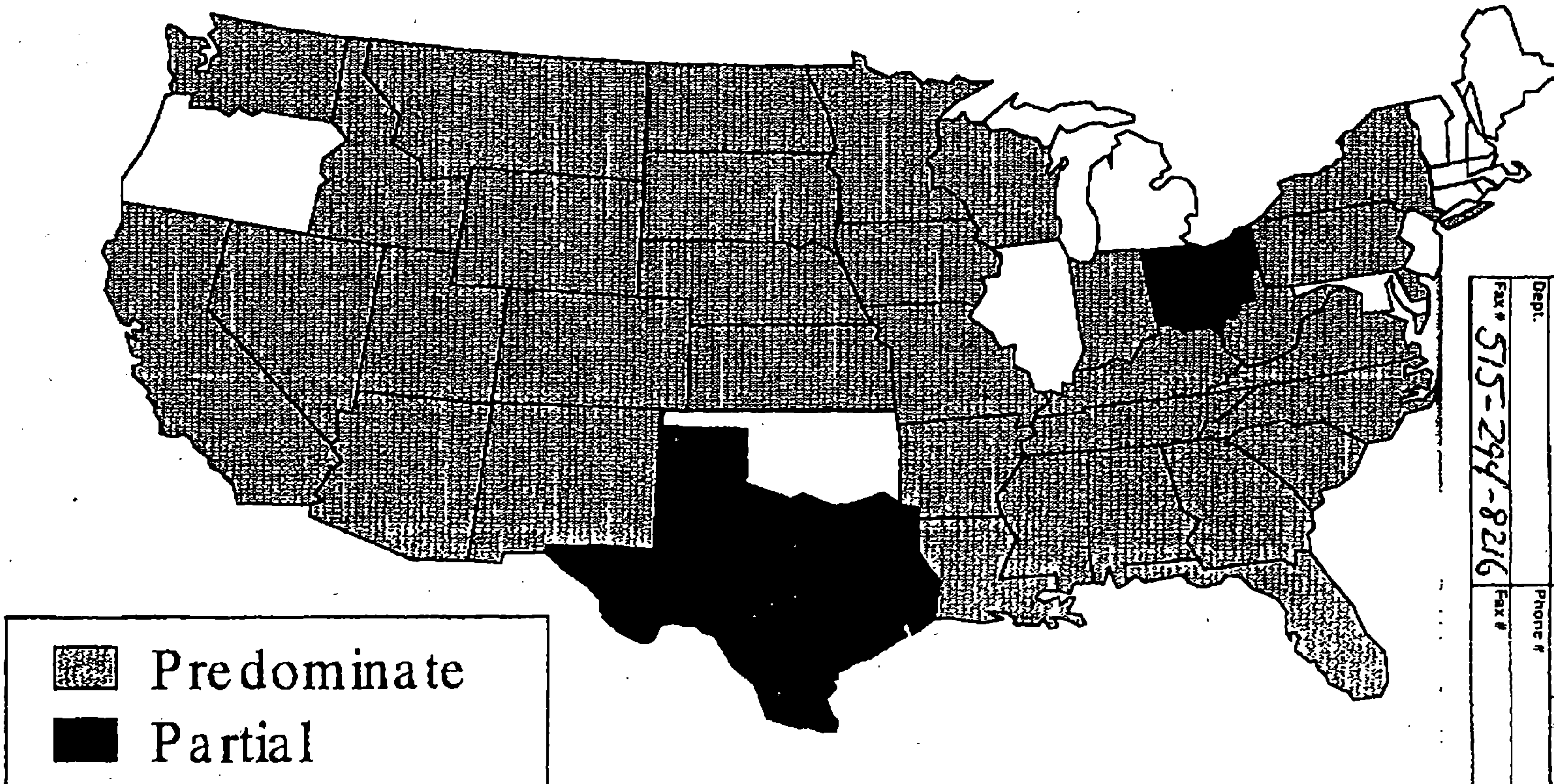
SCOPE. This specification covers the material requirements for mortar used in laying block for catch basins, manholes, field inlets, drop inlets and other masonry products as specified.

MATERIAL REQUIREMENTS. Ingredients for mortar shall comply with the following:

Portland Cement, Type 2	701-01
Masonry Cement	701-02
Mortar Sand	703-03
Concrete Sand	703-07
Water	712-01

Appendix D U.S. Maps of Relative CRP and JRP Use

States Using Plain Jointed Pavement on Major Highways



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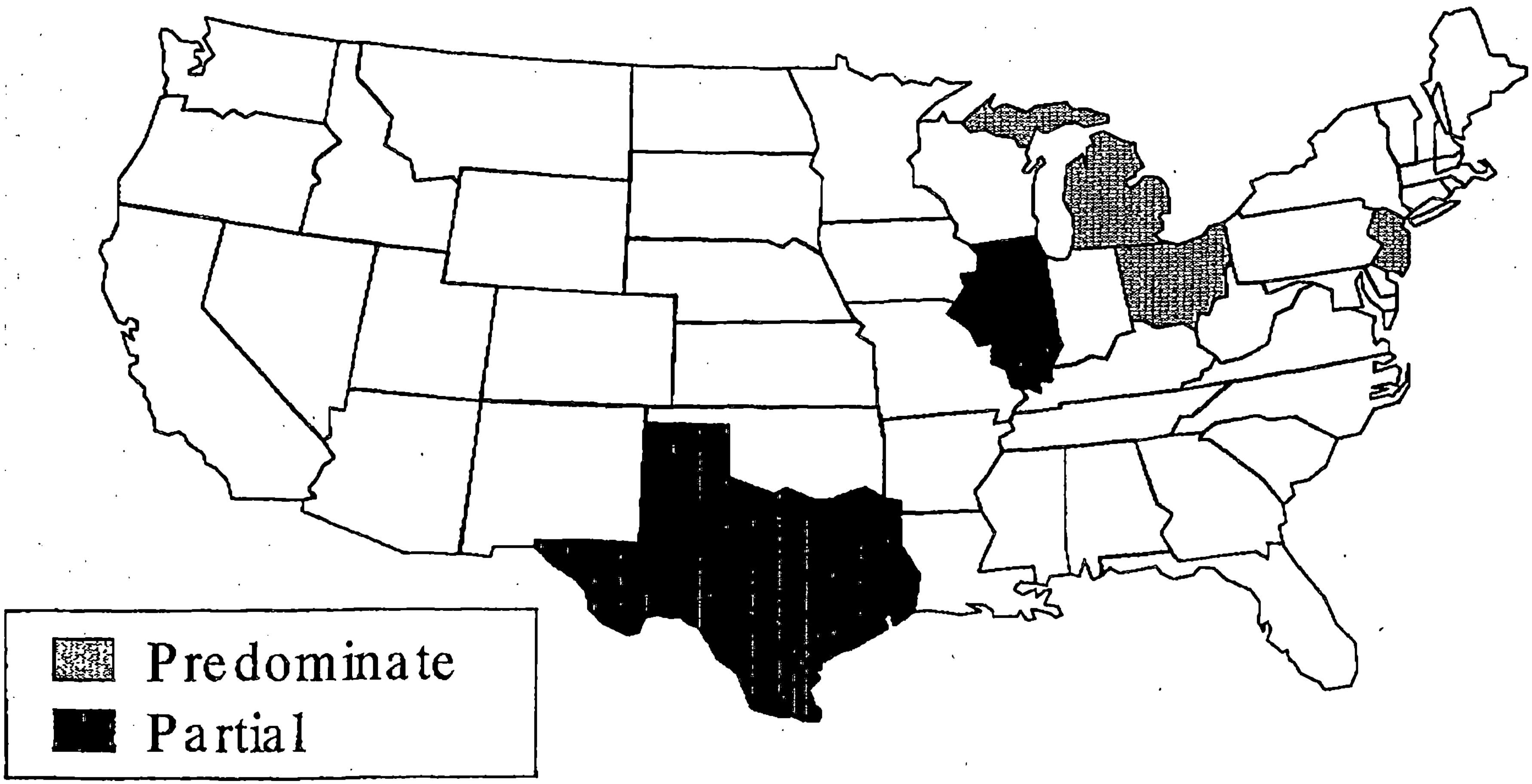
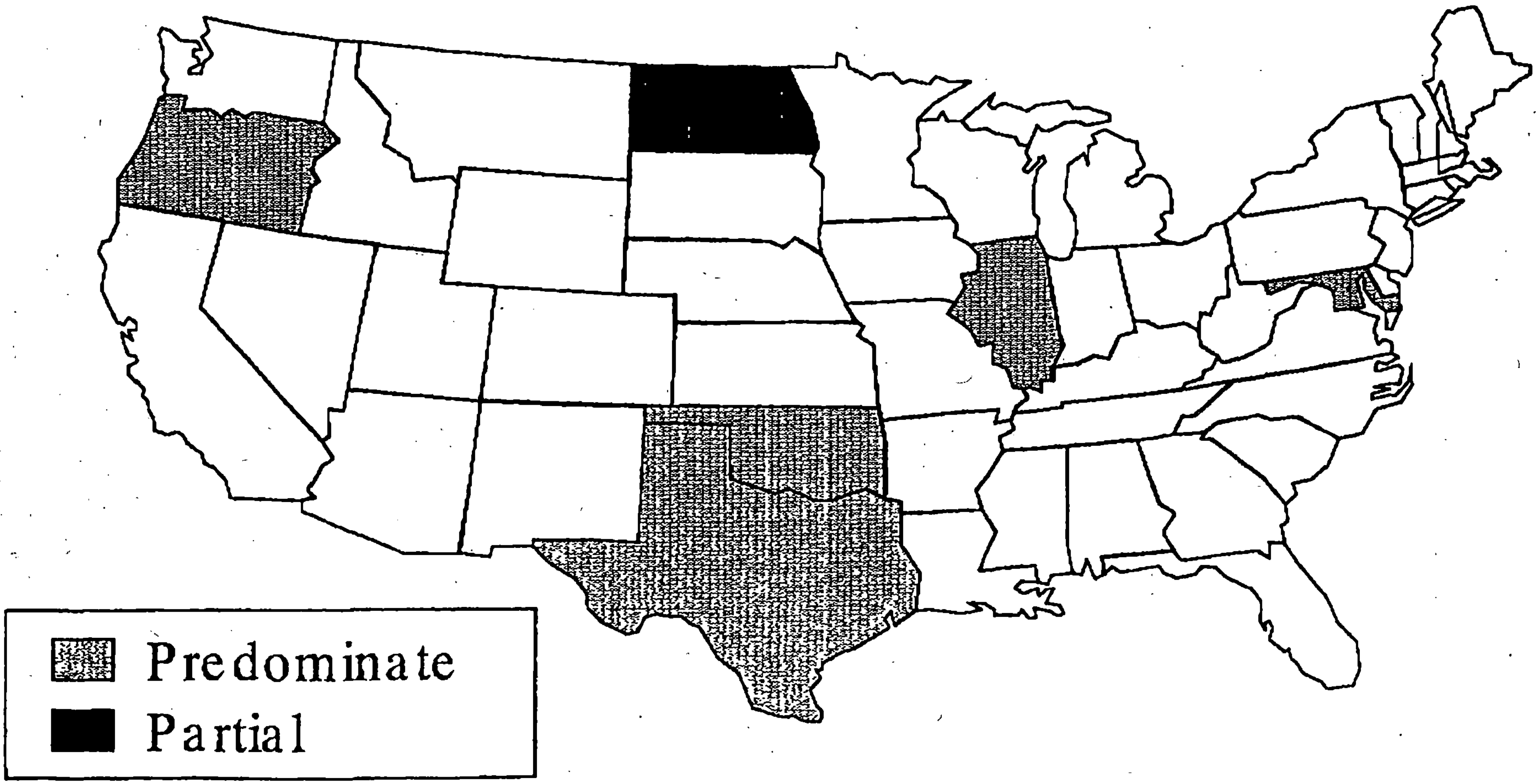
To RANDY BRAUN	From JERRY VOIGT
Co.	Co. ACPA
Dept.	Phone #
Fax # 515-294-8216	Fax #

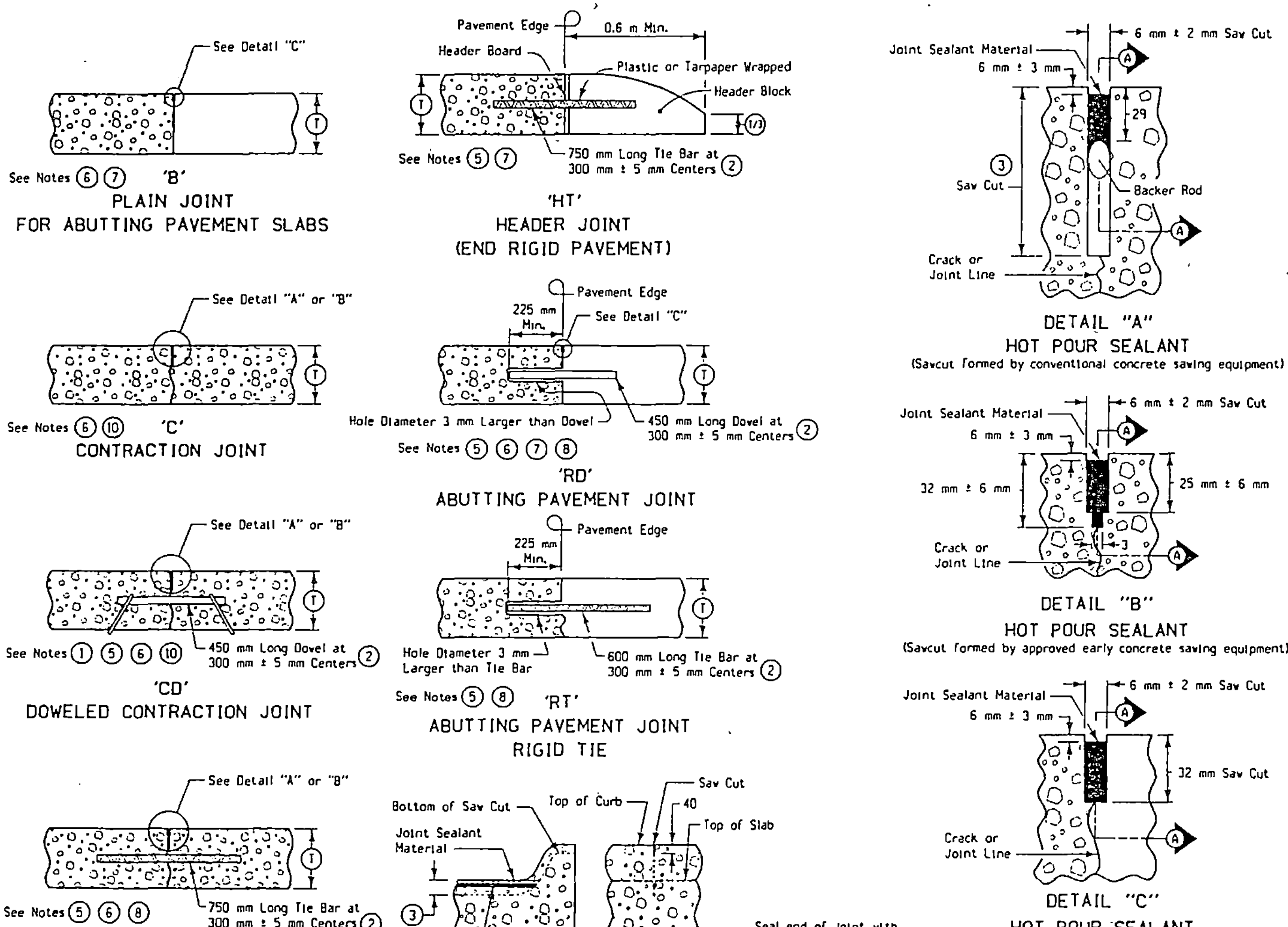
States Using Jointed Reinforced Pavement on Major Highways

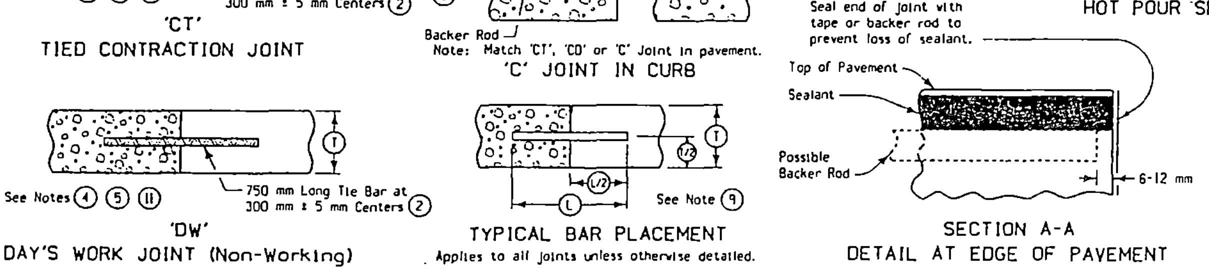


States Using Continuously Reinforced Pavement on Major Highways



Appendix E Iowa Department of Transportation Road Plan of Joint Detail





BAR SIZE TABLE			
(T)	< 200 mm	≥ 200 mm but < 250 mm	≥ 250 mm
DOWEL SIZE	20	30	35
TIE BAR SIZE	#20	#30	#35

GENERAL NOTES:

All materials and construction features used in the construction of pavement joints shall conform to the requirements of current Standard and Supplemental Specifications. Refer to other appropriate Standard Road Plans and project plans for additional information. Alternate methods for construction of joints may be submitted to the Engineer for consideration.

Dowels for the 'CD' joint shall be properly positioned by the use of an approved support assembly.

Tie bars shall be held in place by devices or methods approved by the Engineer. Bars placed after concrete slab is poured shall be installed prior to vibration of pavement slab.

Epoxy coat all bars (smooth and tie bars), see "Pavement Reinforcement" in the current Standard Specifications.

The joints as detailed hereon shall not be measured for payment. The construction detailed hereon including the furnishing of the dowels, dowel assemblies, and joint filler material shall be considered incidental to PCC paving, unless noted otherwise.

1. Free moving ends of dowel support assembly shall be placed alternately across joints.
2. Refer to Bar Size Table.
3. Depth of sawcut shall be T/3, except 'C' joint shall be T/4.
4. 'DW' joint shall be located at a midpanel location between future 'C' or 'CD' joints. It shall be no closer than 1.5 meters to a 'C' or 'CD' joint.
5. Bars in Transverse Joints shall be placed so that no bar will be closer than 150 millimeters to any Longitudinal Joint (centerline or laneline). The distance to the first bar from edge of pavement will vary from 150 to 300 millimeters depending upon pavement width.
6. Joints shall be sealed according to the Standard and Supplemental Specifications on "Sealing Joints".
7. Edge with 5 millimeter tool for length of joint indicated if formed; edging not required when cut with diamond blade saw. Remove header block and board when second slab is poured.
8. Placement of dowels or tie bars shall be in accordance with the current Standard Specification on "Reinforcement". The method of anchoring bars into existing pavement shall be as approved by the Engineer as set forth in appropriate Materials Instructional Memorandums.
9. When tieing into old pavement, (T) represents the depth of sound Portland Cement Concrete.
10. Unless otherwise specified, transverse contraction joints in mainline pavement shall be 'CD' when (T) is greater or equal to 200 millimeters. 'C' when (T) is less than 200 millimeters.
11. 'RT' joint may be used in lieu of 'DW' joint at the end of the days work. Any pavement damaged due to the drilling shall be removed at the contractor's expense.

All dimensions given in millimeters unless noted.

M	Iowa Department of Transportation *Project Development Division*	
METRIC VERSION	STANDARD ROAD PLAN	RH-50
	REVISION: Change 300 millimeter dimension in Note 5 to 150 millimeters.	REVISION NO. 11
	08-12-96 APPROVED BY DESIGN METHODS ENGINEER	REVISION DATE 12-03-96
	JOINTS (TRANSVERSE CONTRACTION)	