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Final Report

EVALUATION AND POLICY FOR BRIDGE DECK EXPANSION JOINTS

Luh-Maan Chang Yao-Jong Lee

February 2001

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Evaluation and Policy for Bridge Deck Expansion Joints

Introduction

To continuously improve the performance of expansion bridge deck joints on Indiana Department of Transportation (INDOT) bridges prompted this research. The performances of

several types of joints were investigated through questionnaire surveys, expert interviews, analysis of INDOT historical data, and site assessment.

Findings

This research focused on five types of joints: Compression Seal (B.S.) joint, Strip Seal (S.S.) joint, Poured Silicone (XJS) joint, Integral Abutment Jointless (I.A.) joint, and Polymer Modified Asphalt (LDI and PaveTech) joint. The findings are listed as follows:

- The problems and their causes, the merits, the potential improvements, and the estimated lives of these types of joints were identified from the questionnaire surveys. The results show that the S.S., B.S., and I.A. joints are rated as the top three for their longer estimated lives, as well as other attributes.
- The results of the factor and logistic regression analyses of the INDOT Roadway Management data indicate that the S.S., B.S., and I.A. joints are ranked first, second, and third respectively for their

- performance. The ranking is based on deterioration rates under identical conditions of traffic loading, settlement, and age. The performance of other types of joints could not be rated due to insufficient data.
- 3. The investigation of the practices of surrounding states revealed that each state has its own experiences in using and maintaining the bridge deck expansion joints. There are no uniform specifications, drawings, and maintenance strategies among the investigated states. The investigation also found that the Integral Abutment Expansion joint (I.A.) is being commonly used in the surrounding states.
- 4. Based on the research findings, a more objective evaluation method was developed for inspecting bridge deck expansion joints.

Implementation

This research generates several recommendations for implementation. They are as follows:

1. From the research result, S.S. and I.A. joints were shown to have better performances and

are thus recommended to be continually used. The B.S. joint could perform well if materials such as seals are properly selected and the installation correctly done. The XJS joint needs to be evaluated for its long-term performance.

- 2. If Polymer Modified Asphalt joints are used, caution should be taken to use them in locations where there is less truck traffic and bridge movement is small.
- 3. Many joint problems resulted from steel and concrete. Concrete needs to be protected by sealers and the plate and bars holding the seal need to be more corrosion-resistant.
- 4. To hold contractors accountable, the implementation of warranty clauses in the contract is recommended, which could also enhance the quality of expansion joints installed.
- 5. The proposed expansion joint condition rating schemes are more objective and ready for use.

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16. Abstract

This report is an overview of the research that was performed for the Indiana Department of Transportation (INDOT) concerning the performance of bridge deck expansion joints. The purpose of the research is to evaluate several types of joints currently in use and also provides the evaluation criteria for rating the joint condition. The types of joints investigated are Compression Seal (B.S.) joint, Strip Seal (S.S.) joint, Integral Abutment Jointless (I.A.) joint, Poured Silicone (XJS) joint, and Polymer Modified Asphalt (LDI and PaveTech) joint. The research was performed by questionnaire surveys, Roadway Management data analysis, expert interviews, and site assessment.

The problems and their causes, the merits, the potential improvements, and the estimated lives of these types of joints were identified from the questionnaire surveys. The results showed that the S.S., B.S., and I.A. joints are rated as the top three for their longer estimated lives as well as other attributes

The results of the factor and logistic regression analyses of the INDOT Roadway Management data indicate that the performances of the S.S., B.S., and I.A. joint are rated first, second, and third respectively, based on deterioration rates under identical conditions of traffic loading, settlement, and age. Other types of joints could not be analyzed due to insufficient data.

The investigation of the practices of surrounding states revealed that each state has its own experiences in using and maintaining the joints. There are no uniform drawings, specifications, and maintenance strategies among the investigated states. The investigation also showed that the Integral Abutment Expansion joint (I.A.) is commonly being used in the surrounding states.

Finally the research provides pilot evaluation schemes for inspecting joints. Based on the findings of this research, an implementation policy has been designed to ensure the longer service life of expansion joints.

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CHAPTER 1

INTRODUCTION

1.1 Problem Statement

Bridge deck expansion joints are among the smaller elements of a bridge structure, but when they fail to function properly, joints can create problems out of proportion to their size. The potential for developing serious structural problems comes from the expansion joint's role in accommodating necessary structural movements of the bridge elements. Whenever the expansion join system becomes unable to accommodate the movement, the bridge elements experience over-stress that may eventually result in damage to those elements and/or the expansion joints themselves.

It is important to appreciate that expansion joints are located in the most vulnerable position possible on any bridge. Situated at surface level, the expansion joints are subject to the impact and vibration of traffic and exposed not only to the effects of natural elements such as water, dust, grit, UV rays, and ozone, but also those of applied chemicals such as salt solutions, cement alkalis, and petroleum derivatives. All the aforementioned external effects can cause a severe deterioration phenomenon within the various bridge elements, which is presumably protected by the expansion joints, if the existing system fails to perform properly. It is not uncommon to notice seriously deteriorated spots beneath the deck expansion joints of both steel and concrete bridges. A survey of 200 concrete bridges identified leaking expansion joints, poor or faulty drainage detail, defective or ineffective waterproofing, and limited access to bearing shelves as being major factors in the deterioration of those structures (Department of Transportation, London, 1989).

The results of an improper expansion joint system can be extremely expensive. However, if the expansion joint is carefully designed and detailed, properly installed by specialists and functioning, and given reasonable maintenance in service, there is no reason why it should not give trouble-free performance for its lifetime. Today, there are

a large number of proprietary expansion joints on the market and the problem facing the engineer is often that of selecting the most suitable joint to give good performance and a trouble-free life for at least as long as that of the surfacing material. This decision is by no means an easy one to make, especially with the inclusion of various technical and financial parameters (Brinckerhoff, 1993; and Lee, 1994).

1.2 Purpose and Objectives

The most important objective was to determine the reason for failure and the short life span of the expansion joints. This was further investigated by observing the practices of surrounding states that may have better expansion joint performance than INDOT. The observation was done by acknowledging the types of joints used and when they are used. Also the maintenance and aging of existing joints was observed and compared to the current INDOT practice in detail to determine what differences may exist.

The purpose of this research was to develop a reliable evaluation system for assessing various bridge deck expansion joints and to establish a corresponding policy. The policy is aimed at assisting INDOT personnel to assure that the put-in-place expansion joints will have the capacity of accommodating up to 4" movements and at least have 10 years service life.

To accomplish the above purpose, the following objectives needed to be achieved accordingly.

- 1. To investigate the critical parameters attributing to the poor and successful performance of expansion joint systems currently used by INDOT.
- 2. To identify the expansion joint systems that have a successful in-service performance record in Indiana and surrounding states.
- 3. To construct reliable evaluation criteria for assessing expansion joint systems that are either put in place or available on the market.

- 4. To perform in-service performance verification on the identified expansion joint system.
- 5. To supply the framework for a policy that INDOT can use for selecting and evaluating expansion joint systems.

CHPATER 2

BACKGROUND

A deck joint, depending on the type of movement it accommodates, can be classified as fixed or expansion. A fixed expansion joint allows only rotation, whereas an expansion joint may accommodate all required movements (longitudinal, transverse, and rotational). Several expansion joint systems are currently available on market. The list includes: open joints, filled joints (field-formed joint sealers/pre-formed joint sealers), compression seal joints, sliding plate joints, finger plate joints, saw-tooth plate joints, strip seal joints, sheet seal joints, modular joints, Jeene system joints, etc. Some of the aforementioned systems are presented in greater detail in the following sections (Brinckerhoff, 1993).

2.1 Types of Joints

2.1.1 Filled Joints (Field-Formed Sealers/Pre-Formed Sealers)

A filled joint is an open joint filled and sealed with a flexible and compressible material. Filled joints are inexpensive and easy to install and maintain. As a result, they have enjoyed widespread use in bridges. They are frequently encountered in existing bridges and in deck joint rehabilitation projects. The joint sealers, depending on the manner in which they are applied, are classified as field-formed, which are useful for movements up to 1 inch, or preformed useful up to 4 inches.

Field-formed joint sealers are commonly composed of hot applied thermoplastics or chemically cured thermosetting sealants. Application of a field-formed joint sealer requires a pre-formed backup material and water stop beneath it to control the sealer depth and shape, and at the same time provide support to the sealer. Pre-formed sealers are somewhat newer and hence have a shorter record of proven service than field-formed sealers. An important advantage they offer is quick installation time and less interruption to traffic. Most commonly used types of pre-formed sealers for deck expansion joint rehabilitation projects are extruded shapes made of elastomeric material.

The types of joints currently in use by INDOT belonging to this type are Poured Dow Corning Silicone Joint (XJS), PaveTech Joint, and Polymer Modified Asphalt Expansion Joint.

2.1.2 Sliding Plate Joints

Sliding plate joints are frequently encountered in existing medium-span bridges, and they continue to be used in new bridges and the rehabilitation of existing deck joints. Most of the existing sliding plate joints were constructed without any joint drainage system since the joint itself was considered to restrict the amount of infiltrating water to a minimum. The joint does not, however, completely eliminate the intrusion of water. Therefore, in recent systems, a trough is often supplemented to the plate system for long-term protection of the surrounding bridge components. The sliding plate joint features a steel plate spanning an open joint and embedded in adjoining deck slabs. It can also be arranged to bear on the steel structure itself.

2.1.3 Finger (Tooth) Plate Joint

Finger plate joints have been successfully used in medium- and long-span bridges for some time. They continue to be a popular option for new medium- and long-span bridges or in deck joint rehabilitation projects, as they are able to accommodate relatively large movements. Typical finger plate joints are made up of two loosely interlocking pieces of steel plates that cantilever into the deck joint opening. The cantilevered portion of each plate is made up of rows of finger-shaped protrusions that fit into the rows of grooves in the opposing plate. The finger plates are anchored into the deck slab or directly attached to the underlying superstructure steel. In most existing finger plate joints, the water and debris passing through the finger joint are collected and carried away by a trough system similar to the one previously described.

2.1.4 Compression Seal Joints

Compression seals are made of either pre-formed closed-cell plastic or, more commonly, hollow extruded neoprene shapes. The seals are generally installed by squeezing and inserting the seal into a pre-formed joint opening. Properly sized seals remain in compression under all anticipated deck joint movements. To improve the water tightness of the joint, the contract surfaces between the gap and seal are coated with a high-solids urethane adhesive prior to the insertion of the compression seal into the joint opening. The number of successful armored neoprene compression seal applications in the past decades has made this type of seal probably the most popular one. Neoprene compression sealers are available in a variety of configurations and movement ratings. The largest size seal can accommodate a total movement of 4 inches.

2.1.5 Strip Seal Joints

Although strip seals were introduced for bridge use later than compression seals, they have established a successful performance record. They continue to be a popular choice in deck joint replacement projects. Strip seals, as the name implies, is a strip of specially shaped elastomeric material that spans a deck joint opening. The seal is mechanically locked into a pair of rolled or extruded metal shapes that are in turn anchored to the edges of deck slabs. Strip seals are available in a number of configurations and a wide range of movement ratings. The largest size strip seal can provide up to 5 inches of total movement although most designers limit the total movement to 4 inches.

2.1.6 Sheet Seal Joints

Sheet seal is a sheet of fiber-reinforced elastomeric membrane with a center corrugation that bridges a deck opening. At both ends, the seal is held down and anchored into the corners of deck slabs by means of metal, elastomeric, or combination hold-down bar (retainer bars) and anchor bolts. Similar to the strip seal, the sheet seal functions either in tension or in compression and the deformation of the center corrugation accommodates the deck slab movements. Sheet seals represent one of the possible choices for deck joint

replacement in existing medium-span bridges, and are available in a variety of shapes, configurations, and sizes. A maximum of 4 inches of total movement is obtainable in a sheet seal.

2.1.7 Plank Seal Joints

Plank seals are molded neoprene sections of varying widths. The seal spans the deck opening and is bolted down to the deck slab at each end. A typical cross section displays a number of grooves placed alternately on each face of the neoprene plank, with metal plates spanning between these grooves. The checkered metal plates that are placed on the roadway face of the seal improve the skid resistance and protect the seal against snowplow damage or simple wear and tear. A plank seal accommodates the deck slab movements by the closing and opening motions of the grooves in the blank surface. This type of joint system, depending on the width of the plank and the number of grooves, can allow total movements ranging from $1\frac{1}{2}$ to 13 inches.

2.1.8 Modular Joints

Modular joints represent the state-of-the-art approach to accommodating the complex movements in long-span or curved bridges. Although the number of past applications is not as numerous as single compression or strip seals, the success rate of modular joints, particularly the ones with steel components, is encouraging. The modular joint system is composed of three main components: sealer, separator beams (for sealers), and support bars (for separator beams). Sealers can be of compression, strip, or sheet seal type. Separator beams are often extruded or rolled metal shapes to provide for the joining of seals in a series. The separator beams are supported on support beams at frequent intervals. The modular joint system, because of its refined mechanical performance, can accommodate the complex movements of long-span bridges as well as those of horizontally curved bridges. The modular systems available on the market today can provide total movements in the range of 4 feet.

2.2 Joints Investigated in the Research

A detailed classification of the types of joints studied here is shown in Table 2.1. The bridge joint data showing the types of joints currently in use and the total numbers of each used on INDOT bridges (excluding Toll Roads) are listed in Table 2.2. A summary of the features, advantages, and disadvantages of each type of joint is shown in Table 2.3.

Table 2.2 shows that B.S., S.S., and I.A. joints account for most of the joints currently in use. XJS, LDI, and PaveTech joints are new and their performances are not well known. Metal types of joints such as Tooth/Finger joints performed well in the past. Thus, the Study Advisory Committee (SAC) decided to exclude metal types of joints and evaluate B.S., S.S., I.A., XJS, LDI and PaveTech joints only in this research.

Table 2.1 Types of Joints Studied in this Research

Classification	Joint Type	Abbreviation
Compression Seal Joints	Compression Seal	B.S.
Strip Seal Joints	Strip Seal	S.S.
	Jointless (Neoprene Seal)	I.A.
	Jointless (Poured Sealer)	I.A.
Filled Joints (Field- formed Sealers/Pre-	Dow Corning Silicone	XJS
formed Sealers)	Polymer Modified Asphalt (manufactured by Linear Dynamic Incorporation)	LDI
	Polymer Modified Asphalt (manufactured by PaveTech)	PaveTech

Table 2.2 Bridge Joint Data on INDOT Bridges – minus Toll Road

04/27/98

BRIDGE JOINT TYPE	NUMBER OF BRIDGES			
	JOINT LOCATIONS			
Code - Description	SOUTH/WEST END	EAST/NORTH END	INTERIOR LOCATION	
NO DATA LISTED YET	116	115	126	
A = B.S. joint	1,855	1,873	415	
B = S.S. joint	469	462	154	
C = Tooth/Finger joint	34	34	11	
D = General Tire jt. Trans Flex joint	20	18	9	
E = Feldspar joint	2	2	1	
F = Sliding Steel Plate jonit	51	53	12	
G = Armor joint (2 Steel angles)	20	20	19	
H = IA joint	918	909	34	
I = Modular joint	25	43	24	
J = Open Joint	73	71	2	
K = No joint	935	939	80	
L = Unknown/Covered	385	386	69	
M = Structural Expansion Joint	116	109	44	
N = N/A	11	10	4,205	

BRIDGE JOINT TYPE	NUMBER OF BRIDGES		
	JOINT LOCATIONS		
Code - Description	SOUTH/WEST	EAST/NORTH	INTERIOR
_	END	END	LOCATION
O = Poured Dow Silicone joint (XJS joint)	52	51	10
P = Pave Tec joint	45	44	6
Q = Polymer Modified Asphalt Expan. Jt.	127	115	33

TOTALS 5,254 5,254 5,254

Table 2.3 Summary of Features, Advantages, and Disadvantages of Each Type of Joint

Joint Type	Open Joint	Filled Joint	Compression Seal	Sliding Plate Joint	Finger (Tooth)
			Joint		Plate Joint
Features	Mostly encountered in old short-span bridges. The width of the joint is from 1/2 to 2 inches.	Encountered in most existing bridges. It can be classified as fieldformed, useful for movements up to 1 inch, or preformed, which is useful up to 4 inches.	The most popular joints. The largest size seal can provide for a total movement of 4 inches.	Frequently encountered in existing mediumspan bridges. It can accommodate up to 4 inches of total movement.	Successfully used in medium- and long-span bridges. It can accommodate total movements from 4 to over 24 inches.
Advantages	Initial construction cost is relatively low.	Inexpensive and easy to install and maintain. Fast installation time and less interruption to traffic.	A large variety of choices in movement ranges, watertightness, relative ease of installation, and cost effectiveness.	The joint itself was considered to restrict the amount of infiltrating water to a minimum.	It can accommodate relatively large movements.
Disadvantages	Prone to the intrusion of deicing salts and water, creating costly repairs on surrounding bridge components in the long run.	It is newer and hence has a shorter record of proven service.	The success depends on the quality of the installation and the correct choice of the seal size and seal material. The compression seal may be ozonesensitive.	A trough system is often needed beneath this type of joint for long-term protection of the surrounding bridge components.	Possible accumulation of debris and eventual clogging of the trough through the finger joint.

Table 2.3 Summary of Features, Advantages, and Disadvantages of Each Type of Joint

Joint Type	Sawtooth (Serrated)	Strip Seal Joint	Sheet Seal Joint	Plank Seal Joint	Modular Joint
	Plate Joint				
Features	Encountered in existing medium span bridges. The movement can be in the range of 3 inches.	It has a successful performance record comparable with that of neoprene compression seals. The largest size strip can provide up to 5 inches of total movement.	The sheet seal can function either in tension or in compression. A maximum of 4 inches of total movement is easily obtainable.	An alternative for the replacement of existing joints in medium- and long-span bridges. It can allow total movements ranging from 1-1/2 to 13 inches.	It represents the state-of-the-art approach to accommodating the complex movements in long span or curved bridges. It can provide total movements in the range of 4 feet.
Advantages	The direction changes can be easily achieved by welding the steel plates.	Perform better than the compression seal at locations in which transverse slab movements are anticipated and provide a superior seal against water leakage.	The ability to accommodate directional changes and skews in the joint configuration, often without any need for a splice in the seal.	The checkered metal plates that are placed on the roadway face of the seal improve the skid resistance and protect the seal against snowplow damage or simple wear and tear.	It provides large movements and also permits nonparallel horizontal movement, differential settlement, rotation, and high shearing movements.
Disadvantages	Need to provide a trough system to collect water and debris.	The performance depends on the correct choice of seal size and seal material.	Failure of anchorage systems, under repetitive live-load impact, has been a frequently encountered problem.	Leakage at joints between segments, loose anchorages, excessive noise, and snowplow damage have been the problems commonly reported.	The noise under live-load impact, water leakage at seal splice locations, debris accumulation in seals, and snowplow damage.

2.3 Successful Performance of Expansion Joints

To function properly, bridge expansion joints must satisfy the following conditions (Lee, 1994):

- 1. accommodate all movements of the structure, both horizontal and vertical;
- 2. withstand all applied loading;
- 3. have a good riding quality without causing inconvenience or hazards to any class of road users;
- 4. not present a skid hazard;
- 5. be silent and vibration-free in operation;
- 6. resist corrosion and withstand attack from grit and chemicals;
- 7. require little or no maintenance;
- 8. allow easy inspection, maintenance, repair, or replacement.

The foregoing conditions could be considered as the evaluation criteria for selecting suitable joints for bridges.

2.4 Deterioration Indicators

Although a deck joint system is often composed of a variety of materials (concrete, steel, aluminum, copper, plastics, neoprene, epoxy, etc.) with different physical and chemical properties, they all share a common fate: aging and deterioration. Starting with the day they are installed, the deck expansion joints are continually exposed to both natural elements and those introduced by humans. The combined effect of these elements on the joint components is a steady and unavoidable deterioration process. Therefore, deck expansion joint components should be carefully inspected to uncover the following common defects (U.S. Department of Transportation, 1970):

- 1. Loose, torn, split, cracked, damaged, or hardened seals.
- Accumulation of debris and incompressible materials in the seals, drainage troughs, downspouts, and silting basins.

- 3. Loose, rusted, cracked, missing, or damaged steel plates, shapes, anchorage, bolts, nuts, and other metal components.
- 4. Cracked and spalled concrete, and rusted or exposed reinforcement, steel, or structural steel in the deck joint substrate.
- 5. Evidence of water leakage on the underside of the deck.
- 6. Evidence of noise during the passage of vehicles over the joints.
- 7. Restriction on freedom of joint movement.
- 8. Evidence of rotation, tilting, or settlement.
- 9. Incorrect joint opening or improper joint clearance and alignment.

Each of the aforementioned defects is an indicator of the degree of deterioration of the expansion joint system. The observed deterioration phenomena play a major role in establishing the deterioration curve of the expansion joint system under study, e.g., the service life of the system.

In recent years resources for the repair or replacement of any type of expansion joint have become extremely scarce. As a result, the cost-effectiveness of the various expansion joint systems on the market becomes the most important aspect in deciding which type to use. This decision, unfortunately, is not an easy one to make. The difficulty arises from the fact that the service life of any system is affected to a noticeable degree by the level of service on the bridge, the environmental conditions in the area, and several other secondary parameters. The possible change in any of those parameters can affect the expected lifetime of the expansion joint system to varying degrees. This necessitates the generalization of the service life concept to allow for all possible parameters.

CHAPTER 3

METHODOLOGY

The research can be divided into seven tasks shown as follows:

1. <u>Literature Search</u>

The purpose of the literature review was to find any information from older studies on the topic of expansion joints. This procedure also helped in structuring the research. Once a beginning process is determined for a research project, knowledge and qualitative information can be conjoined to produce effective results in the research. Subsequently, search on the topic of expansion joint systems in published books and technical journals was performed, and special emphasis was given to the various classifications of expansion joint systems, contemporary practices, and future trends.

2. <u>Background Review</u>

A broad review of in-service expansion joint systems currently used by INDOT was conducted, and those systems already recognized as potential candidates for immediate use by INDOT New Product Evaluation Committee were also evaluated. This step also included an investigation of the major problems encountered, any possible pitfalls causing early failures, the expected improvements in the selected systems, and the parameters attributing to successful performance.

3. <u>Investigation of Surrounding States</u>

Direct inquires were made into the current practices of the surrounding states. Special emphasis was given to identifying the expansion joint systems that have successful inservice performance record and their strengths and weaknesses.

4. Establishment of Evaluation Criteria

Based on the literature search and information found in the current practices of INDOT and surrounding states, an evaluation criteria and procedure for in-service systems was developed. General appearance, condition of anchorage, debris accumulation, water tightness, surface damage, noise under traffic, ease of or need for maintenance, and/or other factors were established as the criteria.

5. Expert Interview

Various specialists in the area of bridge deck expansion joint systems were interviewed to verify the materials collected in the previous steps. The interviews with the experts form the field, design groups, research labs, and market suppliers helped to develop a more reliable evaluation mechanism and identify countable expansion joint systems that can accommodate for 4 inch movements and that have at least 10 years service life.

6. Field Assessment

Once the evaluation mechanism was developed and verified by experts, field assessment on the identified expansion joint systems was performed. The objective was to experiment and to assure the reliability of the evaluation mechanism and to establish whether the evaluated expansion joint systems actually performed in the field as designed before the guideline policy was drafted for general implementation by INDOT.

7. Policy Development

The results from the above steps were synthesized to formulate standard provisions for using bridge deck expansion joint systems in Indiana. A draft policy was introduced to all the concerned parties for further input, and the feedback was incorporated into a final policy statement with recommended implementation procedures.

A flow chart depicting the methodology of this research is shown in Figure 3.1 below.

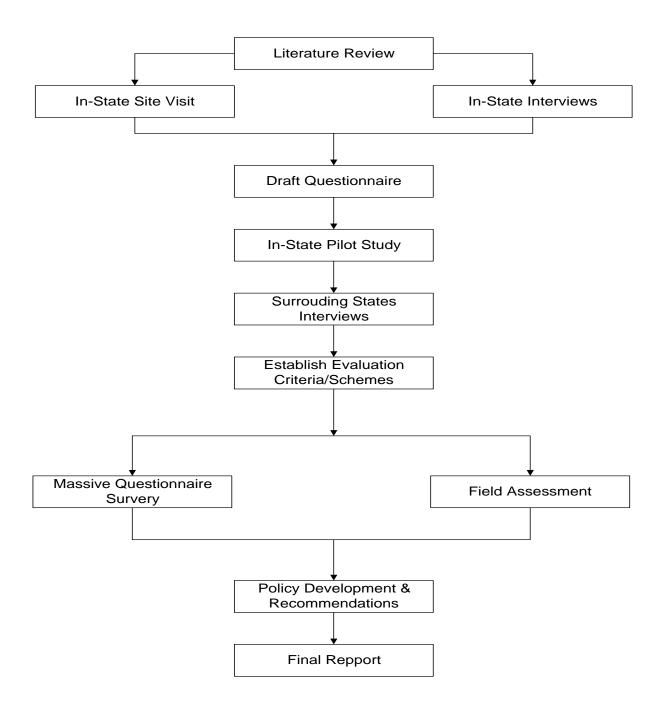


Figure 3.1 Research Methodology

CHAPTER 4

LITERATURE REVIEW

Expansion joints are widely used across the United States, which has led to some studies on the performance and rating of joints. These studies were a solid base for conducting this research and the information provided from the literature gave some insight on the performance and life span of the INDOT joints. The literature review was limited to certain joints, however, and often times did not include newer designs. Therefore, it was very important to use the literature as a framework only for conducting research and relaying pertinent information found.

One report of note (Fincher, 1980) was an INDOT project that evaluated the progress of rubber expansion joints for bridges, which included the Transflex 150-A, Transflex 200-A, Transflex 250-A, Transflex 400-A, Transflex 650, Wabo Flex SR-1.5, SR-2.5, SR-4.0, SR-6.5, Delastiflex CP-200, Reynolds Aluminum, Fel-Pro Type T-30, and the Wabo Maurer Strip Seal SB-200, SB-300, S-400E. The Wabo Maurer Strip Seal is no longer used by INDOT. However, strip seal systems are still commonly used.

The second report (FHWA, 1983) was performed on many types of joints. The joints included were the Compression, Strip Seal, Sheet Seal, Tooth Finger, Modular, and Sliding Plate, and the performance of these joints, as well as the evaluation criteria process, was documented. INDOT currently uses all of these joints in existing bridges. The newer acceptable joints are the compression, strip seal, and modular types.

In the early 1960's and 1970's, the Watertight Bridge Deck Expansion Joint was developed and put in use. Up until the late 1970's, FHWA conducted a National Experimental and Evaluation Program called the program NEEP II, in which 40 states participated and 825 joints were investigated across the nation. INDOT also participated in NEEP II and 97 joints from Indiana's 38 structures were evaluated.

In 1983, FHWA launched another research program entitled "Experimental Project No. 5, Bridge Deck Expansion Joints." Field review and evaluation was performed on 1,119 expansion joints with five or more years of service. Arkansas, Maine, Michigan, Nebraska, Ohio, and Pennsylvania participated in this research program, which was completed in 1987.

Between May 1990 and September 1991, FHWA conducted a follow-up field evaluation on modular and finger expansion joints. There were 136 and 42 respectively for each. Twelve state Departments of Transportation (DOT) participated in this effort. The findings from the above three studies can be summarized as follows:

I. INDOT Findings by Howard Fincher in 1983

Fifty percent of the assessed joints had poor vertical alignment, and 40% had snowplow damage. There were many premature sealant failures and none of the joints evaluated had substantial merits due to the following facts. Sixty percent of them were leaking water and 40% of them were experiencing problems detrimental to the service life of the joint.

II. FHWA-NEEP II Findings by George Romack in 1990

- A. Metal Reinforced Elastomeric Seal system was rated as poor.
- B. Compression Seal expansion joint system was rated as fair.
- C. Strip Seal expansion joint system was rated as fair.
- D. The sample size of Modular, Finger Dam, and Sliding Plated expansion joints evaluated in the study were too few to conclude.

E. Other findings

- 1. The condition of the bridge structure located below the deck was directly dependent upon the watertightness of the expansion joint.
- 2. Skewed joints are more susceptible to buckling and/or folding or neoprene damage.

- 3. The successful performance of the joint device is greatly affected by the quality of the anchorage system used.
- 4. The average rating of the B.S joint was slightly higher than the S.S. joint

F. Other Concerns/Issues

- 1. Lack of designer's awareness of the critical importance of the bridge joint.
- 2. Plan details need to clearly show the joint installation procedure.
- 3. Inspection should be by well-trained inspectors.
- 4. The use of specialty constructors should be considered.
- 5. Consideration should be given to making manufacturer responsible for this installation.
- 6. A maintenance program is a necessity.
- III. Findings from Study on Modular and Finger Expansion Joints by George Romack in 1992.
 - A. Modulars were performing as intended.
 - B. Fingers were performing as designed, although half of them had minor scrapes and gouges.

C. Other concerns/issues

- 1. Whether the particular system will provide for the necessary bridge movements and properly control the bridge runoff.
- 2. Quality of the fabrication of the components.
- 3. Adherence to plan details to insure proper installation.
- 4. Accessibility of proper inspection and maintenance activities.
- 5. Product warranties from the manufacturer.
- 6. Incomplete AASHTO specification.
- 7. Limited research and testing by the joint industry.
- 8. Insufficient slope for troughs to activate self-cleaning.

- IV. Findings from Studies on B.S. and S.S. Expansion Joints by Different State DOTs.
 - A. The study conducted in Maine (Price and Simonsen 1986) showed that the S.S. joint was performing well and that the B.S. joint performed well if a good adhesive was used and it was properly installed.
 - B. The studies conducted in Arkansas (Benson 1986) and Pennsylvania (Dahir and Mellot 1985) showed that the B.S. and S.S. joints were approximately equal in overall performance.
 - C. The study conducted in Ohio (Minkarah et. al. 1987) showed that the performance of the S.S. joint was slightly better overall than the B.S. joint.

Based on the literature review, questionnaires were designed and surveys were conducted of bridge inspectors and engineers to obtain more insight on the performance of expansion joints. The surveys' implementation and their results are described in the next chapter.

CHAPTER 5

QUESTIONNAIRE SURVEY

Questionnaires were developed to help to evaluate the joints investigated in this research. The questionnaire survey played an important role in this study because by soliciting the opinions of bridge inspectors and engineers, a better understanding can be obtained on joint problems and their causes, advantages, possible improvements, and service life.

5.1 Introduction

Two surveys and a follow-up survey were conducted. The first survey and the follow-up survey were designed for Indiana bridge inspectors and the second survey was designed for bridge inspectors in Indiana and the surrounding states, i.e., Michigan, Ohio, Illinois, and Kentucky. The follow-up survey will be introduced in detail in section 5.5. The first survey questionnaire is in Appendix A and the second survey is in Appendix C of this report.

Five types of joint are included in the survey, B.S., S.S., I.A. (poured sealer and neoprene seal), XJS, and Polymer Modified Asphalt joints (LDI and PaveTech). The questionnaires are divided into three parts:

1. Background

This part of the survey established the years of experience of the person completing the questionnaire, his/her title of position, and district in which he/she is working. The years of personal experience were later used as the weights in calculating the ranking of the answers.

2. The Problems, Causes, Merits, and Improvements Associated with the Bridge Deck Expansion Joints

This part asked the respondent to identify, for each type of expansion joint, what he/she thinks are the most serious problems and their causes, advantages, and possible improvements. Respondents were asked to select three answers for each question by the order of the severity (for problems and causes), the importance (for advantages), or the possibility (for improvements).

3. Recommendation

In this part the respondents were asked to estimate the life of each type of joint; to select three better joints in their opinions; and to provide their personal comments on the bridge expansion joints as well as the questionnaire design.

Sample answers were attached with the questionnaires; however, if none were found suitable from the list of sample answers, the respondent could write his/her own answers. The two questionnaires were slightly different because the questions of the second survey were modified for more detail based on the answers of the first survey. The format of the second survey was also changed to facilitate filling out the questionnaire. Also in the second survey, two more types of joints were added (I.A. joints were separated into those with poured sealers and those with neoprene seals, and the PaveTech joint was added). Respondents were also asked to select three better joints as well in the second survey.

5.2 Analysis of the First and Second Questionnaire Survey Data

1. Joint problems

In this part, respondents were asked to provide the three most severe problems for each joint by using the numbers 1, 2, and 3, with one representing the most severe. Each problem was subsequently ranked by the score, which was calculated by the weighted average method (using years of experience as the weight) for each type of the joint. Finally, the total score of each problem was divided by the number of people who selected it. The problem with the lowest minimum value is indicated as

the most severe problem, the second minimum value as the second most severe problem, and the third minimum value as the third most severe problem.

2. Causes of joint problems

After identifying the most severe problems of each joint, their causes were identified from the answers of correspondents who selected those problems as the most severe ones in the first part. Then the method similar to the ranking process of the most severe problems was used to obtain the three most likely causes for each problem.

3. Strengths and improvements of joints

The same method as ranking problems was used.

4. Estimated life of joint

The estimated service life of each type of joint by each respondent was recorded from the questionnaires. Then the weighted average (using years of experience as the weight) method was used to calculate the estimated life of each joint.

5. Recommended better joint

Two methods were used here. The first one was the weighted average method as used above, and the second one was to sum up the values assigned to each joint and divide it by the number of people who selected it.

6. Comments

Many comments were made on the questionnaires, which are summarized and discussed in more detail later in this chapter.

A numerical example demonstrating the analysis of survey data is shown in Appendix E.

5.3 Implementation of the First and Second Questionnaire Survey

In the first survey, five types of joints were investigated: Compression Seal Joints (B.S.), Strip Seal Joints (S.S.), Jointless Joints (I.A.), Poured Dow Corning Silicone Joints (XJS), and Polymer Modified Asphalt Joints (LDI). This survey was distributed to bridge inspectors and engineers in Indiana only at an annual inspector meeting. Eighteen responses were finally received and covered all six districts and the Central Office of INDOT.

In the second survey, seven types of joints were included. In addition to the original ones in the first survey, the Jointless joints and the Polymer Modified Asphalt joints were each separated into two subtypes. They became the Jointless joint (I.A.) with Neoprene Seal, the Jointless joint (I.A.) with Poured Sealer, Polymer Modified Asphalt joints (LDI), and Polymer Modified Asphalt joints (PaveTech). This survey was conducted in Indiana and four surrounding states: Michigan, Ohio, Kentucky, and Illinois. In Indiana, the questionnaires were sent out to the same people who filled out the first survey. In addition to gathering information that was lacking from the first survey, the second survey could also be used to confirm the results of the first survey. As for the surrounding states, the questionnaires were sent out to the bridge engineers and bridge inspectors in each district. Table 5.1 shows the number of questionnaires issued and returned in each state. The number of surveys returned is much less than the issued number partly because some districts returned one copy of the questionnaire to represent the common opinions in one district instead of returning each inspector's survey.

Table 5.1 Number of Questionnaires Issued and Returned

	Issued	Returned	Effective
Illinois	27	9	9
Indiana	20	8	7
Kentucky	34	7	7
Michigan	9	1	1
Ohio	36	8	8
Total	126	33	32

5.4 Discussion of Findings from the First and Second Questionnaire Survey

The results of the first and second questionnaire survey are shown in Appendices B and D. Following is the analysis and summary of those results.

Findings on Each Type of the Joint

The findings described here are from the questionnaire survey results, i.e., the most severe problems and their causes, possible improvements, advantages of each type of joint, and comments from respondents. The quantitative results of two surveys are shown in Appendices B and D; following is a summary of the important findings.

1. B.S. Joint

Spalled concrete and loose seal were selected and designated as the most severe problems for this type of joint. Loss of concrete for B.S. joint leads to loose joints and leaks with subsequent salt deterioration and spalling of back wall, substructure bridge seats, and bearing areas. This in turn can cause raised decks and have an impact on traffic. Debris problems also occur in some cases and the seal can become hardened, whereby no expansion back to the original thickness occurs after a period of time.

The aforementioned problems were possibly due to the impact of traffic loadings, incorrect joint openings, and failure of bonding agents. The traffic loadings caused the concrete to spall and crack and brought debris on the seal. The incorrect joint openings and failure of bonding agents could accelerate the deterioration of bearings.

There are several suggestions for solving problems stated above. 1) Adding admixtures to concrete to increase its resistance for freezing and thawing and reduce cracks. 2) The seal should be tested before installation. 3) Armoring the joint against the live-load impact from traffic. 4) Strengthening the bonding between seals and the concrete.

In summary, this type of joint could function well if concrete and seals are in good shape. Some respondents felt it is easy to replace this type of joint and maintain but some did not.

2. S.S. Joint

Debris seems to be the major problem of this type of joint. Deicing abrasive sand and blowing sand usually accumulate in the S.S. joint and passing trucks pound down sand to pop out the rubber from holding glands. Sometimes armor angle breaks under wheel loading can catch snowplows and create maintenance problems.

Debris, poor installation and maintenance seemed to be major causes of problems of the S.S. joint. Poor or faulty drainage details, deicing chemicals, snowplows, and traffic loadings all contributed to the problems of this type of joint and shortened its service life.

Several suggestions to the above problems were proposed. 1) The joint should be designed with self-flushing capabilities, such as the sufficient slope or larger curb opening. 2) It is better to use non-corroding extrusion and larger diameter bolts to hold down the anchor blocks. 3) Regular and frequent maintenance should be conducted.

Some respondents indicated that this type of joint is very durable if well maintained. It may be more expensive than the B.S. joint but considering maintenance it is more cost effective than B.S. joint.

3. I.A. Joint (Poured Sealer)

It appears from the survey that there are no major complaints with this type of joint. However, it was found that joint materials do not always completely fill the opening and spalled and cracked concrete occurred 5 to 10 feet from the end of the deck.

The causes of problems include poor installation, improper selection of materials, traffic loadings, and deicing chemicals. The snowplows also occasionally caused seals to break.

Several suggestions were made on the survey for improving the performance of this type of joint. 1) The notch should be made deeper and filled with silicone. 2) Beveled edges can reduce concrete spalling due to wheel loads. 3) Approach slabs should be tied to deck to eliminate movements.

The advantage of this type of the joint is that the poured silicone can flow into and conform to any concrete imperfection due to construction forming of concrete seal edges. Some respondents commented that it is durable and maintenance-free.

4. I.A. Joint (Neoprene Seal)

The problems and suggested improvements for this type of joint are similar to the one stated above. However, most respondents indicated that its performance seems to be worse than the I.A. joint with the poured sealer.

5. XJS Joint

This type of joint has several problems. The epoxy materials were found to come in contact with traffic, which caused holes in the seals. This could be due to installing it too high, structure expansions causing it to shove upwards, or hot weather. There are debris and gravel problems for this type of joints, and the nosing materials are also frequently damaged, which may cause leaking problems. The silicone material also was found to be not mixed correctly and frequently there were holes and cracks on the seal.

The problems of this type of joint could be caused by poor installation and inferior quality of bonding agents. Poor installation caused the silicone to be installed too low or too high and frequent damages of bonding agents could cause the holes and cracks on the seal.

Several suggestions were made for problems of this type of joint. 1) The polymers should be kept slightly below the top of the deck elevation and the chamfer should be large enough to prevent spalling of the nose. 2) Silicone thickness should be placed correctly and the silicone material should be mixed correctly. 3) Detailed installation plans should be provided by the manufacturer or the contractor.

Some respondents preferred this type of joint because of its easy installation and repair; this type of joint can be repaired by bridge crews within one working day. It is also easy to make a spot repair in one particular location without removing the entire joint.

6. LDI Joint

Several problems were found with this type of joint. The polymer modified asphalt materials are found missing with steel plates rusted and cracked. The asphalt materials also experienced shoving and rutting during hot weather and had cracks in the shoulder area. The mixing of the materials was not up to the standard quality.

The problems stated above could be caused by the unacceptable range of the bridge movement or the inferior quality of asphalt materials. The large bridge movement could cause the cracks on the seal and the inferior quality of asphalt materials may cause serious shoving and rutting during hot weather.

There were some suggestions for improving the performance of this type of joint. 1) The bonding between the header and the adjacent concrete should be improved by using better materials. 2) The material testing should be done before installation. 3) Selection for use in locations where heavy truck traffic is not present or bridge movement is small may improve the joint performance.

This type of joint has the advantages of providing excellent ridibility, would not require flushing, and would not be damaged by snowplow blades.

7. PaveTech Joint

The problems and improvements of this type of joint are similar to those of LDI joints. However, its polymer modified asphalt material was found to be softer than that of LDI and hence the problems of shoving and rutting were more serious.

Overview of the Joint Problems

The overall ranking of the joint problems was obtained by using the result of the first questionnaire survey (In-State). Problems of each type of joint were first ranked according to the weighted average score considering the years of experiences of each respondent. After the ranking of problems for each type of joint was obtained, the ranking of each problem under each type of joint was summed and the final scores were used for the overall ranking. For instance, assume that there are five joint problems and five types of joints shown in the Table 5.2 below. Five joint problems were first ranked under each type of joint. By summing the ranking of each problem under each type of joint, the total scores were put in the column entitled "Total". The total scores were then used to obtain the overall ranking of the joint problems. The numerical example of the data analysis was shown in Appendix E and the actual result was shown in Table 5.3.

Table 5.2 Methodology for Ranking Overall Joint Problems

Joint Problem	B.S.	S.S.	I.A.	XJS	PMJ	Total	Ranking
Damaged seal	1	3	3	1	1	9	1
Deteriorated bearing	2	4	5	3	2	16	3
Damaged adhesives	3	1	1	4	4	13	2
Water leakage	4	5	2	2	5	18	4
Spalled concrete	5	2	4	5	3	19	5

Table 5.3 Overall Ranking of Joint Problems (First Survey)

Problem	Ranking	Symptom
а	1	Loose, torn, split, cracked, damaged, hardened seals, or holes in seals
j	2	Deterioration along bearing areas on the pier caps and on the columns
b	3	Damage of epoxy fillers or adhesive lubricants causing separation of the joint material from the joint face
е	4	Evidence of water leakage on the underside of the deck or at the curbline
d	5	Cracked and spalled concrete, and rusted or exposed reinforcement steel or structural steel in the deck joints substrate
k	6	Poor ridebility
С	7	Accumulation of debris and incompressible materials in the seals
f	8	Evidence of noise during the passage of vehicles over the joint
h	9	Evidence of rotation, tilting, or settlement of joints
i	10	Incorrect joint opening and alignment
I	11	Inadequate skid resistance
g	12	Restriction on freedom of joint movement causing problems such as transverse movements of the deck
n	13	Loose, torn, split, cracked, damaged, or hardened nosing materials
q	14	Traffic comes into contact with silicone
р	15	Tracking and flowing of polymer during hot weather

Table 5.3 showed that the five most serious joint problems obtained from the surveys are: broken seals, deteriorated bearings, damaged adhesives, water leakage, and spalled concrete and rusted steel. The seal problems include loose, torn, split, cracked, hardened, or holes in seals. Deterioration of bearing happens on the pier caps and the columns. Damage of adhesives or epoxy fillers causes separation of the joint material from the joint face. Water leakage happens on the underside of the deck or at the curbline. Concrete are usually found cracked and spalled and steel found rusted or exposed in the deck joints substrate.

Debris accumulation, traffic loading, poor installation, and inferior material quality frequently cause the damage of the seals. Bearing is deteriorated by deicing chemicals, rain, leaking joint, or poor maintenance. Poor installation and inadequate bonding strength may damage the adhesives. Water leaks from the damaged seal and adhesives, and spalled concrete. The traffic loading, deicing chemicals, and the poor quality of the used material make the concrete and steel problems worse.

Several suggestions were made to solve the aforementioned problems. The joint materials such as seals or adhesives should be tested and well installed by the specialty contractor. The joint can be armored to be protected against the traffic impact. Concrete needs to be protected by sealers and the plate and bars holding the seal need to be more corrosion-resistant. A large curb opening can flush the joint itself clear and reduce the accumulation of debris. Regular and frequent maintenance is important to extend the service life of the joint. Finally, the joints need to be selected from those, which can meet the requirement of the deck expansion range and the traffic density.

Some of the problems may happen more frequently to one type of joint than the other. For instance, cracked and spalled concrete happened most to the B.S. joint while the damage of the adhesive lubricants usually happen to the XJS joint. The rest of the problems that were ranked from the 6th to 15th can also be seen from the table. The results of the overall ranking of the joint problems for the second survey and the follow-up survey (introduced in Section 5.5) were provided in Appendix F.

Estimated Life of Joints

The results of both surveys regarding the estimated life of the joints were very similar, as seen from Table 5.4 and 5.5. The S.S. joint was rated to have the longest estimated life in both surveys, followed by the B.S. joint, and then the I.A. joint. The major difference among them was in the LDI joint. In the first survey, the LDI joint had the shortest estimated life, 3.5 years. In the second survey, the estimated life of the LDI joint is 5.74 years. Thus, the LDI joint was ranked before the XJS joint in the second survey while it was last in the first survey. In summary, it can be concluded that the S.S. joint has the longest estimated life on average in both surveys. The I.A. joint with a poured sealer has a longer life than the one with a neoprene seal. The performance of the PaveTech joint was very similar to the LDI joint. The XJS, LDI, and PaveTech joints had a considerably shorter estimated life compared to the S.S., B.S., and I.A. joints.

Table 5.4 Estimated Joint Life (Survey #1)

Joint Type	S.S.	B.S.	I.A.	XJS	LDI
Weighted	11.9	11.706	8.728	5.19	3.502
Average (yr.) Range (yr.)	0 – 20	0 - 20	0 – 20	1 - 15	1 - 10
S.D. (yr.)	5.79	5.59	5.91	3.97	2.85

Table 5.5 Estimated Joint Life (Survey #2)

Joint Type	S.S.	B.S.	I.A. (Poured sealer)	I.A. (Neoprene seal)	PaveTech	LDI	XJS
Weighted Average (yr.)	10.92	10.3	9.79	7.33	5.82	5.74	5.56
Range (yr.)	1.5 – 25	2 - 20	1.5 - 20	1.5 – 15	1.5 – 10	0 - 20	0 - 20
S.D. (yr.)	5.34	4.86	6.24	4.07	2.74	6.9	6.41

S.D.: Standard Deviation

Recommended Types of Joints

Since this question was only asked in the second survey, there is only one result available, which is shown in Table 5.6. Two ranking methods were used and they showed very different results. The S.S. joint was one of the top two recommended joints using both methods. The I.A. joint with a poured sealer is preferred more than the one with a neoprene seal, and the PaveTech joint is the least favored joints in both methods.

Table 5.6 Recommended Types of Joints

a. By the weighted average score

Ranking	1	2	3	4	5	6	7
Joint type	B.S.	S.S.	XJS	I.A.	I.A.	PaveTech	LDI
				(Poured	(Neoprene		
				sealer)	seal)		

b. By the average score (not considering the years of experience)

Ranking	1	2	3	3	5	6	7
Joint type	S.S.	I.A.	LDI	I.A.	B.S.	XJS	PaveTech
		(Poured		(Neoprene			
		Sealer)		seal)			

5.5 Follow-up Survey

To better understand the performance of each type of joint in each specific category, namely, riding quality, water leakage, noise, and difficulty of maintenance, a follow-up survey was conducted. Bridge inspectors were asked this time to rank the joint problems according to the aforementioned four categories. Six inspectors from each district of INDOT and one inspector from INDOT's Central Office participated.

Seventeen problems were selected from the first questionnaire for ranking in the follow-up survey. The problems were ranked one through seventeen by survey participants according to their severity in each category, with one being most severe and seventeen the least severe. For instance, in the categories of riding quality, water leakage, and noise, inspectors were asked to rank each problem according to its contribution to the poor riding quality of joints, water leakage, and noise. In the category of difficulty of maintenance, problems were ranked depending on how severely each problem influenced the difficulty of repair.

All of the inspector's rankings in each category were then summarized to obtain the final ranking in each category. The ranking of each problem was then matched and assigned to the three selected most severe problems from the result of the first survey and a total score was obtained for each type of joint in each category. Since smaller numbers in the ranking designated more severe problems in a particular category, a larger total score indicates better performance by a joint in that category. The results are shown in Table 5.7.

Table 5.7 Performance of Joints based on Riding Quality, Water Leakage, Noise, and Difficult of Maintenance

Ranking	Riding Quality	Water Leakage	Noise	Maintenance
Good	XJS	S.S.	XJS	XJS & S.S.
	S.S.	LDI	S.S.	B.S.
	I.A.	B.S.	B.S.	LDI
₩	B.S. & LDI	XJS	I.A.	I.A.
Worse		I.A.	LDI	

The results of the follow-up survey generally confirmed the results of the first and second questionnaire surveys. The S.S. joint performed better than the B.S. joint, which then performed better than the I.A. joint. The LDI did not perform well in any category, except water leakage.

The major difference in the follow-up survey results was that the XJS joint performed better than other types of joints in almost every category except water leakage. However, possibly due to its short history of usage and long-term performance was not well known, in the first and second surveys, its ranking as to its estimated life and recommended type of joint was not good. Furthermore, this type of joint is usually installed where the expansion range is small and the traffic volume is low. It could become a good joint if it proves to have good long-term performance and meet various expansion and traffic requirements. The questionnaire of the follow-up survey, the analysis of data, and the result were shown in Appendix F.

5.6 Summary

- 1. Almost all the severe problems of each type of joint are related to the seal and the concrete, and these problems usually consist of holes in the seal, hardened seal, cracked seal, loose seal, and torn seal. The problems of concrete are mainly spalled concrete and cracked concrete. The seal and concrete problems often cause leaking of the joint, which can cause the deterioration of the substrate elements such as abutment walls, caps, bearings, and beam end.
- 2. The causes of most joint problems are related to traffic loading, snowplow damage, weather, poor installation, inferior materials, and the incorrect selection of the joint type.
- 3. One major problem of the B.S. joint is spalled and cracked concrete. The prudent preparation of concrete will insure its quality. Further, the seal materials should be tested before installation.
- 4. One major problem of the S.S. joint is the accumulation of debris and grit. How fast the debris accumulates or how well the maintenance is done could affect the outcome. One suggestion for solving this problem was to make a larger curb opening or a sufficient slope so that rain can flush the debris.

- 5. The causes of several XJS joint problems were poor installation, poor workmanship, and inadequate site preparation. It can be concluded from the survey that the performance of the XJS joint depends greatly on the installation quality, i.e., the mixing of materials and the thickness of the silicone.
- 6. The LDI and PaveTech joints both have similar problems and causes. Their seals can be pushed up during hot weather (rutting) and then holes are formed in the seal. The inferior materials used in both types of joints and installation of this particular joint at locations with high traffic volume, as well as its greater expansion requirements, are also main concerns in its poor performance.
- 7. The results for estimated joint life in the first and second survey were very close. The S.S., B.S., and I.A. joint were ranked first, second, and third in both surveys according to the length of their estimated life. The I.A. joint with poured sealers lasts longer than the one with neoprene seals. The performance of the PaveTech joint was very similar to the LDI joint. The XJS, LDI, and PaveTech joints were rated to have considerably shorter estimated lives compared to S.S., B.S., and I.A. joints.
- 8. The overall ranking of the joint problems showed that the five most severe problems were the seal problem, deterioration along bearing areas, damage of adhesive lubricants, water leakage, and cracked and spalled concrete. However, some of the problems may happen more frequently to one type of joint than the other. For instance, cracked and spalled concrete happen most to the B.S. joint while the damage of the adhesive lubricants usually happens to the XJS joint.
- 9. The recommended joints, using both ranking methods, were very different. The only conclusions that can be derived is that the S.S. joint remained among the strongly recommended joints and the PaveTech joint is among the weakest joints in both rankings.

10. The results of the follow-up survey generally confirm the results of the previous two questionnaire surveys. The performance of each type of joint, from good to worst, was shown in the pattern of the S.S., B.S., and I.A. joints in the categories of riding quality, water leakage, noise, and difficulty of maintenance. The LDI joint did not perform well in any category except water leakage. Although the XJS joint was ranked well in most categories, its long-term performance needs to be evaluated because of its short history of usage.

CHPATER 6

IN - STATE SITE VISITS

Several types of joints were observed and their performance evaluated by site visits to see the problems currently identified with INDOT bridges (no county or city maintained bridges have been included in the scope of this project). Of the bridges visited, the joints observed were the Compression Seal, the Strip Seal, Modular, Polymer Modified Asphalt, Integral Abutment, Poured Silicone, Tooth/Finger, and Modular. All of the joints were photographed and documented, and their performance evaluated by visual inspection of their deterioration.

The installation of joints was also observed during the site visits, namely the placements of a strip seal joint and a poured silicone joint. The strip seal joint was installed on I-70 and the poured silicone joint was installed on a state bridge. These joints and other joints stated previously were observed twice, one in the summer and the other in the winter, to establish a seasonal difference in the joint condition. However, there was no noticeable difference between winter and summer for these joints. The reason might be that the joint was observed for only one winter. There was small difference in the joint's appearance, but it could have been caused by other factors such as age, traffic, installation quality, which were imposed on the joints with the weather factor at the same time.

The following paragraphs describe the observations made in the site visits. Please see Appendix G for photographs of these joints.

- B.S. Joint

The B.S. joint was located on I-465 over Fall Creek Road. The seal looked fine, but the surrounding concrete was spalled and had cracks. This observation agrees with the results of the survey.

- Flexcon 2000

This is a type of joint similar to the XJS joint. The major difference is in the joint materials used. Two locations were visited, one on I-65 and Greenwood Road and the other on I-70 adjacent to Harding Street and Conrail. Both joints still contained the heading materials, but the seals were severely broken. The first one was loose and had many holes; and the second one was split and cracked. The seal of the second joint was not deep enough and came in contact with vehicle tires, which could be the reason for its seal's rapid deterioration. The heading material in the second joint was also severely worn.

- I.A.

This I.A. joint is located on South Port Road over Little Buck Creek. This joint and its surrounding concrete looked very good and there were no signs of deterioration.

- LDI

This LDI joint looked good in its appearance. However, there were some small cracks on the edge of the joint, which could be due to the debonding of the joint materials and concrete.

- Modular

This joint is located on I-65 over White River. This joint appeared to be performing well but debris was already accumulating in the seal and there was spalled concrete on the edge of the joint.

PaveTech

Two PaveTech joints were observed. The first one was located on I-65 over Martin Luther King Drive and the second one is located on I-65 at Clinton Street. The first joint contained holes and parts of the surface were worn out. The baker rod fell off the joint as can be seen from the pictures.

The second joint also had serious problems with deep holes in the seal. These holes could be attributed to the fact that the polymer materials of the PaveTech joint are soft during the hot weather. Thus, holes are formed under the heavy traffic load.

- Sliding Plate

This joint was located on I-70 eastbound over Rural Street. The overall appearance of this joint was fine but there was a hole in the plate, which could be due to the pounding of the traffic.

- Tooth Finger

This joint was located on I-70 eastbound over Rural Street. The overall appearance of the joint was good except that there were a few broken teeth on the plate.

- S.S.

There were two S.S. joints visited. The first one was located on the 38th Street eastbound lane over I-65 and the second one was on I-74. The first joint contained substantial debris in the seal and some portions of the seal were loose (the photo in Appendix G shows that a hand can go through the seal). The anchors were deteriorated as seen from the photos.

The second joint had been installed for about one year and its performance looked fine, however, substantial debris had already accumulated in the seal.

- XJS

There were two XJS joints visited. The first one was located on I-74 at the east side of Indianapolis and the second was located on I-59 near Carbon. The joint's appearance looked good but actually it had holes (the photo shows the finger able to go through the seal), and the seal was debonded from the edge of the heading materials. From the bottom of the bridge deck it was observed that the bearing was seriously deteriorated, which indicated that this joint had a serious leaking problem.

The second joint was performing well since it had been installed for only one year and not much debris had accumulated. This could be also due to the fact that this joint was located on a state road, which has less traffic. There was no nosing material and small cracks were seen on the edge of the joint.

In summary, the problems observed in the field paralleled the results of the questionnaire survey. Although only a few samples were observed for each type of joint, the results of the questionnaire survey were confirmed by these site visits.

CHAPTER 7

EXPERT INTERVIEWS

Interviews were performed with INDOT staff members and those of surrounding state

DOTs of Illinois, Kentucky, Michigan, and Ohio. These interviews were conducted by

telephone or person-to-person. The objective of the interviews was to determine each

state's practices for selecting, evaluating, and maintaining the joints.

7.1 In-State Interviews

Indiana Department of Transportation Informal Expansion Joint Approved List

From the interview with NPEC committee members, it was discovered that INDOT does

not have a formal approved list of expansion joints. The current method of selecting

joints is basically a trial and error process. In the past, joints were selected based on

vendor data without any formal approval. The joints then were put into use and evaluated

on performance. If they performed well, then they became commonly used. Poor

performance of the joint resulted in suspending its use or the manufacturer was asked to

redesign it and complete the testing process once again. Once this process was

completed, then an evaluation was done by INDOT and the joints were either continued

in use or discontinued. This whole process has repeated itself a few times in the past 20

years. Since the formation of the NPEC, the "trial and error" process has been discarded.

Hence, a criteria scheme is needed to assist in the review of joints and joint material

before they are installed.

This following list of expansion joint products was provided by Advanced Performance

Products of Indianapolis, a supplier of joint materials to INDOT. These joints are

currently being supplied to INDOT.

1. B.S.

Watson Bowman

D.S. Brown

43

2. S.S.

Watson Bowman

D.S. Brown

R.J. Watson

Structural Accessories

3. Modular

Watson Bowman

D.S. Brown

4. Poured Silicone

Dow Corning

5. Integral Abutment (I.A.)

The Maintenance of the Bridge Expansion Joints

The maintenance of bridges and roads is fulfilled by INDOT after the contractor has fulfilled the contract requirements. INDOT has a two-year cycle of inspection of bridges to determine their structural state. District bridge inspectors conduct the inspection using a specific form for this purpose. Once the report has been reviewed, any necessary repairs are then scheduled.

INDOT allocates a specific amount of money each year to be used specifically for maintenance; however, resource allocation is usually depleted before all of the projected work is completed, which could lead to loss of maintenance on bridges, and/or lack of proper maintenance due to poor time management.

The Use of the Integral Abutment Expansion Joint

INDOT has begun using the Integral Abutment (I.A.) Expansion Joint in most bridge designs. The purpose of the I.A. joint is to place the expansion characteristics of the

bridge onto the approach slabs, which helps prevent maintenance problems and failures of the joint in the future. However, there have been problems with cracking in the approach slabs, and the design of the approach slab has changed almost yearly for the past three years. Underneath the slab and behind the abutment, the area has been backfilled with granular materials, and the material has changed from sand to coarse aggregates. There has also been the addition of a corrugated pipe that runs transverse of the slab behind the abutment to remove water from the area. Once water is in the area, it can cause the slab to crack and fail and also cause settlement. The current design for the approach slab allows for expansion onto the slab, which is overlaid with asphalt. The asphalt allows for more expansion and contraction than does the concrete.

7.2 Surrounding States Interviews

States surrounding Indiana were surveyed to find out current practices on expansion joints. Particular emphasis was placed on the type of joints used, why they are used, and their strengths, weaknesses, and performance history. Interviews were conducted with state DOT officials to obtain these answers.

Michigan

Several bridge engineers with the Michigan Department of Transportation (MDOT) were contacted to gain information about the techniques and products Michigan uses for bridge expansion joints. Specifically, MDOT officials were asked to provide a list of the joints they use and the standards and specifications for these joints. A listing of any rehab jobs in MDOT was also requested and they responded by e-mailing a copy of plans and specifications for a rehab job that was designed specifically for expansion joints. MDOT specifications indicated that they are current using S.S., XJS, and Polymer Modified joints. They also mentioned that the maintenance work in some districts is subcontracted, rather than using the in-house force.

Ohio

Bridge designers with the Ohio Department of Transportation (ODOT) were contacted about their use of expansion joints, and they referred us to their web page, www.dot.state.oh.us/se/standard/metric/indexm.htm, which has standard drawings and specifications of the type of joints used and their manufacturers. They also supplied the names of the construction engineers of each district and their telephone numbers. Eight types of joints are specified in ODOT's standard drawings and specifications, including B.S., S.S., Semi-Integral, Integral, Steel Sliding Plate, Modular, and Tooth/Finger joints. They mentioned that in most rehabilitation jobs for recent years, they tend to use more I.A. joints because they experienced less maintenance problems.

Mr. Hopwood of the Kentucky Transportation Cabinet also provided information regarding some of the joints current in use by ODOT, much of which pertained to Semi-Integral and Integral Abutment bridges. This information included detailed sketches of integral abutments, a small report about integral abutments that was presented at the Transportation Research Board's 75th Annual Meeting in Washington D.C. in January of 1996, and an information packet from a workshop on integral abutments. Average daily traffic information and types of joints were also provided, as well as an interoffice memorandum that indicated the polymer modified expansion joint performed poorly in heavy traffic (Inter-Office Communication, ODOT, 1995). A copy of the standard drawings and specifications for ODOT joints that are currently in use were included in this information.

Illinois

Bridge engineers in the Illinois Department of Transportation (IDOT) were asked to provide a list of IDOT approved expansion joints and their manufacturers, a list of the district construction engineers, post-construction evaluation procedures, and their procedure for new products approval.

IDOT provided the list of joints below and their manufacturers. They also provided a list of districts and the engineers to contact. Post-construction evaluation techniques were discussed in an interview, and it was revealed that IDOT has had only one post-construction evaluation on expansion joints in the past 10 years. This evaluation began as a testing of the Poured Silicone joint, for the purpose of observing how well the joint performed while flooded with water. The research then moved into all joints and a report was constructed. This report is to be given to at a later date, but INDOT confirmed that the report shows that the Poured Silicone joint performed well. IDOT's only other evaluation is done during the FHWA inspection every two years, where when maintenance is also performed. The IDOT uses five different levels to rate the joint condition: 5 for new, 4 for good, 3 for fair, 2 for poor, and 1 for replacement required.

Like INDOT, IDOT has a New Products Evaluation Committee; however, the committee member to whom we were referred has not responded to the survey request. IDOT also provided information from the Bridge Design Manual regarding expansion joints.

Illinois Department of Transportation Informal Expansion Joint Approval List

1. Strip Seal

Watson and Bowman

D.S. Brown

2. Neoprene Joint

General Tire

3. Reinforced Neoprene Seal

D.S. Brown

Watson and Bowman

4. Compression Seals (B.S.)

Whoever meets accepted standards

5. Poured Silicone

Dow Corning

6. Bonded Preformed Joint

Watson and Bowman

7. Modular

Watson and Bowman

R.J. Watson

D.S. Brown

8. Integral Abutment (I.A.)

Kentucky

The Kentucky Transportation Cabinet was somewhat helpful during the interview process, however with no backing documentation provided. The following was obtained from direct contacts with bridge engineers in the Division of Bridges of the Kentucky Transportation Cabinet:

- 1. Specifications for the different types of joint materials were provided.
- Modular joints are not used at all in Kentucky, and there is wide use of Integral type,
 B.S. and S.S. joints.
- 3. Information on their evaluation process and inspector list was referred to a head bridge engineer, who has not returned any information.

7.3 Summary

1. Although most states DOTs were willing to provide us their approved expansion joint lists and their specifications and drawings, not much information was obtained regarding their practices for approving the expansion joints.

- 2. From the interviews and materials collected, it was found that different states have had different experience using the joints. For instance, ODOT has a good performance history with the Integral Abutment joints, but has a poor history with the Polymer Modified joints, while IDOT has a good history with the Poured Silicone joints. There is consensus among all DOTs that the older joints, such as the B.S. and S.S., are performing well but could be improved. It was also found that the use of Integral Abutment Expansion Joints is gaining popularity in the investigated states, and its design and performance are also being examined and improved.
- 3. It appears that the maintenance strategies for expansion joints are not specific in the states surveyed. For instance, MDOT provided information for a statewide rehab/maintenance program that was dependent upon funding not necessarily upon the condition of the bridge. This does not mean that damaged bridges were ignored, rather they may be repaired instead of replaced. Additionally, most bridge engineers spoken to mentioned that maintenance and repair measures that have been used for badly damaged joints have been classified as temporary. In other words, they suggested that repair measures would be more economical in the long run if joints were replaced entirely to prevent further damage spreading to reinforcements within the bridge, resulting in even greater maintenance expenses in the future. A common complaint was that the temporary measures did not sufficiently prevent seepage.
- 4. Interviewed engineers seemed to decline favoring any specific expansion joint over others. They claimed that no joint has been designed that has been proven more economical over the expected life of the bridge in all applications. Expansion joints are all too often overlooked in bridges, because they are just a small portion of the bridge. However, their impact can have costly and severe adverse results if their selection and maintenance are not appropriate on both old and new bridges.
- 5. Sometimes joints may not be properly selected by design consultants. The requirements of the joints for certain applications are not identified and therefore lead to shortened life. Also, standards and specifications are constantly being revised and

consultants may not be aware of revisions and continue to design decks with joints that were acceptable in the past. Once this happened and the project is then let for bid, the responsibility of replacing the improper joint with the acceptable one is placed on the field project engineer. This is often overlooked and the improper joint is then placed on the bridge.

CHAPTER 8

ESTABLISH EVALUATION CRITERIA/SCHEMES

Inspectors complete bridge evaluations once every two years according to FHWA and INDOT regulations and policy. Many components of the bridge are inspected, including the expansion joints. The evaluation of the joints is currently done based on the personal experience of each inspector and is then given a ranking of poor, fair, or good. New evaluation criteria are proposed in this report to provide a uniform rating guideline and establish a more objective evaluation process.

8.1 Current Practices of Evaluating Existing Expansion Joints

The current INDOT evaluation of joints is visual and is based on the experience of the inspector. The condition of the bridge joint is evaluated on a scale of good, fair, and poor. The joints of the bridge are evaluated separately from the decks that use a 0 to 9 scale. A type of joint is selected and then rated based on inspector's experience. There is no clear definition of good, fair, and poor condition for each type of joint.

The ambiguity with the current evaluation system is that it allows decisions to be made upon personal experience, which can result in subjective observations because of the differing experiences of individuals. For instance, an inspector who has been inspecting bridges for 15 years may be more critical than a person who has only one or two years experience. This problem can be alleviated if standard scheme utilized for the evaluation, which would give each bridge inspector/engineer the same criteria for evaluating expansion joint performance.

8.2 Proposed Evaluation Schemes

The evaluation scheme for in-service expansion joint systems was developed based on the literature search, questionnaire surveys, and information pertaining to the current practices of INDOT and surrounding states DOTs. The criteria of general appearance, condition of anchorage, debris accumulation, water tightness, surface damage, noise under traffic, ease of or need of maintenance, and/or other were established.

Each type of joint will exhibit different problem symptoms. Thus, specific evaluation criteria are utilized for each type of joint, including B.S., S.S., I.A., Poured Silicone, and Polymer Modified joints. There are six different levels of the joint conditions: new, nearly new, good, fair, bad, and poor. Each condition corresponds to a numerical rating as 10, 9-8, 7-6, 5-4, 3-2, and 1-0. Except 10 as a single number for the rating, inspectors can use his/her judgement to decide which number to use for other ratings. For instance, inspectors can choose the rating 8 if the joint condition falls into the interval of nearly new but it is closer to the condition good of the next level. If the joint condition is closer to the condition new of the upper level, then the rating 9 can be chosen. By doing this, the evaluation process is more consistent and objective since the conditions are classified into more detail while inspectors can use the subjective judgement to choose one numerical rating out of two within each condition state.

Finally, the bottom of each table is used in case inspectors cannot find the symptoms on the list, which although it is intended to be comprehensive, some symptoms might not happen with each type of joint. Thus, inspectors can fill out the symptoms at the bottom of the table and put a numerical rating for it. These symptoms will be added in the table for further modifications in the future. The following pages show the tables of evaluation criteria for each type of joint.

Table 8.1 B.S. Joint Evaluation Scheme

Rating	Condition		Symptor	n	
		Appearance	Anchorage	Leakage	Noise
0-1	Poor	Joint is missing/fallen out completely	Joint anchorage or surrounding concrete is destroyed. Rusted and exposed deck steel	Evidence of total water leakage	Extreme noise during traffic passage
2-3	Bad	Joint is partially in place	Joint anchorage is in poor/brittle condition. Limited deck steel exposure	Evidence of water leakage	Noise during traffic passage
4-5	Fair	Joint is in place with debris. Broken seal in small areas with embedded debris	Joint anchorage is cracked/ in bad condition with little or no reinforcing steel exposure	Small water leaks	Noise during traffic passage
6-7	Good	Joint is solidly in place with debris and no breaks in the seal	Joint anchorage is in good condition with limited cracking and no deck steel exposure	No water leaks evident	Slight noise during passage of traffic
8-9	Nearly New	Joint appears new with some debris which does not affect performance	Joint anchorage is in good condition with no cracking and no deck steel exposure	No water leaks evident	Quiet during passage of traffic
Other Summ	New	Joint has excellent appearance with no debris in joint	Joint anchorage is in excellent/new condition	No water leaks evident	Quiet during passage of traffic

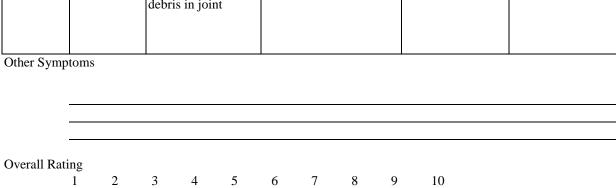


Table 8.2 S.S. Joint Evaluation Scheme

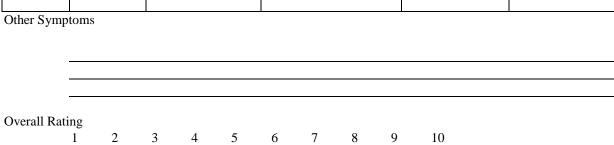
Rating	Condition		Sympton	n	
		Appearance	Anchorage	Leakage	Noise
0-1	Poor	Joint is missing/fallen out completely	Joint anchorage or surrounding concrete is destroyed. Rusted and exposed deck steel	Evidence of total water leakage due to holes, loose, torn, split, or hardened seal	Extreme noise during traffic passage
2-3	Bad	Joint is partially in place with large amounts of debris	Joint anchorage is in poor/brittle condition. Limited deck steel exposure	Evidence of water leakage due to holes, loose, torn, split or hardened seal	Noise during traffic passage
4-5	Fair	Joint is in place with debris. Broken seal in small areas with embedded debris	Joint anchorage is cracked/ in bad condition with little or no reinforcing steel exposure	Small water leaks due to holes, loose, torn, split or hardened seal	Noise during traffic passage
6-7	Good	Joint is solidly in place with debris slightly affecting performance	Joint anchorage is in good condition with limited cracking and no deck steel exposure	No water leaks evident, but loose or hardened seal condition	Slight noise during passage of traffic
8-9	Nearly New	Joint appears new with some debris which does not affect performance	Joint anchorage is in good condition with no cracking and no deck steel exposure	No water leaks evident	Quiet during passage of traffic
10	New	Joint has excellent appearance with no debris	Joint anchorage is in excellent/new condition	No water leaks evident	Quiet during passage of traffic

Overall Rating

1 2 3 4 5 6 7 8 9 10

Table 8.3 I.A. Joint Evaluation Scheme

Rating	Condition		Sympton	m	
		Appearance	Cracks on Deck	Leakage	Noise
0-1	Poor	Cracked and spalled concrete, exposed deck and abutment reinforcing steel	Numerous amounts of large midspan cracks on deck	Evidence of total water leakage due to holes, loose, torn, split, or hardened seal	Extreme noise during traffic passage
2-3	Bad	Joint is fully intact with large amounts of cracked and broken concrete	Few large midspan cracks on deck	Evidence of total water leakage due to holes, loose, torn, split, or hardened seal	Noise during traffic passage
4-5	Fair	Joint is fully intact with small amounts of cracked and broken concrete	Few small midspan cracks on deck	Small water leaks due to holes, loose, torn, split, or hardened seal	Noise during traffic passage
6-7	Good	Little cracking and broken concrete around abutments and deck	Little to no midspan cracks on deck	No water leaks evident, but loose or hardened seal condition	Slight noise during passage of traffic
8-9	Nearly New	No cracking between abutments and deck	No cracking on midspan of deck	No water leaks evident	Quiet during passage of traffic
Other Symp	New	New concrete between abutment and deck	No cracking on midspan of deck	No water leaks evident	Quiet during passage of traffic



6 7 8

10

Table 8.4 XJS Joint Evaluation Scheme

Rating	Condition	Symptom				
		Appearance	Nosing/Concrete/Steel	Leakage	Noise	
0-1	Poor	Joint is missing/fallen out completely	Joint nosing or surrounding concrete is destroyed. Rusted and exposed deck steel	Evidence of total water leakage	Extreme noise during traffic passage	
2-3	Bad	Joint is partially in place	Joint nosing is in poor/brittle condition. Limited deck steel exposure	Evidence of water leakage	Noise during traffic passage	
4-5	Fair		Joint nosing is cracked/ in bad condition with little or no reinforcing steel exposure	Small water leaks	Noise during traffic passage	
6-7	Good	Joint is solidly in place with debris and no breaks in the seal	Joint nosing is in good condition with limited cracking and no deck steel exposure	No water leaks evident	Slight noise during passage of traffic	
8-9	Nearly New	Joint appears new with some debris which does not affect performance	Joint nosing is in good condition with no cracking and no deck steel exposure	No water leaks evident	Quiet during passage of traffic	
10 Other Symp	New	Joint has excellent appearance with no debris in joint	Joint nosing is in excellent /new condition	No water leaks evident	Quiet during passage of traffic	

Overall Rating

1 2 3 4 5 6 7 8 9 10

Table 8.5 Polymer Modified Asphalt Joint Evaluation Scheme

Rating	Condition		Symptom				
		Appearance	Steel Plate	Leakage	Noise		
0-1	Poor	Joint is missing/fallen out completely	Missing steel plates	Evidence of total water leakage due to holes, loose, torn, split, or hardened polymer material	Extreme noise during traffic passage		
2-3	Bad	Joint is partially in place	Loose and/or broken steel plates	Evidence of water leakage due to holes, loose, torn, split, or hardened polymer material	Noise during traffic passage		
4-5	Fair	Joint is in place with rutting and broken seal in small areas	Loose steel plates	Small water leakage due to holes, loose, torn, split, or hardened polymer material	Noise during traffic passage		
6-7	Good	Joint is solidly in place with few breaks in the seal	Steel plates sufficiently intact and in place	No water leaks evident, but loose or hardened seal condition	Slight noise during passage of traffic		
8-9	Nearly New	Joint appears new with some breaks which does not affect performance	Steel plates in excellent condition	No water leaks evident	Quiet during passage of traffic		
Other Symp	New	Joint has excellent appearance	Steel plates in new condition	No water leaks evident	Quiet during passage of traffic		



CHAPTER 9

DATA ANALYSIS

1998 INDOT Roadway Management data was used for the analysis. The objective of the data analysis was to compare the performance of each type of joint under the same condition of age, traffic loading, and structure settlement. Through the analysis, the statistic distribution of the joint types, their conditions and ages, and the related parameter such as traffic on INDOT bridges, was also presented.

9.1 Simple Statistics

Table 9.1 shows the statistics of the numbers of the joints in the SW (south or west) end, NE (north or east) end, and the interior end. It can be seen that I.A. joints, B.S. joints, and S.S. joints account for most of the existing joints, making up 93% of the total number of joints. There are not many interior joints, the percentage of which is only 8.3%.

Table 9.1 Joint Number Statistics

	Joint Type												
	A	В	Н	0	P	Q	Total	Percentage					
Location													
South or West	1804	480	986	62	51	134	3517	45.9%					
North or East	1820	477	978	61	50	121	3507	45.8%					
Interior	405	150	32	13	6	33	639	8.3%					
Sub Total	4029	1107	1996	136	107	288	7663	100%					
Percentage	52.6%	14.4%	26.0%	1.8%	1.4%	3.8%	100%						

A: B.S. Joint, B: S.S. Joint, H: I.A. Joint, O: XJS Joint, P: Poured Silicone Joint (in old I.A. Joint), Q: Polymer Modified Asphalt Joint

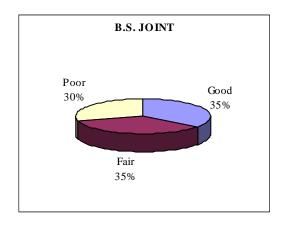
Table 9.2 shows the quantity and the percentage of the condition (good, fair, poor) for each type of joint and the statistics of the age and average daily traffic on it. The distribution of the condition of each joint is plotted as shown on the pie chart in Figure 9.1. The statistics for each type of joint in each district is listed in Appendix H. The age of each joint is obtained by subtracting the year in which a bridge with this joint was built from the year of the inspection.

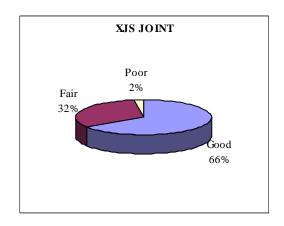
Table 9.2 Simple Statistics of the Joint Data

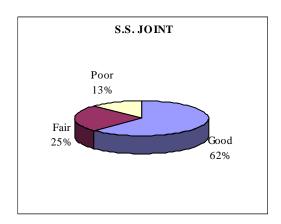
Joint Type	Condition	Quantity	Percentage	Ag	e	ΑĽ	T
	Good	1410	34.94%	Mean	11.58	Mean	13549
B.S. Type	Fair	1432	35.49%	Std. Dev.	5.35	Std. Dev.	29024
••	Poor	1193	29.57%	Median	11	Median	7104
	Subtotal	4035		Max.	39	Max.	992572
				Min.	0	Min.	0
	Good	694	62.41%	Mean	9.9	Mean	12362
S.S. Type	Fair	279	25.09%	Std. Dev.	7.14	Std. Dev.	18210
••	Poor	139	12.50%	Median	9	Median	6896
	Subtotal	1112		Max.	34	Max.	114440
				Min.	0	Min.	0
	Good	13	16.67%	Mean	21.12	Mean	19531
Tooth Type	Fair	53	67.95%	Std. Dev.	8.19	Std. Dev.	31253
(Finger Joint)	Poor	12	15.38%	Median	24	Median	7536
(0 /	Subtotal	78		Max.	31	Max.	127450
				Min.	2	Min.	64
	Good	9	20.93%	Mean	20.72	Mean	6214
General Tire Type	Fair	16	37.21%	Std. Dev.	6.5	Std. Dev.	8123
(Trans flex Type)	Poor	18	41.86%	Median	22	Median	3783
(JI - /	Subtotal	43		Max.	28	Max.	35491
				Min.	3	Min.	0
	Good	0	0.00%	Mean	22	Mean	885
Feldspar Type	Fair	5	100.00%	Std. Dev.	1	Std. Dev.	603
1 71	Poor	0	0.00%	Median	21	Median	885
	Subtotal	5		Max.	22	Max.	1311
				Min.	20	Min.	458
	Good	55	47.83%	Mean	27.6	Mean	1491
Sliding Steel Plate	Fair	56	48.70%	Std. Dev.	15.33	Std. Dev.	3005
C	Poor	4	3.48%	Median	27.5	Median	407
	Subtotal	115		Max.	73	Max.	12505
				Min.	0	Min.	58
	Good	0	0.00%	Mean	31.76	Mean	1460
Armor Type	Fair	20	38.46%	Std. Dev.	1.92	Std. Dev.	2728
(Two steel angles)	Poor	32	61.54%	Median	32	Median	290
ζ ,	Subtotal	52		Max.	34	Max.	9139
				Min.	26	Min.	74
	Good	1435	70.93%	Mean	6.03	Mean	8309
IA Type	Fair	391	19.33%	Std. Dev.	6.43	Std. Dev.	10109
71	Poor	197	9.74%	Median	4	Median	5441
	Subtotal	2023		Max.	46	Max.	114440
				Min.	0	Min.	1
	Good	56	61.54%	Mean	8.04	Mean	11267
Modular Type	Fair	31	34.07%	Std. Dev.	4.47	Std. Dev.	8333
71	Poor	4	4.40%	Median	8	Median	9852
	Subtotal	91		Max.	15	Max.	30308
				Min.	0	Min.	1248

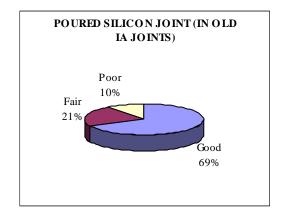
Open Joint	ondition Quantity Percentage Age	Quantity	Condition	Joint Type	uantity F	Percentage	Age		AD'	T
Poor Subtotal 141	Good 27 19.15% Mean	27	Good		27	19.15%	Mean	25.63	Mean	4697
Subtotal 141 Max. 35 Max. Min. 2 Min.	Fair 87 61.70% Std. Dev.	87	Fair	Open Joint	87	61.70%	Std. Dev.	5.93	Std. Dev.	5715
Poured Dow Corning Silicone Fair 46 32.39% Std. Dev. 4.16 Std. Dev.	Poor 27 19.15% Median	27	Poor		27	19.15%	Median	26	Median	1752
Poured Dow Corning Silicone Fair 46 32.39% Std. Dev. 4.16 Std. Dev.	Subtotal 141 Max.	141	Subtotal		141		Max.	35	Max.	19317
Poured Dow Corning Silicone Fair 46 32.39% Std. Dev. 4.16 Median 2 Median 2 Max. 20 Max. Min. 0 Min. 0 Min. 0 Min. 0 Min. 0 Median 2 Me	Min.						Min.	2	Min.	78
Joint (wide width)	Good 93 65.49% Mean	93	Good		93	65.49%	Mean	2.66	Mean	227.6
Subtotal 142 Max. 20 Max. Min. 0 Min.	Fair 46 32.39% Std. Dev.	46	Fair	Poured Dow Corning Silicone	46	32.39%	Std. Dev.	4.16	Std. Dev.	26401
Poured Silicone Joint (narrow width - in old IA joints)	Poor 3 2.11% Median	3	Poor	Joint (wide width)	3	2.11%	Median	2	Median	12361
Poured Silicone Joint (narrow width - in old IA joints)	Subtotal 142 Max.	142	Subtotal		142		Max.	20	Max.	94860
Poured Silicone Joint (narrow width - in old IA joints)	Min.						Min.	0	Min.	0
(narrow width - in old IA joints) Poor Subtotal 11 107 10.28% Median 2 Median 2 Max. 36 Max. 36 Min. 0 Min. Max. 36 Min. 0 Min. Polymer Modified Asphalt Expansion Joint Fair Fair 62 21.23% Std. Dev. 4.34 Std. Dev. 4.34 Std. Dev. Median 2 Median Subtotal 292 Median 2 Median 2 Median 2 Median 2 Max. 22 Max.	Good 73 68.22% Mean	73	Good		73	68.22%	Mean	5.73	Mean	8548
Subtotal 107 Max. 36 Max. Min. 0 Min.	Fair 23 21.50% Std. Dev.	23	Fair	Poured Silicone Joint	23	21.50%	Std. Dev.	10.62	Std. Dev.	8680
Min. O Min.	Poor 11 10.28% Median	11	Poor	(narrow width - in old IA joints)	11	10.28%	Median	2	Median	5109
Polymer Modified Asphalt Expansion Joint Good Fair Poor Foor Subtotal Fair Poor Foor Subtotal Fair Poor Foor Foor Subtotal Fair Fair Foor Foor Foor Foor Foor Foor Foor Fo	Subtotal 107 Max.	107	Subtotal		107		Max.	36	Max.	40501
Polymer Modified Asphalt Expansion Joint Poor 62 21.23% Std. Dev. 4.34 Std. Dev. Expansion Joint Poor 62 21.23% Median 2 Median Max. 22 Max.	Min.						Min.	0	Min.	21
Expansion Joint Poor 62 21.23% Median 2 Median Subtotal 292 Max. 22 Max.	Good 168 57.53% Mean	168	Good		168	57.53%	Mean	3.38	Mean	20461
Subtotal 292 Max. 22 Max.	Fair 62 21.23% Std. Dev.	62	Fair	Polymer Modified Asphalt	62	21.23%	Std. Dev.	4.34	Std. Dev.	25632
	Poor 62 21.23% Median	62	Poor	Expansion Joint	62	21.23%	Median	2	Median	12415
Min 0 Min	Subtotal 292 Max.	292	Subtotal		292		Max.	22	Max.	111620
Mill. U Mill.	Min.						Min.	0	Min.	100
Total 8236	Total 8236	8236	Total		8236					

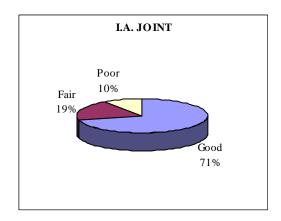
Std. Dev.: Standard Deviation











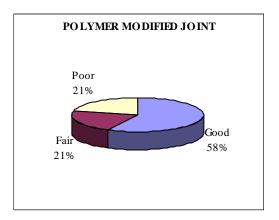


Figure 9.1 Percentage Distribution of Joint Conditions

Table 9.3 shows the comparison of condition distributions for each type of joint at both ends of a bridge. It shows that on the same bridge, the joint types and their conditions are very similar at the NE and SW end. For instance, there are 1558 B.S. joints (A) that have the same conditions at the both ends of bridges. This number accounts for 86.36% of the total SW B.S. joints and 85.6% of total NE B.S. joints. S.S. joint (B) has a smaller percentage, but the number of total S.S. joints is only 480. Table 9.4 shows the percentage distribution of the conditions of each type of joint at different locations of the bridge.

Table 9.3 Comparison of Joint Types and Conditions at Both Ends of Bridge

	A	В	Н	О	P	Q
SW VS. NE						
Fair	530	63	163	18	9	16
Good	586	208	673	35	34	60
Poor	442	25	72	0	4	19
Sub Total	1558	296	908	53	47	95
Total (SW)	1804	480	986	62	51	134
Percentage	86.36%	61.67%	92.09%	85.48%	92.16%	70.90%
Total (NE)	1820	477	978	61	50	121
Percentage	85.60%	62.05%	92.84%	86.89%	94.00%	78.51%

 Table 9.4 Percentage Distribution of Joint Conditions

Interior Joint

	A		В		Н		О		P		Q	
G	90	22.22%	62	41.33%	5	16.13%	8	61.54%	2	33.33%	18	54.55%
F	172	42.47%	66	44.00%	7	22.58%	5	38.46%	1	16.67%	11	33.33%
P	143	35.31%	22	14.67%	19	61.29%	0	0.00%	3	50.00%	4	12.12%
Total	405	100.00%	150	100.00%	31	100.00%	13	100.00%	6	100.00%	33	100.00%

NE Joint

	A		В		Н		О		P		Q	
G	659	36.21%	316	66.25%	695	71.06%	38	62.30%	35	70.00%	71	58.68%
F	633	34.78%	100	20.96%	190	19.43%	21	34.43%	11	22.00%	25	20.66%
P	528	29.01%	61	12.79%	93	9.51%	2	3.28%	4	8.00%	25	20.66%
Total	1820	100.00%	477	100.00%	978	100.00%	61	100.00%	50	100.00%	121	100.00%

SW Joint

	A		В		Н		O		P		Q	
G	655	36.31%	311	64.79%	707	71.70%	41	66.13%	36	70.59%	75	55.97%
F	627	34.76%	113	23.54%	194	19.68%	20	32.26%	11	21.57%	26	19.40%
P	522	28.94%	56	11.67%	85	8.62%	1	1.61%	4	7.84%	33	24.63%
Total	1804	100.00%	480	100.00%	986	100.00%	62	100.00%	51	100.00%	134	100.00%

From Table 9.1 through 9.4, several conclusions were made. First, it was very hard to tell the performance of each type of joint just through the simple statistics since the joint performance was influenced by its age, the traffic volume, or other factors. Second, since there is only a small amount of interior joints, they can be excluded in the further analysis. Finally, the types and conditions of joints at both ends of the bridge are almost the same. Therefore, only joints at one end of each bridge (SW or NE) will suffice for further data analysis. The joints on the SW end of the bridge are selected in this study. The regression technique is used to analyze the relationship between the joint condition and the influencing factors.

9.2 Regression Analysis

Regression analysis is a statistic approach that is used to understand how the dependent variables are influenced by the independent variables. The first step of the analysis is to acquire the influencing variables. Sixteen items from the management data were selected as the independent variables and one item, joint condition, was selected as the dependent variable since the objective is to understand how the joint condition is influenced by factors such as age, traffic volume, settlement, etc. All of the selected variables and their definitions, data patterns, and ranges are shown in Table 9.5. After developing the regression equations for each type of the joint, a comparison of joint performance was conducted based on the same conditions to establish which type of joint performs better. The SAS computer program is used to perform the regression analysis and the computer codes and output can be found in Appendix I.

Although the joints were in three locations on each bridge, i.e., interior, south or west, and north or east, it was concluded from simple statistics that the joint types and

conditions at each end were almost identical and most bridges do not have interior joints. Thus, only the joint condition at the SW (south or west) end of each bridge was used in the next stage of analysis.

Table 9.5 Variables Selected for the Regression Analysis

No.	Independent Variables	Definition	Range	Pattern
1	SMA	STRUCT-MATERAIL	0-9	Most concentrated on 1 and 2
2	SCN	STRUCT-CONSTRUCTION	0-22	Most concentrated on 2 and 4
3	AMA	APPROACH-MATERIAL	0-9	Most concentrated on 0
4	ACN	APPROACH- CONSTURCTION	0-22	Most concentrated on 0
5	TRD	TRAFFIC-DIRECTION	0-3	Most concentrated on 1 and 2
6	SBR	SPSTR-BEARING	0-9, N	Most concentrated on 6,7, and 8
7	SIM	SPSTR-IMPACT	0-9, N	Most concentrated on 7 and 8
8	SBS	SBSTR-SETTLEMENT	0-9, N	Most concentrated on 7 and 8
9	INS	SBSTR-INTERMD-SETTLE	0-9, N	Most concentrated on 7 and 8
10	SKEW	SKEW	0-99	Most concentrated on 0
11	LMS	LENGTH-MAX-SPAN		
12	SL	STRUCTURE-LENGTH		
13	BRW	BRIDGE-ROADWAY-WIDTH		
14	DW	DECK-WIDTH		
15	ADT	ADT-OVER (AVARAGE		
		DAILY TRAFFIC)		
		(VEHICLES/DAY)		
16	AGE	AGE		
No.	Dependent Variables	Definition	Range	
1	COND	BRIDGE-JOINT-COND-(SW, NE, or IN)	Good, Fair, Poor	

9.2.1 Simple Regression Analysis

Although there are 16 independent variables, some of them may not significantly influence the joint condition. By using simple regression analysis, the insignificant variables can be eliminated. The levels of the response variable (Joint Condition) were changed to 1, 2, and 3 from good, fair, poor, to accommodate the computer program requirements.

Table 9.6 shows the variables selected and unselected for each type of joint after the simple regression analysis. The selection criteria reflect its relationship with the dependent variable and the significance level was set at 0.05. For instance, if a variable was found not to be highly correlated with the joint condition, it was excluded in the analysis, which means this variable does not have much influence on the dependent variable, the joint condition. Table 9.6 illustrates that the variables selected for each type of joint are quite different. The B.S. joint has the largest number of variables which might be due to the fact that since the B.S. joint has the largest quantity of data, it is easier to identify the relationships between the joint conditions and the independent variables. The newer joint type, however, such as the Polymer Modified Asphalt joint, has a shorter history of usage and less available data so the fewer variables are selected than for the B.S. joint.

Table 9.6 Variables Selected by Simple Regression Analysis

Joint Type	Selected variables	Unselected variables
B.S.	ADT, AGE, DW SMA, SIM,	SL, AMA, ACN
	LMS, SMA, SCN, TRD,	
	SBR, SIM, SBS, INS	
S.S.	AGE, SIM	SKEW, ADT, DW, SL,
		LMS, SMA, SCN, AMA,
		CAN, TRD, SBR, SIM,
		SBS, INS
I.A.	ADT, AGE, SIM, SBS	SKEW, DW, SL, LMS,
		SMA, SCN, AMA, CAN,
		TRD, SBR, INS

XJS	LMS, AMA, ACN, SIM	SKEW ADT AGE, DW,
		LMS, SMA, SCN, TRD,
		SBR, SBS, INS
Poured Silicone (in old	SBS	SKEW ADT, AGE, DW,
I.A. joints)		SL, LMS, SMA, SCN,
		AMA, ACN, TRD, SBR,
		SIM, SBS, INS
Polymer Modified Asphalt	SKEW, AGE, LMS, SCN,	ADT, DW, SL, SMA,
joints	TRD, SIM	AMA, CAN, SBR, SBS,
		INS

It should be noted that even though the S.S. joint has a relatively long history of usage (the mean age is 11.58 years compared to 13.33 years of the B.S. joint), there are only two variables selected. The reason might be that the selection of variables not only depends on the relationships between independent and dependent variables but also the relationships between the independent variables. Therefore, if two independent variables are highly correlated, it is very likely that both of them will be excluded in the regression analysis because it becomes more difficult to distinguish which variable is more important. Therefore, another statistic approach, factor analysis, is used to solve the correlation problems among the independent variables.

9.2.2 Factor Analysis

The primary purpose of the factor analysis is to define the underlying structure in a data matrix. It addresses the problem of analyzing the structure of the correlation among a large number of variables by defining a set of common underlying dimensions, known as factors. The advantage of using factor analysis is its ability to condense the number of independent variables by grouping the variables that are highly correlated. After performing the factor analysis, three groups were identified. The name of each group and the variables included are shown in Table 9.7. The first group is named settlement since it consists of all variables related to settlement, such as structure impact, substructure settlement, substructure bearing condition, and intermediate settlement. The second group is named traffic loading since the included variables are average daily traffic, deck width, and bridge roadway width, which are all related to traffic volume. The third group is named the structure design and includes structure length, length max span, approach

material, and approach construction. Some variables, such as age, traffic direction, skew, etc., were not included because they have little or no relationship with other variables and thus can form an individual group. These individual variables will also be included in the final regression analysis with the three groups (factors). The final goal is to find out the coefficients of each factor and the individual variables. Comparisons can then be made based on the coefficients of each joint to establish which one has better performance. Details of the comparison process are explained in the next section.

Table 9.7 Factor Analysis Result

	Factor 1	Factor 2	Factor 3	Individual
				Variables
Name	Settlement	Traffic loading	Structure design	
Elements	SBR, SIM,	ADT, DW,	SL, LMS AMA, ACN	AGE, SKEW,
	SBS, INS	BRW		TRD, SMA,
				SCN

9.2.3 Logistic Regression Analysis

Different types of regression methods can be used to analyze the data. In this analysis, the dependent variable, joint condition, has three levels (good, fair, and poor). This is called the ordinal scale in Statistics and logistic regression is used to analyze this kind of data. The advantage of logistic regression is that the procedure is simple and the results can be obtained quickly and accurately. To simplify the analysis, the condition of good and fair was combined together into one condition state. The advantage of doing this is to show the distinct characteristic of poor condition vs. (good and fair conditions) since poor was a very critical state in the joint performance. If a joint is rated as poor, INDOT will take remedy measures on them. In addition, the binary responses (good and fair vs. poor) of the dependent variable is much easier and efficient to analyze than the three responses.

9.2.3.1 Interpretation of the Selected Factors

In the logistic regression analysis, it was found that two types of joints could not be analyzed due to insufficient data. They are XJS and Poured Silicone (in old I.A. joints) joints, both of which have only one and four joints rated as poor. Thus, the number of poor joints is too small for the regression analysis to identify the relationship between good and poor since most of the joints are good. Therefore, only four types of joints remained in the final analysis and the result is shown in Table 9.8. For each type of the joint shown in the table, the variables or factors selected for each joint were identified as having a close relationship with the dependent variable, the joint condition. The significance level of the selection is set at 0.1. There is no correlation problem among the independent variables now since the factor analysis already grouped the correlated variables together.

From the analysis results shown in Table 9.8, it was found that some factors and variables were eliminated, such as structure design, structure construction, and structure material, which can be reasonably explained. For example, the factor of structure design was not included in the other three types of joints, except the Polymer Modified Asphalt joint. This means the factor of the structure design, which includes structure length, length max span, approach material, and approach construction, does not have significant influences on the performance of most joints. This was substantiated by the expert interviews; however, the influence of this factor is not significant when compared to that of age or traffic.

Table 9.8 Logistic Regression Analysis Result

B.S. Joint (1804 observations)

Factor	Odds ratio
Settlement	3.12
Traffic loading	0.651
Age	0.805

S.S. Joint (480 observations)

Factor	Odds ratio
Settlement	1.564
Traffic loading	0.675
Age	0.848

I.A. Joint (986 observations)

Factor	Odds ratio
Settlement	3.363
Age	0.736

Polymer Modified Asphalt Joint (134 observations)

Factor	Odds ratio
Structure design	3.30
SMA, SIM	1.54

9.2.3.2 Interpretation of the Regression Coefficients

The odds ratio is defined as the ratio of the probabilities of $good^1$ over poor. The formula is: Odds Ratio = P(good)/(1-P(good)) = P(good)/P(Poor). Thus, if the ratio is larger than 1, it means as the value of the independent variable gets larger, the chance of becoming good over poor increases. The higher the ratio is, the greater the chance the joint will become good rather than poor. For instance, if the settlement is selected as the basis of comparing joint performance, the joint with the higher odds ratio has more chances of becoming good over poor when the settlement index increases one unit. However, if the ratio is less than 1, it means that as the value of the independent variable increases, the chance of becoming good over poor decreases. Thus, if age is selected as the basis of comparison, the joint with the smaller odd ratio (which is smaller than 1) deteriorated faster. That is, the chance of becoming poor over good is higher. Figure 9.2 to Figure 9.4 show the performance curve based on each factor. The numbers shown beside the vertical axis of the slope were derived by (1 - Odds Ratio).

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¹ In the logistic regression analysis, the condition Fair was combined into Good to fit a binary response regression model (which only has Good and Poor).

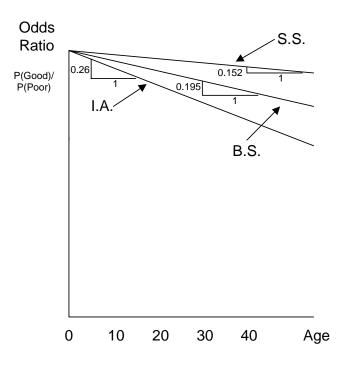


Figure 9.2 Performance Curve Based on Age

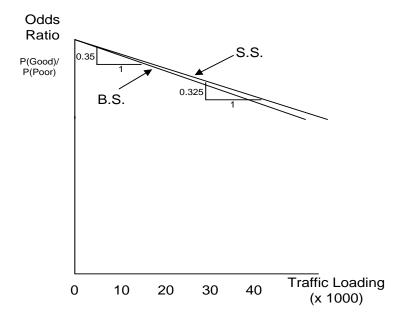


Figure 9.3 Performance Curve Based on Traffic Loading

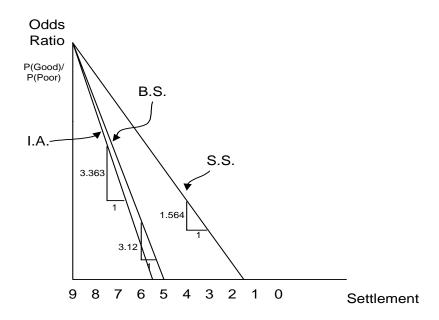


Figure 9.4 Performance Curve Based on Settlement

9.3 Summary

The joint performance rankings based on each variable (the factor) are shown in Table 9.9. The higher ranking means this type of joint has a slower deterioration rate under the influence of this factor. As seen from Figure 9.2 through Figure 9.4, the curve with the flatter slope means the deterioration rate is slower and hence the joint has the better performance. Thus, the historical data analysis clearly indicated that the S.S. joint performed the best, B.S. joints the second, and I.A. joints the third, under the same conditions of age, traffic loading, or settlement.

Since each joint includes different types of factors, not all of the joints can be compared. For instance, traffic loading only appears in the B.S. joint and the S.S. joint, so only the two of them can be compared based on traffic loading. This also means traffic loading is not an important factor for the performance of the I.A. joint since the result of the regression analysis shows it is not significant. For the Polymer Modified Asphalt joint, the factor of structure design seems to have more influences on its performance since this factor only appears for this type of joint.

Table 9.9 Joint Ranking Based on the Deterioration Rate

	Ranking			
Variable	1	2	3	
Age	S.S.	B.S.	I.A.	
Traffic loading	S.S.	B.S.	-	
Settlement	S.S.	B.S.	I.A.	

CHAPTER 10

GUIDELINE OF POLICY DEVELOPMENT

Throughout the research, the goal was to produce a provision for the evaluation and use of expansion joints on bridges in Indiana. Following are the recommendations of this research for future policy development regarding the selection and evaluation of bridge deck expansion joints, as well as suggestions for improving joint performance.

10.1 Selection of Bridge Deck Expansion Joints

In this study, five types of joints, B.S., S.S., I.A.(poured sealer and neoprene seal), XJS, and Polymer Modified Asphalt Joints (LDI and PaveTech) were investigated. From the questionnaire survey, it can be concluded that the S.S. joint is considered the most reliable joint. The I.A. joint with a poured sealer is preferred over the same joint with a neoprene seal, and the PaveTech joint is one of the least favored joints from both surveys. The XJS joint was ranked well in the follow-up survey but evaluation of its long-term performance is needed. From the expert interviews, it was learned that the Integral Abutment joints (I.A.) are showing promising results with good performance and less maintenance requirements. The XJS joints obtained some positive comments while Polymer Modified Asphalt joints were less favored. The older joints, such as the B.S. and S.S., are performing well but could be improved. Through the data analysis, the performances of S.S., B.S., and I.A. joints were rated as first, second, and third under the same conditions of age, traffic loading, and settlement. Other types of joints could not be analyzed due to insufficient data.

The questionnaire survey results showed that the S.S. joint was better than the B.S. joint in terms of the estimated joint life and the recommended joint types. The result of the historical data analysis showed the performance of the S.S. joint was better than the B.S. joint in terms of age, traffic loading, and settlement. The expert interviews showed that the performance of S.S. joint and B.S. joint could be improved; however, the expert interviews did not clearly reveal whether the S.S. or B.S. joint performs better. Literature review showed the performance of the S.S. joint was slightly better than the B.S. joint in

the overall rating. Therefore, from the evaluations of the previous four categories, the S.S. joint is favored than the B.S. joint in overall in this study.

Synthesizing the above results, S.S. and I.A. joints are recommended for their overall performance. I.A. joints with poured sealers are better than those with neoprene seals. The B.S. joint could perform well if material such as seals could be properly selected and the installation correctly done. The XJS joint is new and has a limited performance history so this type of joint requires more research and observation to adequately judge its performance. Finally, the Polymer Modified Asphalt joints, including LDI and PaveTech, are the least favored joints from the investigation conducted in the research.

10.2 Evaluation of the Existing Joint Conditions

Currently INDOT only uses three conditions to evaluate the existing joints, i.e., good, fair, and poor. The drawbacks of these evaluation criteria are that the definitions of these conditions are not clear and thus each condition could be subjectively decided by the bridge inspectors. The following is a recommendation for evaluation of existing joint conditions.

1. Using the new evaluation criteria

The new evaluation criteria were discussed in Chapter 8. These new criteria were assembled from the results of the questionnaire survey and the expert interviews. The advantages of these new criteria are that more detailed levels of joint conditions are defined and each level is represented by a numerical value. This can make the evaluation less subjective by the inspector and the numerical value will simplify the data analysis in the future.

2. Inspection training

From the results of the questionnaire surveys and interviews with bridge experts, the answers regarding joint problems and their causes were very different among bridge inspectors. This could be due to different years of experiences and different personal opinions. With better inspection training, subjective opinions among inspectors could be minimized and more common points of view could be reached.

10.3 Improvement of the Joint Performance

Recommendations to improve the performance of the types of joints investigated in this research are as follows:

1. B.S. Joint

Spalled and cracked concrete was selected as one of the most severe problems for this type of joint. One solution to this problem would be to add sealer to concrete to increase its resistance to freezing and thawing, and thereby reduce spalling and cracking. Since the seal could become hardened and will not expand back to its original thickness, the seal should be tested and properly selected before installation.

2. S.S. Joint

Debris seems to be the major problem of this type of joint. The joint should be designed with self-flushing capabilities, such as sufficient slope in the design or a larger curb opening. Sometimes armor angle breaks under wheel loading can catch on snowplow blades and create more maintenance problems. It is better to use non-corroding extrusion and larger diameter bolts to hold down the anchor blocks.

3. I.A. Joint (Poured Sealer)

It appears there are no major problems with this type of joint, although it was found that joint materials do not always completely fill the opening. The notch should be made deeper and filled with silicone. Beveled edges can reduce concrete spalling due to wheel loads. To reduce spalled and cracked concrete 5 to 10 feet from the end of the deck, approach slabs should be tied to the deck to eliminate movements.

4. I.A. Joint (Neoprene Seal)

The problems and suggested improvements of this type of joint are similar to those for the previous I.A. joint. However, the survey results show its performance is worse than the one with a poured sealer.

5. XJS Joint

This type of joint has several problems. The epoxy materials were found to come in contact with traffic, which causes holes in the seals. This could be due to installing it too high, structure expansions causing it to shove upwards, or hot weather. The polymers should be kept slightly below the top of deck elevation and the chamfer should be large enough to prevent spalling of the nose. Silicone thickness should be placed correctly and the silicone material mixed correctly.

6. LDI Joint

Several problems were found with this type of joint. Polymer modified asphalt materials were found missing with steel plates rusted and cracked. The asphalt materials experience shoving and rutting during hot weather, and there were cracks in the shoulder area. The mixing of materials was not up to the standard quality. Thus, the bonding between the header and adjacent concrete could be improved by using better materials.

The material testing should be done before installation. The proper selection of locations where heavy truck traffic is not present or where large expansion is not required may improve the joint performance.

7. PaveTech Joint

The problems and improvements of this joint are similar to those of LDI joints. However, its polymer modified asphalt material were found softer than that of LDI and hence the problems of shoving and rutting were more serious.

CHAPTER 11

CONCLUSION

INDOT has encountered problems with the poor performance of bridge expansion joints, which have led to increase joint replacements and maintenance. This research attempted to find the sources of the problems and to develop policy for the corrective measures.

The problems that INDOT has faced with the joints include the misplacement of the joint, misalignment, deterioration, rutting, or leaking of joint materials. These problems could be due to aging of the joint, traffic volume, weather, or installation quality. All of the aforementioned problems and causes have been investigated and quantified through the questionnaire surveys, site visits, expert interviews, and analysis of INDOT historical data.

Two questionnaire surveys and a follow-up survey were conducted; the first one and the follow-up survey was in Indiana only and the second one included the four surrounding states of Illinois, Ohio, Michigan, and Kentucky. Interviews were also conducted with bridge inspectors and engineers in Indiana and the four surrounding states. The joints studied in this research are B.S., S.S., XJS, I.A., and Polymer Modified Asphalt joints.

11.1 Results

The results of the study were obtained by conducting the questionnaire surveys, data analysis, and expert interviews. In this section, the result summary of each is presented and comparisons are made among these results.

11.1.1 Questionnaire Survey

The result of the In-State questionnaire survey on the estimated joint life is as follows:

Table 11.1 Estimated Life of Each Type of Joint

Joint Type	S.S.	B.S.	I.A.	XJS	LDI
Estimated	11.9	11.706	8.728	5.19	3.502
Life					

The survey of other states DOT's generally confirmed the In-State results. Although the estimated life of the same joint is a little different in both surveys, the ranking of the joint by the length of the estimated life is very similar.

However, caution should be used interpreting the results. Since B.S., S.S., and I.A. joints have a longer performance history, their estimated life is certainly longer than the other joints. Most bridge inspectors expressed their concerns that they did not have much experience with the newer types of joints, i.e., XJS, LDI, and PaveTech, and it was therefore difficult for them to estimate their life.

The ranking from the questionnaire survey on the recommended better joints is shown in the following table (averaging the ranking from both methods in Table 5.4):

Table 11.2 Summarized Ranking for Recommended Types of Joints

Ranking	1	2	2	4	5	6	7
Joint type	S.S.	I.A.	B.S.	I.A.	XJS	LDI	PaveTech
		(Poured		(Neoprene			
		sealer)		seal)			

Finally, the ranking of the performance of each type of joint in riding quality, water leakage, noise, and difficulty of maintenance from the follow-up survey is shown in Table 11.3. The results shown in the table generally confirm the results of the previous questionnaire surveys. The performance of each type of joint, from good to worst, was shown in the pattern of the S.S., B.S., I.A., and the LDI joint. Although the XJS joint

received good ranking in most categories, due to its limited history of usage, its long-term performance should be evaluated for a longer period of time.

Table 11.3 Performance of Joints based on Specific Categories

Ranking	Riding Quality	Water Leakage	Noise	Maintenance
Good	XJS	S.S.	XJS	XJS & S.S.
	S.S.	LDI	S.S.	B.S.
	I.A.	B.S.	B.S.	LDI
₩	B.S. & LDI	XJS	I.A.	I.A.
Worse		I.A.	LDI	

11.1.2 Data Analysis

The analysis on INDOT Roadway Management data yielded the following ranking in Table 11.4

Table 11.4 Joint Ranking based on the Deterioration Rate

		Ranking	
Variable	1	2	3
Age	S.S.	B.S.	I.A.
Traffic loading	S.S.	B.S.	-
Settlement	S.S.	B.S.	I.A.

Based on the results, the S.S. joint had the best performance; the B.S. joint was second; and the I.A. joint was third based on the same conditions of age, traffic loading, and settlement.

The results of the Roadway Management data analysis are very similar to the results of the questionnaire survey. However, the result of data analysis is only limited to the S.S., B.S., and I.A. joints. Other types of joints could not be rated due to insufficient data.

11.1.3 Expert Interviews

This part of research was mainly performed by telephone and personal interviews. During these interviews, there was common consensus among all investigated DOTs that the older joints, such as the B.S. and S.S., are performing well, though they still have room for improvement. The experts also indicated that the I.A. and XJS joints have good life spans and lower maintenance costs. It is likely that the usage of these joints will increase once it is learned that they are superior to the other joints. Meanwhile, many interviewees commented that the Polymer Modified Asphalt Expansion joints cause many problems with maintenance and have short life spans.

From the expert interviews it was found that maintenance strategies are not systematic in all of the investigated states. Maintenance efforts usually depend on the amount of time and funding allocated, but the resources are usually depleted before all of the projected work is completed.

11.2 Limitations

The research does have limitations. In the questionnaire surveys, although the expert opinions of the bridge inspectors were collected, each inspector's opinion could be subjective. Second, the number of survey responses may not be adequate to get an effective result. The number of responses to the second survey was only 32. If more responses can be obtained, the result might be more objective and accurate. Finally, the quality of the survey result also depends on the design of the questionnaire. Although the questionnaires were designed to obtain as many opinions as possible from the inspectors, some questions may not be clear or easy for the inspectors to answer. Thus, the answers from the survey may not be appropriate or the response rate was low due to the complexity of answering the questions.

The limitation of the data analysis is the quantity and quality of the data. There needs to be enough data for good analysis and the data should be accurate enough to produce a useful result. In this research, XJS joints and Polymer Modified Asphalt joints did not have enough historical data for analysis. In addition, since the condition rating is subjective, the results of the analysis may not represent the actual performance of each joint. The limitation of the interviews is similar to the questionnaire survey, the number of interview conducted, the people who were interviewed, and the information experts were willing to provide all influenced the results of the interview.

11.3 Recommendations and Implementation for Future Work

Following are the most important recommendations for future work. The order of the list does not represent the order of importance.

1. Selection of better joints for use

From the research result, S.S. and I.A. joints were shown to have better performances and are thus recommended to be continually used. The B.S. joint could perform well if materials such as seals are properly selected and the installation correctly done. Further, it should be noticed that the I.A. joint with poured sealers performs better than the one with neoprene seals. The XJS joint was rated well in the follow-up survey but its long-term performance needs to be evaluated.

2. Cautions on using joints with poor performance

The Polymer Modified Asphalt Joints were the least favored joints in the investigation. Although they have good ridibility, do not require flushing, and are not damaged by snowplow blades, their overall performance is poor according to the survey conducted. If they will be used in the future, their use is recommended in locations where the truck traffic is light and the bridge expansion/contraction range is small.

3. General recommendations for improving joint performance

Almost all of the severe problems for each type of joint are related to the seal and concrete, mainly holes in the seal, and hardened, cracked, loose, or torn seals, and spalled or cracked concrete. The causes of these problems could be traffic loading, snowplow damage, weather, poor installation, inferior materials, and incorrect selection of the joint type.

Several recommendations are proposed for improving joint performance. Coating concrete with sealers may reduce the spalling and cracking. The seal should be tested before installation. Whenever it is feasible, a larger curb opening or a sufficient slope should be provided so that rain can flush the joint clear. The use of a specialty contractor to install the joints would also enhance the installation quality and joint performance.

4. The Feasibility of Using the Warranty Clauses

Some states include the warranty clauses in the pavement or bridge painting contract. In some respects, the problems of joints are similar to those of the pavement and bridge painting since their performance is all subject to the influences of the environment and the installation quality. The survey results indicate that the workmanship plays an important role in joint performance. Thus, the advantage of a warranty clause is that the contractor or manufacturer becomes accountable for the product's performance and the installation quality could improve as a result.

If a warranty clause is used, three items must be defined clearly: the scope of warranty, the warranty period, and the performance and payment bond. To reach a well-defined warranty scope, the following also needs to be considered: (1) a clear definition of the defects that the poor workmanship or poor product quality may cause, (2) the method of measuring the degree of severity for all the predefined

defects, and (3) the limit that identifies the contractor's or manufacturer's involvement in the occurrence of the defect (Chang and Georgy 1999).

5. The Testing of the Joint Materials

From the interviews, it was found that some joints are not tested before installation, and the material quality and properties are judged only on the documentation provided by the manufacturers. It is recommended that all types of joints be tested before their use and the testing data stored for future reference.

6. Proposed Evaluation Schemes

The evaluation schemes on in-service expansion joint systems were developed. The criteria of general appearance, condition of anchorage, debris accumulation, water tightness, surface damage, noise under traffic, ease of or need of maintenance and/or others were established. The schemes were designed to achieve a more objective evaluation process.

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INVESTIGATION OF BRIDGE DECK EXPANSION JOINTS

Objective: The deck expansion joints are among the smaller elements of a bridge structure but they could incur costs higher than anticipated because of frequent maintenance and repair problems such as deterioration of concrete around bridge seats on the piers and on the abutments. Thus, in order to get more insight into the performance of the joints, a study including field investigation and data collection is being conducted. This questionnaire is a part of this study. It is designed to quantify the problems and causes related to the bridge deck expansion joints, and to obtain feedback from bridge engineers and inspectors. It is hoped that in this way better understanding of the performance of the joints can be obtained, and it serves as the future reference of the selection criteria for the different types of joints.

Introduction: There are four parts in this questionnaire. Part I is a simple investigation of your background. Part II is the statement of problems related to the different types of joints. Part III is the statement of causes of the problems listed in Part II. Finally, Part IV is your recommendation. Since the list of choices in the questionnaire may not be very comprehensive, please write your own answers if you can not find them from the list. If you do not have experience with one of the types of the joints, simply answer with question mark.

Part I: Background

1.	How many years have you worked as an inspector?years
2.	How many years have you worked as an inspector for INDOT? years
3.	What kind of position do you have?
	a. Bridge Engineerb. Inspectorc. Assistant Inspectord. Others (specify)
4.	Which district are you in?
	 a. Crawfordsville b. Fort Wayne c. Greenfield d. La Porte e. Seymour f. Vincennes

Part II: The Problems Associated with the Bridge Deck Expansion Joints

The following pages list possible problems for each type of the expansion joint. They are B.S. joint, S.S. joint, I.A. joint, poured Dow silicone (XJS) joint, and LDI – polymer modified asphalt joint. Please rank the three most severe problems by 1, 2, and 3 for each type of joint. 1 represents the most severe problem, 2 is the next, and 3 is the least severe.

1. B.S. Joint

the joint
eel or
line
transverse
S

2. S.S. Joint

Loose, torn, split, cracked, damaged, hardened seals, or holes in seals	
Damage of epoxy fillers or adhesive lubricants causing separation of the joint material from the joint face	
Accumulation of debris and incompressible materials in the seals	
Loose, rusted, cracked, missing, or damaged steel plates, shapes, anchorage, bolts, nuts, holddown bars, and other metal components	
Others parts missing in addition to metal components	
Cracked and spalled concrete, and rusted or exposed reinforcement steel or structural steel in the deck joints substrate	
Evidence of water leakage on the underside of the deck or at the curbline	
Evidence or noise during the passage of vehicles over the joint	
Restriction on freedom of joint movement causing problems such as transvers movements of the deck	se
Evidence of rotation, tilting, or settlement of joints	
Incorrect joint opening and alignment	
Deterioration around bearing areas on the pier caps and on the abutments	
Poor rideability	
Cracked or damaged welding	
Inadequate skid resistance	
Others	

3. I.A. Joint

Loose, torn, split, cracked, damaged, hardened seals, or holes in seals
Damage of epoxy fillers or adhesive lubricants causing separation of the joint material from the joint face
Some components of the joint are missing
Cracked and spalled concrete, and rusted or exposed reinforcement steel or structural steel in the deck joints substrate
Evidence of water leakage on the underside of the deck or at the curbline
Evidence or noise during the passage of vehicles over the joint
Restriction on freedom of joint movement causing problems such as transverse movements of the deck
Evidence of rotation, tilting, or settlement of joints
Incorrect joint opening and alignment
Deterioration around bearing areas on the pier caps and on the abutments
Poor rideability
Inadequate skid resistance
Others

4. Poured Dow Silicone Joint (XJS)

Loose	, torn, split, cracked, damaged, hardened seals, or holes in seals
	ge of epoxy fillers or adhesive lubricants causing separation of the joint al from the joint face
Accum	nulation of debris and incompressible materials in the seals
Loose	, torn, split, cracked, damaged, or hardened nosing materials
Backe	r rods fall off
Some	parts missing in addition to backer rods
	ed and spalled concrete, and rusted or exposed reinforcement steel or ural steel in the deck joints substrate
Evider	nce of water leakage on the underside of the deck or at the curbline
Evide	nce or noise during the passage of vehicles over the joint
	ction on freedom of joint movement causing problems such as transverse ments of the deck
Evide	nce of rotation, tilting, or settlement of joints
Incorr	ect joint opening and alignment
Deteri	oration around bearing areas on the pier caps and on the abutments
Poor r	ideability
Inadeo	quate skid resistance
Others	S

5. LDI – Polymer Modified Asphalt Joint

Loose, torn, split, cracked, damaged, hardened seals, or holes in seals (polymer material)
Damage of epoxy fillers or adhesive lubricants causing separation of the joint material from the joint face
 Loose, rusted, cracked, missing, or damaged steel plates
Other parts missing in addition to metal components
Cracked and spalled concrete, and rusted or exposed reinforcement steel or structural steel in the deck joints substrate
 Evidence of water leakage on the underside of the deck or at the curbline
Evidence or noise during the passage of vehicles over the joint
 _Tracking and flowing of polymer during hot weather
Restriction on freedom of joint movement causing problems such as transverse movements of the deck
Evidence of rotation, tilting, or settlement of joints
_Incorrect joint opening and alignment
_Deterioration around bearing areas on the pier caps and on the abutments
Poor rideability
_Inadequate skid resistance
Others

Part III: Causes of the Problems of the Bridge Deck Expansion Joints

The following list consists of possible causes contributing to the problems associated with the bridge deck expansion joints.

1. Natural Forces

- 1.1 Rain
- 1.2 Sun
- 1.3 Snow
- 1.4 Dust
- 1.5 Ozone
- 1.6 Temperature changes
- 1.7 Moisture
- 1.8 Carbon dioxide
- 1.9 Ultraviolet rays

2. Vehicle Loading

- 2.1 Traffic density and axle loading live loads
- 2.2 Traffic-induced movements
- 2.3 Traffic-induced vibration

3. Bridge structure

- 3.1 Camber growth
- 3.2 Fatigue of the metal components
- 3.3 Lateral movement, such as abutment tilting or embankment movement
- 3.4 Abutment settlement
- 3.5 Approach slab movement and settlement
- 3.6 Excessive shrinkage, creep, deflection, or rotation in deck slabs
- 3.7 Displacement of bearings
- 3.8 Insufficient size or imbedment of anchorage systems

4. Design

- 4.1 Improper design of the joint (e.g., unarmored joint edges)
- 4.2 Improper selection of joint type
- 4.3 Improper selection of materials or using inferior quality of materials in the joint (e.g., seals are too hard or soft, sizes of seal or wall thickness are not adequate)
- 4.4 Poor or faulty drainage details
- 4.5 Defective or ineffective waterproofing
- 4.6 Insufficient clearance between the top of the deck and the top of the joint materials
- 4.7 Limited access to bearing shelves for maintenance
- 4.8 Difficulties of replacement/repair
- 4.9 Difficulties of cleaning

- 4.10 Improper mix preparation, cure, compaction, shrinkage ,or thickness of surfacing and hand mixed materials
- 4.11 Poor design and performance of bearings
- 4.12 Unacceptable range of movements and end rotations of the deck
- 4.13 Incorrect position of bearing
- 4.14 Incorrect elastic modulus of the joints
- 4.15 Different coefficients of expansion of concrete and epoxy mortar casing the shear forces on the bond plane
- 4.16 The exothermic action of epoxy mortar under cure producing shrinkage stresses
- 4.17 Skewed bridge structures
- 4.18 Lack of detailed drawings for the installation of joints

5. Construction

- 5.1 Poor installation
- 5.2 Inappropriate temperature in which the joint was being installed
- 5.3 Inadequate site preparation
- 5.4 Poor workmanship
- 5.5 Inadequate bedding
- 5.6 Inadequate bond
- 5.7 Inadequate anchorage
- 5.8 Failure of the fixings of other steel components
- 5.9 Looseness and pounding
- 5.10 Poor horizontal alignment
- 5.11 Poor vertical alignment (The joint is not at the proper level or not constructed in the same plane as the bridge deck)
- 5.12 Improper construction of the joint gap
- 5.13 Seal punctures during installation resulting in tears later

6. External Forces

- 6.1 Simple wear and tear
- 6.2 Deicing chemicals (e.g. salts)
- 6.3 Industrial pollutants
- 6.4 Cement alkalis
- 6.5 Petroleum derivatives
- 6.6 Grit
- 6.7 Detritus
- 6.8 Debris
- 6.9 Vegetation growth near the curbs

7. Others

- 7.1 Poor maintenance
- 7.2 Poor inspection
- 7.3 Poor fabrication of joints

7.4 Deteriorated bonding agents 7.5 Deteriorated bituminous material	S
7.6 Vandalism	
8. Other causes not included in the list (please specify)
8.1	
8.2	
8.3	
Questions:	
V 2	ct three most possible causes from the list above ed for the five joints in Part II. For example, if the are:
Loose, torn, split, cracked, danEvidence of water leakage on to	the underside of the deck or at the curbline
Then you could fill out three most post follows:	ssible causes (numbers only in your answers) as
B.S. Joint 4.12 (Unacceptable range of movements and end rotations of the deck) 6.1 (Simple wear and tear)	, ,
 Multiple causes (numbers) can be causes have equal weights Answers:	specified in each blank for a problem if these
B.S. Joint	
I.A. Joint	

Poured Dow Silicone Joint (XJS Joint)
LDI - Polymer Modified Asphalt Joint

Part IV: Recommendation

(a) Based on your observations, what are the advantages of each type of the joints? Please select three major advantages of each type of the joints from the list below. Write your own answers if you can not find them from the list. Write them from the most important one to the least important one.

Advantages:

a.	Simpl	le design	and	easy	to	specif	y

- b. Versatile could be used in different sizes of bridge
- c. Easy to install
- d. Easy maintenance and repair
- e. Rapid curing
- f. Durable and trouble free
- g. Long performance history
- h. Few debris accumulated in the joint
- i. Strong seal
- j. Water tight

q.	Others_			
----	---------	--	--	--

k.	Smooth ride
1.	Strong mechanical property
	Low construction cost
	Excellent weathering properties
	Resilient filler
	Eliminating time consuming and costly shop drawings
q.	Others
A	
An	swers:
В.9	S. Joint
S.S	S. Joint
	a. Joint
Po	ured Dow Silicone Joint (XJS joint)
LI	DI - Polymer Modified Asphalt Joint

(b)	The following list sl	hows some r	oossible im	provements or	ı the	service	life	of the	ioints

- 1. Removing the damaged parts and installing new ones
- 2. Repairing or modifying the joint openings
- 3. Armoring protection against live-load impact
- 4. Improving joint drainage system
- 5. Arranging surface slopes and gully positions
- 6. Selecting a correct type of joint
- 7. Better installation process
- 8. Using rubber snowplow blades in the snow removal equipment
- 9. Improving the bridge design
- 10. Improving the joint design
- 11. Promoting the design of jointless bridge decks
- 12. Detailed installation plans provided by the manufacturer or the designer
- 13. Using specialty contractors to install the joints
- 14. Making manufacturers or contractors responsible for the installation and maintenance of the joints
- 15. Regular and frequent inspection
- 16. Regular and frequent maintenance
- 17. A larger curb opening that flush themselves clear
- 18. Others

a.	
b.	
C	
c.	

Please select three most possible ways to improve the service life of each joint. Write them from the most important one to the least important one.

B.S. Joint
S.S. Joint
,
I.A. joint
Poured Dow Silicone joint (XJS joint)
LDI - Polymer Modified Asphalt Join

	your experience, how m s installed?	any years in av	verage did each type of the joint last
anei ii was	s instaneu?		
	oint: years		
	oint:years		
	int:years		
	d Dow Silicone joint (X.		
5. LDI - 1	Polymer Modified Asph	iait Joint:	years
Any other con	mment on each joint:		
Any suggestion	on on the design of the	questionnaire	e:

This concludes the questionnaire; please review your responses and ensure you have answered all questions. Thank you for your participation.



B.S. JOINT (survey #1)

1. Problem

Rank	Symptom	
1	Cracked and spalled concrete,	
	and rusted or exposed	
	reinforcement steel or structural	
	steel in the deck joints substrate	
2	Deterioration along bearing	
	areas on the pier caps and on the	
	columns	
3	Loose, torn, split, cracked,	
	damaged, hardened seals	

2. Cause

Problems	Cause 1	Cause 2	Cause 3
Cracked and spalled	Traffic density and axle	Deicing chemicals (e.g.,	Age and material failure
concrete, and rusted or	loading –live loads	salts)	
exposed reinforcement			
steel or structural steel in			
the deck joints substrate			
Deterioration along bearing	Deicing chemicals (e.g.	Improper design of the	Rain
areas on the pier caps and	salts)	joint (e.g., unarmored	
on the columns		joint edges)	
Loose, torn, split, cracked,	Debris	Traffic – induced	Lateral movement, such as
damaged, hardened seals		movements and	abutment tilting or
		vibration	embankment movement,
			abutment settlement, and
			approach slab movement and
			settlement

3. Strength

Rank	Item
1	Simple design and easy to specify
2	Low construction cost
3	Long performance history

4. Improvement

Rank	Item
1	Promoting the design of jointless
	bridge decks
2	Removing the damaged parts and
	installing new ones
3	Armoring – protection against live-
	load impact

S.S. JOINT (survey #1)

1. Problem

Rank	Symptom	
1	Loose, torn, split, cracked,	
	damaged, hardened seals, or	
	holes in seals	
2	Deterioration along bearing	
	areas on the pier caps and on	
	the columns	
3	Accumulation of debris and	
	incompressible materials in	
	the seals	

2. Cause

Problems	Cause 1	Cause 2	Cause 3
Loose, torn, split, cracked,	Debris	Poor installation	Difficulties of
damaged, hardened seals, or			replacement/repair
holes in seals			
Deterioration along bearing	Deicing chemicals (e.g.,	Poor maintenance	Poor or faulty drainage
areas on the pier caps and on	salts)		details, Deicing
the columns			chemicals (e.g., salts),
			Traffic-induced
			movements and
			vibration
Accumulation of debris and	Debris	Poor maintenance	Traffic density and axle
incompressible materials in			loading –live loads,
the seals			Traffic-induced
			movements and
			vibration

3. Strength

Rank	Item
1	Long performance history
2	Simple design and easy to specify
3	Versatile – could be used in
	different sizes of bridge

4. Improvement

Rank	Item	
1	A larger curb opening that flush	
	themselves clear	
2	Regular and frequent maintenance	
3	Promoting the design of jointless	
	bridge decks	

I.A. JOINT (survey #1)

1. Problem

Rank	Symptom	
1	Cracked and spalled concrete, and rusted or	
	exposed reinforcement steel or structural	
	steel in the deck joints substrate	
2	Loose, torn, split, cracked, damaged,	
	hardened seals, or holes in seals	
3	Damage of epoxy fillers or adhesive	
	lubricants causing separation of the joint	
	material from the joint face	

2. Cause

Problems	Cause 1	Cause 2	Cause 3
Cracked and spalled	Improper design of the	Improper selection of materials	Traffic density and axle
concrete, and rusted or	joint (e.g., Unarmored	or using inferior quality of	loading –live loads,
exposed reinforcement steel	joint edges)	materials in the joint (e.g., seals	Traffic-induced
or structural steel in the deck		are too hard or soft, sizes of seal	movements and vibration
joints substrate		or wall thickness are not	
		adequate)	
Loose, torn, split, cracked,	Age and material failure	Lateral movement, such as	Deicing chemicals (e.g.,
damaged, hardened seals, or		abutment tilting or embankment	salts)
holes in seals		movement, Abutment	
		settlement, and Approach slab	
		movement and settlement	
Damage of epoxy fillers or	Poor installation	Poor or faulty drainage details	Simple wear and tear
adhesive lubricants causing			
separation of the joint			
material from the joint face			

3. Strength

Rank	Item
1	Simple design and easy to specify
2	Low construction cost
3	Easy to install

4. Improvement

Rank	Item
1	Removing the damaged parts and installing new ones
2	Promoting the design of jointless bridge decks
3	Making notch deeper & filling with silicone (eliminate
	neoprene)

XJS JOINT (survey #1)

1. Problem

Rank	Symptom
1	Loose, torn, split, cracked, damaged, hardened nosing
	materials
2	Traffic comes into contact with silicone
3	Damage of epoxy fillers or adhesive lubricants causing
	separation of the joint material from the joint face

2. Cause

Problems	Cause 1	Cause 2	Cause 3
Loose, torn, split, cracked,	Improper design of the	Improper selection of materials or using	Simple wear and tear
damaged, hardened nosing	joint (e.g., Unarmored	inferior quality of materials in the joint	
materials	joint edges)	(e.g., seals are too hard or soft, sizes of	
		seal or wall thickness are not adequate)	
		Improper selection of materials or using	
		inferior quality of materials in the joint	
		(e.g., seals are too hard or soft, sizes of	
		seal or wall thickness are not adequate)	
		Deteriorated bonding agents	
Traffic comes into contact	Poor installation	None	None
with silicone			
Damage of epoxy fillers or	Poor installation	Inadequate bond	Improper selection of
adhesive lubricants causing			joint type
separation of the joint			
material from the joint face			

3. Strength

Rank	Item
1	Simple design and easy to specify
2	Smooth ride
3	Few debris accumulated in the joint

4. Improvement

Rank	Item
1	Use specialty contractors to install the joints
2	Removing the damaged parts and installing new ones
3	Making manufacturers or contractors responsible for the
	installation and maintenance of the joints

LDI JOINT (survey #1)

1. Problem

Rank	Symptom	
1	Loose, torn, split, cracked,	
	damaged, hardened seals, or	
	holes in seals (polymer	
	material)	
2	Tracking and flowing of	
	polymer during hot weather	
3	Loose, rusted, cracked,	
	missing, or damaged steel	
	plates	

2. Cause

Problems	Cause 1	Cause 2	Cause 3
Loose, torn, split, cracked,	Unacceptable range of	Temperature changes	No testing of materials,
damaged, hardened seals, or	movements and end		too much reliance on
holes in seals (polymer	rotations of the deck		material certifications
material)			(type A,B, C, etc.)
Tracking and flowing of	Unacceptable range of	No testing of materials, too	Improper selection of
polymer during hot weather	movements and end	much reliance on material	materials or using inferior
	rotations of the deck	certifications (type A, B, C,	quality of materials in the
		etc.)	joint (e.g., seals are too
			hard or soft, sizes of seal
			or wall thickness are not
			adequate)
Loose, rusted, cracked,	Poor installation	Unacceptable range of	Inadequate site
missing, or damaged steel		movements and end rotations of	preparation, Inadequate
plates		the deck	bond

3. Strength

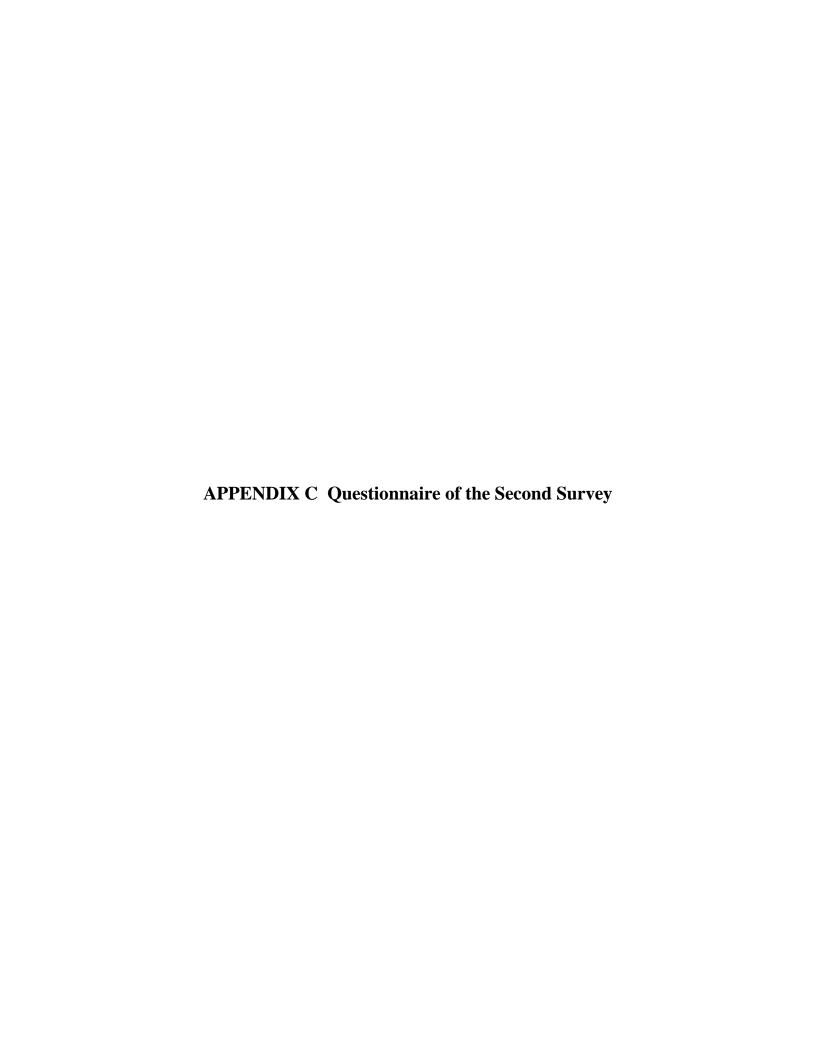
Rank	Item
1	Smooth ride
2	Few debris accumulated in the joint
3	Versatile – could be used in
	different sizes of bridge

4. Improvement

Rank	Item
1	Promoting the design of jointless bridge decks
2	Making manufacturers or contractors responsible for the
	installation and maintenance of the joints
3	Using specialty contractors to install the joints

Estimated Joint Life (survey #1)

Joint Type	S.S.	B.S.	I.A.	XJS	LDI
Estimated	11.9	11.706	8.728	5.19	3.502
Life (yr.)					



INVESTIGATION OF BRIDGE DECK EXPANSION JOINTS

Objective

The deck expansion joints are among the smallest elements of a bridge structure. However, they could incur costs higher than anticipated because of frequent maintenance and repair problems. In order to get more insight into the field performance of the joints, this questionnaire is designed to quantify the problems and causes related to the bridge deck expansion joints. We invite your inputs and to tell us how to fix those problems. It is hoped that in this way better understanding of the performance of the joints could be obtained, and the results could serve as the future reference of the evaluation criteria for different types of joints.

Introduction

There are three parts in this questionnaire. <u>Part I is a simple investigation of your background</u>. We like to know a little about you so we can see how different types of people feel about the issues.

Part II is the investigation of the problems, causes, merits, and improvements for each joint. We like you to point out what are the problems and causes associated with each type of joint, the advantages of using each type of joint, and better ways to improve the joints' performance. In this questionnaire survey, we concentrate on the investigation of seven types of expansion joints. They are Compression Seal (B.S.), Strip Seal (S.S.), Poured Dow Corning Silicone (XJS), Jointless (I.A.) with the poured sealer and the neoprene seal, and Polymer Modified Asphalt joints (LDI and Pave Tech).

To facilitate your correspondence to the questions, we provide a separate set of sample answers for the problems each joint may have, the causes of the identified problems, the advantages of using the specific joint, and better ways to improve the performance of each joint. The simplified example drawings of the joints are attached to help you clarify what kinds of joints we are referring to.

<u>Part III is the recommendation.</u> We like you to select the three best joints on your opinion, to estimate the service life of each joint, and to put any comment you have about the joint and the questionnaire.

Since the list of choices in the questionnaire may not be inclusive, <u>please write</u> your own answers if you could not find them from sample answers. If you do not have experience with one of the types of the joints, simply leave it blank or just put a question mark.

Part I: Background

1.	How many years have you worked related to bridge inspection?years
2.	How many years have you worked related to bridge inspection for (IDOT, INDOT, KDOT, MDOT, ODOT) years
3.	What kind of position do you have?
	a. Bridge engineerb. Bridge inspectorc. Assistant Inspectord. Other (please specify)

Part II: The Problems, Causes, Merits, and Improvements associated with the Bridge Deck Expansion Joints

There will be four sub-sections (a), (b), (c), and (d) for each joint. The section (a) is the investigation of the most severe problems of the joints; the section (b) is the investigation of the causes of the problems identified in (a); the section (c) is of the strengths; and the section (d) is of the improvements. The lists of possible problems, causes, strengths, and improvements are shown in the attached sample answers. Write your own answers if you could not find them from the list. Multiple choices of the answers are allowed in each blank. Please see the example on the next page. If you are not sure which type of joint we are referring to, please see the attached example drawings.

(a) Problems

Please select and rank the three most severe problems for each type of joint from the attached sample answers.

(b) Causes

For each problem you select for each type of the joint in (a), please find three most possible causes from the attached sample answers. The most possible one is filled out first.

(c) Strengths

Please select three major strengths of each type of the joints from the attached sample answers. The most important one is filled out first.

(d) Improvements

For each type of the join, please find out three most possible improvements of its performance from the attached sample answers. The most important one is filled out first.

EXAMPLE: B.S. JOINT (Compression Seal)

(a) Problems (see sample answers, pp. 1-2)
The most severe problem: <u>5.1, 5.2</u> .
The second severe problem: 7.1, 7.2 .
The third severe problem: <u>1.1</u> .
(b) <u>Causes (see sample answers, pp. 3-5)</u>
For the most severe problem: 1. <u>2.1</u> , 2. <u>6.3</u> , 3. <u>4.1</u> .
For the second severe problem: 1. <u>6.3</u> , 2. <u>7.2</u> , 3. <u>1.6</u> .
For the third severe problem: 1. <u>6.2</u> , 2. <u>2.2,2.3</u> , 3. <u>3.1,3.8</u>
(c) Strength (see sample answers, pp. 6)
1. <u>12</u> , 2. <u>9</u> , 3. <u>16</u> .
(d) Improvement (see sample answers, pp. 7)
1. <u>10</u> , 2. <u>5</u> , 3. <u>3</u> .

1. B.S. JOINT (Compression Seal)

(a) Problems			
The most severe problem:			
The second severe problem:			
The third severe problem:			
(b) <u>Causes</u>			
For the most severe problem: 1	, 2	, 3	
For the second severe problem: 1	, 2	, 3	
For the third severe problem: 1	, 2	, 3	
(c) Strength			
1, 2, 3			
(d) Improvement			
1, 2, 3			

2. S.S. JOINT (Strip Seal)

(a) Problems
The most severe problem:
The second severe problem:
The third severe problem:
(b) <u>Causes</u>
For the most severe problem: 1, 2, 3
For the second severe problem: 1, 2, 3
For the third severe problem: 1, 2, 3
(c) Strength
1, 2, 3
(d) Improvement
1

3a. I.A. JOINT (Jointless with the Poured Sealer)

(a) Problems
The most severe problem:
The second severe problem:
The third severe problem:
(b) <u>Causes</u>
For the most severe problem: 1, 2, 3
For the second severe problem: 1, 2, 3
For the third severe problem: 1, 2, 3
(c) Strength
1, 2, 3
(d) Improvement
1, 2, 3

3b. I.A. JOINT (Jointless with the Neoprene Seal)

(a) Problems		
The most severe problem:		
The second severe problem:	-	
The third severe problem:		
(b) <u>Causes</u>		
For the most severe problem: 1,	2,	3
For the second severe problem: 1	, 2,	3
For the third severe problem: 1,	2,	3
(c) Strength		
1, 2, 3		
(d) Improvement		
1, 2, 3		

4. POURED DOW CORNING SILICONE JOINT (XJS)

(a) Problems	
The most severe problem:	
The second severe problem:	
The third severe problem:	
(b) <u>Causes</u>	
For the most severe problem: 1,	2, 3
For the second severe problem: 1,	2, 3
For the third severe problem: 1, 2	2, 3
(c) Strength	
1, 2, 3	
(d) Improvement	
1, 2, 3	

5a. LDI -POLYMER MODIFIED ASPHALT JOINT

(a) Problems
The most severe problem:
The second severe problem:
The third severe problem:
(b) <u>Causes</u>
For the most severe problem: 1, 2, 3
For the second severe problem: 1, 2, 3
For the third severe problem: 1, 2, 3
(c) Strength
1, 2, 3
(d) Improvement
1, 2, 3

5b. PAVE TECH -POLYMER MODIFIED ASPHALT JOINT

(a) Problems
The most severe problem:
The second severe problem:
The third severe problem:
(b) <u>Causes</u>
For the most severe problem: 1, 2, 3
For the second severe problem: 1, 2, 3
For the third severe problem: 1, 2, 3
(c) Strength
1, 2, 3
(d) Improvement
1 2 3.

8/27/99

Part III: Recommendation

(a)	stimated Service Life
	ased on your experience, how many years in average did each type of the joint last fter it was installed?
	B.S. JOINT: years S.S. JOINT: years I.A. (POURED SEALER) JOINT: years I.A. (NEOPRENE SEAL) JOINT: years POURED DOW SILICONE (XJS) JOINT: years LDI JOINT: years PAVE TECH JOINT: years
(b)	ased on your observation, please select the three best joints in terms of its overall erformance and briefly explain the reason why you choose them (not limited to the pints listed in this survey).
	<u> </u>
	eason:
	<u></u>
	eason:
	eason:

If you have any comment on each joint, please write it down here. (d) Any suggestion on the design of the questionnaire?	(c) Comment
(d) Any suggestion on the design of the questionnaire?	If you have any comment on each joint, please write it down here.
(d) Any suggestion on the design of the questionnaire?	
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(d) Any suggestion on the design of the questionnaire?	
	(d) Any suggestion on the design of the questionnaire?

This concludes the questionnaire; please review your responses and ensure you have answered all questions. Thank you very much for your participation.

SAMPLE ANSWERS

(a) Problems 1. Damaged seals due to _____ 1.1 Loose 1.2 Torn 1.3 Split 1.4 Cracks 1.5 Hardened 1.6 Holes 1.7 Other (please specify)_____ 2. Damage of adhesive lubricants causing separation of the joint material from the joint face 3. Accumulation of debris and incompressible materials in the seals 4. _____ components of the joint are damaged 4.1 Steel plates 4.2 Anchorage 4.3 Holddown bars 4.4 Bolts 4.5 Welding 4.6 Aluminum plates 4.7 Other (please specify)_____ 5. concrete around the joint 5.1 Cracked concrete 5.2 Spalled concrete 5.3 Other (please specify)____ 6. Rusted steel components _____ in the deck joints substrate raise the deck that impacts traffic and damages the ends of the deck 6.1 Reinforcement steel 6.2 Bearing elements 6.3 Top flanges of beams 6.4 Other (please specify)_____

7.1 Cap areas

7. Deterioration along _____

7.2 Beam ends7.3 Other (please specify)	
8. Deterioration of	
8.1 Bearings	
8.2 Abutments	
8.3 Columns 8.4 Other (please specify)	
9. Evidence of water leakage on	
9.1 The underside of the deck	
9.2 At the curbline	
9.3 At the bent cap	
9.4 Other (please specify)	
10. Evidence of noise during the passage of vehicles over the joint	
11. Restriction on freedom of joint movement causing problems such as _	of the deck
11.1 Transverse movements	
11.2 Horizontal movements	
11.3 Other (please specify)	
12. Evidence ofof joints	
12.1 Rotation	
12.2 Tilting	
12.3 Settlement	
12.4 Other (please specify)	
13. Poor ridebility	
14. Inadequate skid resistance	
15. Others (please specify)	
15.1	
15.2	
15.3	_
15.4	_
15.5	_
15.6	

(b) Causes

1. Natural Forces

- 1.1 Carbon dioxide
- 1.2 Dust
- 1.3 Ice freezing
- 1.4 Moisture
- 1.5 Ozone
- 1.6 Rain
- 1.7 Snow
- 1.8 Sun
- 1.9 Significant changes of temperatures between summer and winter
- 1.10 Ultraviolet rays

2. Traffic Vehicle

- 2.1 Traffic density and axle loading live loads
- 2.2 Traffic-induced movements
- 2.3 Traffic-induced vibration
- 2.4 Snow plows
- 2.5 Trucks

3. Bridge structure

- 3.1 Abutment settlement
- 3.2 Approach slab movement and settlement
- 3.3 Camber growth
- 3.4 Displacement of bearings
- 3.5 Excessive shrinkage, creep, deflection, or rotation in deck slabs
- 3.6 Fatigue of the metal components
- 3.7 Failure of the fixings of other steel components
- 3.8 Inadequate anchorage
- 3.9 Inadequate bedding
- 3.10 Lateral movement, such as abutment tilting or embankment movement

4. Design

- 4.1 Improper mix preparation, cure, compaction, shrinkage ,or thickness of surfacing and hand mixed materials
- 4.2 Incorrect deck superelevation
- 4.3 Incorrect joint openings
- 4.4 Incorrect joint alignments
- 4.5 Incorrect position of bearing
- 4.6 Insufficient clearance between the top of the deck and the top of the joint materials
- 4.7 Improper selection of the joint type

- 4.8 Lack of detailed drawings for the installation of joints
- 4.9 Poor design and performance of bearings
- 4.10 Poor or faulty drainage details
- 4.11 Skewed bridge structures
- 4.12 Steel plates too thin
- 4.13 Unacceptable range of movements of the joint

5. Construction

- 5.1 Inadequate site preparation
- 5.2 Inappropriate temperature in which the joint was being installed
- 5.3 Joint seal not released sufficiently
- 5.4 Loose concrete adjacent to joint materials
- 5.5 Poor installation
- 5.6 Poor vertical alignment (The joint is not at the proper level or not constructed in the same plane as the bridge deck)
- 5.7 Poor workmanship
- 5.8 Seal punctures during installation resulting in tears later
- 5.9 Seals not properly installed not properly seated in extrusion

6. External Forces

- 6.1 Cement alkalis
- 6.2 Debris
- 6.3 Deicing chemicals (e.g. salts)
- 6.4 Detritus
- 6.5 Grit
- 6.6 Industrial pollutants
- 6.7 Petroleum derivatives
- 6.8 Simple wear and tear
- 6.9 Vegetation growth near the curbs

7. Material Failure

- 7.1 Failure of bonding agents
- 7.2 Improper selection of materials or using inferior quality of materials in the joint (e.g., seals are too hard or soft, inadequate sizes of seal or wall thickness)
- 7.3 Seals being pushed up during hot weather conditions
- 7.4 The failure of the deck overlay adjacent to the joint

8. Others

- 8.1 Deteriorated bituminous materials
- 8.2 Difficulties of cleaning
- 8.3 Difficulties of replacement/repair
- 8.4 Limited access to bearing shelves for maintenance

- 8.5 Poor fabrication of joints8.6 Poor inspection8.7 Poor maintenance8.8 Vandalism
- 9. Other causes not included in the list (please specify)

9.2 9.3
7. .3
9.4
9.5
9.6

(c) Strength

The following list shows possible strengths of the joint.

- 1. Allowing required movements
- 2. Durable and trouble free
- 3. Easy maintenance and repair
- 4. Easy to install
- 5. Eliminating time consuming and costly shop drawings
- 6. Excellent weathering properties
- 7. Few debris accumulated in the joint
- 8. Long performance history
- 9. Low construction cost
- 10. Rapid curing
- 11. Resilient filler
- 12. Simple design and easy to specify
- 13. Smooth ride
- 14. Strong mechanical property
- 15. Strong seal
- 16. Versatile could be used in different sizes of bridge
- 17. Water tight
- 18. Others (please specify)

19.1	
19.2	
19.5	
19.6	

(d) Improvements

The following list shows some possible improvements on the service life of the joints.

- 1. A larger curb opening that flush themselves clear
- 2. A non-corroding extrusion
- 3. Armoring protection against live-load impact
- 4. Arranging surface slopes and gully positions
- 5. Better installation process
- 6. Detailed installation plans provided by the manufacturer or the designer
- 7. Improving joint drainage system
- 8. Making manufacturers or contractors responsible for the installation and maintenance of the joints
- 9. Regular and frequent inspection
- 10. Regular and frequent maintenance
- 11. Repairing or modifying the joint openings
- 12. Selecting a correct type of joint
- 13. Strengthening the bonding between seals and the attached mateirals
- 14. Testing of materials
- 15. Tying approaching slabs to deck
- 16. Using rubber snowplow blades in the snow removal equipment
- 17. Using specialty contractors to install the joints
- 18. Others (please specify)

19.1	
19.6	



B.S. JOINT (survey #2)

1. Problem

Level	Symptom
The most severe	Loose seal
The second severe	Damaged adhesive lubricants
The third severe	Spalled concrete

2. Cause

Problems	Cause 1	Cause 2	Cause 3
Loose seal	Failure of bonding	Incorrect joint openings	Inadequate anchorage
	agents		
Damaged adhesive	Failure of bonding	Inadequate site	1. Poor installation
lubricants	agents	preparation	2. Trucks
Spalled concrete	Traffic density and axle	Failure of bonding	Simple wear and tear
	loading	agents	

3. Strength

1	Allowing required movements
2	Simple design and easy to specify
3	Low construction cost

4. Improvement

1	Strengthening the bonding between seals and the
	attached materials
2	Regular and frequent maintenance
3	Making manufacturers or contractors responsible
	for the installation and maintenance of the joints

S.S. JOINT (survey #2)

1. Problem

Level	Symptom
The most severe	Torn seal
The second severe	Accumulation of debris
The third severe	Split seal

2. Causes

Problems	Cause 1	Cause 2	Cause 3
Torn seal	Debris	Snow plow	Seal punctures during installation resulting in tears later
Accumulation of debris	Debris	Grit	Poor maintenance
Split seal	Debris	Seal punctures during installation resulting in tears later	Simple wear and tear

3. Strength

1	Allowing required movements
2	Easy to install
3	Durable and trouble free

1	Regular and frequent maintenance
2	A larger curb opening that flush themselves clear
3	Better installation process

I.A. JOINT (Poured Sealer) (survey #2)

1. Problem

Level	Symptom
The most severe	Hardened seal
The second severe	Spalled concrete
The third severe	Cracked concrete

2. Causes

Problems	Cause 1	Cause 2	Cause 3
Hardened seal	Ultraviolet rays	Sun	Simple wear and tear
Spalled concrete	Traffic density and axle loading	Seals being pushed up during hot weather conditions	Snow plows
Cracked concrete	Temperatures change between summer and winter Traffic density and axle loading	 Moisture Snow plows 	N/A

3. Strength

1	Easy to install
2	Low construction cost
3	Durable and trouble free

1	Regular and frequent maintenance
2	Better installation process
3	Strengthening the bonding between seals and the
	attached materials

I.A. JOINT (Neoprene Seal) (survey #2)

1. Problem

Level	Symptom
The most severe	Spalled concrete
The second severe	Loose seal
The third severe	Cracked concrete

2. Causes

Problems	Cause 1	Cause 2	Cause 3
Spalled concrete	Traffic density and axle loading	Seals being pushed up during hot weather conditions	Poor installation
Loose seal	Poor installation	Temperatures change	Traffic-induced
		between summer and	movements
		winter	
Cracked concrete	1. Traffic density and	Seals being pushed up	N/A
	axle loading	during hot weather	
	2. Failure of bonding	conditions	
	agents		

3. Strength

1	Easy to install
2	Long performance history
3	Allowing required movements

1	Strengthening the bonding between seals and the
	attached materials
2	Very little use
3	Better installation process

XJS JOINT (survey #2)

1. Problem

Level	Symptom
The most severe	Loose seal
The second severe	Cracked seal
The third severe	Holes in seal

2. Causes

Problems	Cause 1	Cause 2	Cause 3
Loose seal	Poor workmanship	Failure of bonding	Poor installation
		agents	
Cracked seal	Poor installation	Poor workmanship	Inadequate site
			preparation
Holes in seal	Poor installation	Poor workmanship	Inadequate site
			preparation

3. Strength

1	Easy to install
2	Easy maintenance and repair
3	Water tight

1	Better installation process
2	Strengthening the bonding between seals and the attached materials
3	Detailed installation plans provided by the manufacturer or the designer

LDI JOINT (survey #2)

1. Problem

Level	Symptom
The most severe	Cracked seal
The second severe	Holes in seal
The third severe	Split seal

2. Causes

Problems	Cause 1	Cause 2	Cause 3
Cracked seal	Poor installation	Improper selection of materials or using inferior quality of materials in the joint	 Incorrect joint openings Inadequate bedding
Holes in seal	Traffic density and axle loading	Snow plows	Seals being pushed up during hot weather conditions
Split seal	Unacceptable range of movements of the joint	Snow plows	Poor installation

3. Strength

1	Allowing required movements
2	Easy to install
3	Few debris accumulated in the joint

1	Better installation process
2	Very little use
3	Using specialty contractors to install the joints

PAVE TECH JOINT (survey #2)

1. Problem

Level	Symptom
The most severe	Polymer too soft (rutting)
The second severe	Cracked seal
The third severe	Holes in seal

2. Causes

Problems	Cause 1	Cause 2	Cause 3
Polymer too soft	Traffic density and axle	Improper selection of	Incorrect join openings
(rutting)	loading	materials or using	
		inferior quality of	
		materials in the joint	
Cracked seal	Poor installation	1. Snow plows	N/A
		2. Poor workmanship	
Holes in seal	Traffic density and axle	Snow plows	Seals being pushed up
	loading		during hot weather
			conditions

3. Strength

1	Allowing required movements
2	Easy to install
3	Excellent weathering properties

1	Selecting a correct type of joint
2	Very little use
3	Using specialty contractors to install the joints

Estimated Joint Life (survey #2)

Joint Type	S.S.	B.S.	I.A. (Poured sealer)	I.A. (Neoprene seal)	PaveTech	LDI	XJS
Estimated Life (yr.)	10.92	10.3	9.79	7.33	5.82	5.74	5.56



B.S. Problems

No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	Tol.	Num.	Avg1	Avg2
Yr.	20	6	5.5	22	28	5	3.5	14	4	0.25	1	16	4	27	1	5	3.25	1	166.5			_
Prob.																						
1	2	3	1				3	1	2	1	3	2	2			1	2	2	25	13	1.923	0.02303
	20	6	5.5				3.5	14	4	0.25	1	16	4			5	3.25	1	83.5			
2	3					2		1		3			3		3		2		17	7	2.429	0.05113
	20					5		14		0.25			4		1		3.25		47.5			
3								2	1	4			1		2	3	1	2	16	8	2	0.06154
								14	4	0.25			4		1	5	3.25	1	32.5			
4								3	3								2	2	10	4	2.5	0.11236
								14	4								3.25	1	22.25			
5	1	1		1	1	1		3			2	1		2	1		1	2	17	12	1.417	0.00957
	20	6		22	28	5	3.5	14		0.25	1	16		27	1		3.25	1	148			
6			2				2	1		2		3		1			1	2	14	8	1.75	0.02482
			5.5				3.5	14		0.25		16		27			3.25	1	70.5			
7								2									3		5	2	2.5	0.14493
								14									3.25		17.25			
8								3									3		6	2	3	0.17391
								14									3.25		17.25			
9								3									3		6	2	3	0.17391
								14									3.25		17.25			
10								3									3		6	2	3	0.17391
								14									3.25		17.25			
11		2	3	2		2	1	1			1	1		3		2	1	2	21	12	1.75	0.01275
		6	5.5	22	28	5	3.5	14			1	16		27		5	3.25	1	137.25			
12				3	3	3		2									3		14	5	2.8	0.03875
				22	28	5		14									3.25		72.25			
13								3									3		6	2	3	0.08276
					28	5											3.25		36.25			
14					2														2	1	2	0.07143
					28														28			
15						1													1	1	1	0.2
						5													5			

For each problem:

- 1. 1 is assigned to the most severe problem, 2 is to the second, and 3 is to the third severe problem.
- 2. The sum of numbers assigned to the problem is divided by the number of people who selected it to obtain the value of Avg1.
- 3. The value of Avg1 is divided by the total numbers of years of experiences of the people who selected this problem to obtain the value of Avg2.
- 4. Finally the problem with the smallest value of Avg2 is the most severe problem, the one with the second smallest value is the second most severe problem, and so on.

B.S. Causes

No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Cause 1	8.1	4.15	4.12	2.1	2.1	2.1	6.2	2.1	7.3	5.4	6.2	1, 6.2, 2.2, 2.3	6.8	5.1,5.4	4.1	6.8,5.9	6.2	7.1
Cause 2	2	5.4	6.2	4.1	4.1	1.1,1.6,1.7	1.1	6.1	1.2		1.1	3.3, 3.4, 3.5	7.1	6.2	7.1	7.1	6.1	5.1
Cause 3	6.1	6.8	6.1	4.8	4.8	6.2	8.1	6.2	4.1		6.1	3.3, 3.4, 3.5		6.2	5.1	7.1	6.8	6.7

Prob. 1	8.1	8.1	2.1	6.2	1.1	2.2,2.3	4.1	5.1			
Yr. of Exp.	20	6	55	44.25	1	16	1	1			
Num.	1	1	3	3	1	1	1	1			
Total	20	6	165	132.75	1	16	1	1			
Rank	3		1	2							
Prob. 2	5.4	6.1	4.1	1.6,1.7	1.1	2.1	6.2	7.1	5.1		
Yr. of Exp.	6	5.5	22	5	8.5	14	47.25	5	1		
Num.	1	1	1	1	2	1	4	1	1		
Total	6	5.5	22	5	17	14	189	5	1		
Rank			2		3		1				
Prob. 3	2.2,2.3	6.8	4.12	8.1	2.1	1.2	5.4	6.1	3.3, 3.4, 3.5	7.1	5.9
Yr. of											
Exp.	20	11	5.5	3.5	14	4	0.25	4.25	16	4	5
Num.	1	2	1	1	1	1	1	2	1	1	1
Total	20	22	5.5	3.5	14	4	0.25	8.5	16	4	5
Rank	2	1							3		

- 1. The three most severe problems are obtained from the result of the previous page.
- 2. For each cause selected for the problem, the total number of the years of experiences of people who selected the cause are multiplied by the number of people to get the value of Total.
- 3. The cause which has the largest value of Total is the most possible cause for the problem, the cause with the second largest value is the second most possible cause, and so on.

B.S. Advantages

No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	Tol.	Num.	Avg1	Avg2	Rank
Adv.1	а	а	g	а	m	m	b	С	а	а		f	i	а	q	а	а						
Adv.2	g	m	b	m	а	а	С	а	р			g	n	g	q	m	b						
Adv.3	d	С	d	b	b	b	m	g				h		i	q	р	С						
а	1	1		1	2	2		2	1	1				1		1	1		14	11	1.273	0.00946	1
	20	6		22	28	5		14	4	0.25				27		5	3.25		134.5				
b			2	3	3	3	1										2		14	6	2.333	0.0347	
			5.5	22	28	5	3.5										3.25		67.25				
С		3					2	1									3		9	4	2.25	0.08411	
		6					3.5	14									3.25		26.75				
d	3		3																6	2	3	0.11765	
	20		5.5																25.5				
е																							
f												1							1	1	1	0.0625	
												16							16				
g	2		1					3				2		2					10	5	2	0.0292	3
	20		5.5									16		27					68.5				
h												3							3	1	3	0.1875	
												16							16				
i														3					3	1	3	0.11111	
														27					27				
j													1						1	1	1	0.25	
													4						4				
m		2		2	1	1	3									2			11	6	1.833	0.02638	2
		6		22	28	5	3.5									5			69.5				
n													2						2	1	2	0.5	
													4						4				
0																							
р									2							3			5	2	2.5	0.27778	
									4							5			9				
q															2				2	1	2	2	
															1				1				

- 1. 1 is assigned to the most important advantage, 2 is assigned to the second most important advantage, and 3 is to the third most important advantage.
- 2. The method of obtaining the ranking is the same as that for joint problems.
- 3. No one selected k and I and they are deleted to save the space of the page.

B.S. Improvements

lmpt2	14	6	11		18 ¹	6	3	1	6	4	1	4	7	15,16	2	15						
lmpt3	1	7	6		18 ²		11	4	10	7	7	1		11	4	7						
1	3							2	1		2	3			1		12	6	2		0.03265	2
2	20							14	4		16 1	4			3.25 2		61.25 3	2	1.5	2	0.07792	
3							2				16		1	1	3.25		19.25 4	3	1.333		0.03756	3
4							3.5	3		2		2	27	5	3		35.5 10	4	2.5		0.11628	
6		2	3			2		14	2	0.25		4			3.25		21.5 9	4	2.25		0.10976	
7		6 3	5.5			5	1		4	3	3		2			3	20.5 15	6	2.5		0.04651	
		6	1				3.5			0.25	16		27			1	53.75	1	1	1		
9			5.5														1 5.5			1	0.18182	
10									3								3 4	1	3		0.75	
11	1	1	2 5.5	1 22	1 28	1 5	3							3 5			13 95	8	1.625	3	0.01711	1
14	2																20	1	2		0.1	
15														2 5		2	4 6	2	2		0.33333	
16								1		1 0.25		1		2 5		1	6 24.25	5	1.2		0.04948	
18 ¹					2			14		0.23		4		ິນ —			2	1	2		0.07143	
18 ²					28 3												28 3	1	3		0.10714	
					28												28					

- 1. 1 is assigned to the most important improvement, 2 is assigned to the second most important, and 3 is to the third most important improvement.
- 2. The method of obtaining the ranking is the same as that for joint problems.
- 3. 18¹ and 18² are the improvements suggested by inspectors who filled out the questionnaire..
 4. No one selected the improvement 5, 8, 12, 13, and 17, and they are deleted to save the space of the page.

Recommended Types of Joints

No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Yr.	5	22	8	5	15	2	15	6	20	25	3	20	5	17	3	8	25	5	9	8	18	17	3
B.S.	2	2	2	2	1		1	3	2						2	2	1	1	1		1	2	3
S.S.		1	3		2					3			1				2		3	1	2	1	1
I.A.(a)	1			1		1		2		1													
I.A.(b)						2				1					1					2			
XJS			1					1	1				2		3	1	3	2	2				
LDI						3								1									
PT		3			3	3								2						3			2

No.	24	25	26	27	28	29	30	31	32	33	Tol	Sum	Avg	Rank1	Wsum	Wqty	Wavg	Rank2
Yr.	4	6	1	5	20	5.5	6	11	17	23								
B.S.							2		3	3	19	36	1.8947	5	422	230	0.0966	1
S.S.				1		1	1	1		1	16	25	1.5625	1	347.5	205.5	0.1057	2
I.A.(a)		1		2		2		3	2		10	16	1.6	2	143	87.5	0.1634	4
I.A.(b)		2		2							6	10	1.6667	3	70	49	0.2381	5
XJS	1	3		3				2		2	14	27	1.9286	6	269	138	0.1392	3
LDI									1		3	5	1.6667	3	40	36	0.3704	7
PT									1		7	17	2.4286	7	198	84	0.3367	6

- 1. The type of joint that is chosen as the best one is assigned as 1, the second best is assigned as 2, and the third one is assigned as 3.
- 2. The value of Avg is obtained by dividing the total numbers given to a type of joint by the number of people who select it.
- 3. The Wsum and Wqty are obtained by including the year of experience of each person.
- 4. The Wavg is obtained by dividing the Wsum by the value of Wqty for each type of joint.

Estimated Life of Joints

No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	Sub total
Yr.	20	7-10	15	5	8	0-4	0	20	10	0	15	15	15	0	0.5	6	10-15	3-8	
Avg.	20	8.5	15	5	8	2	0	20	10	0	15	15	15	0	0.5	6	12.5	5.5	158
Yr.	20	6	5.5	22	28	5	0	14	4	0	1	16	4	0	1	5	3.25	1	135.75
Sum	400	51	82.5	110	224	10	0	280	40	0	15	240	60	0	0.5	30	40.6	5.5	1589.125

Weighted Average 11.70626

- Sum = Year x Avg.
 Weighted average = Total of sum / Total of year

Example Data Analysis of Overall Problem Ranking

	B.S.			S.S.			I.A.	
Symptom	Score	Ranking	Symptom	Score	Ranking	Symptom	Score	Ranking
а	0.023	3	а	0.011	1	а	0.024	2
b	0.051	6	b	0.111	10	a a	0.111	11
С	0.062	7	С	0.037	3	b	0.028	3
d	0.010	1	d	0.068	6	d	0.013	1
е	0.025	4	е	0.044	4	е	0.052	6
f	0.145	11	f	0.143	1 2	f	0.110	1 0
g	0.174	1 2	g	0.214	16	g	0.081	9
h	0.174	1 2	h	0.088	9	h	0.059	8
i	0.174	1 2	i	0.158	13	i	0.174	1 2
j	0.013	2	j	0.026	2	j	0.036	4
k	0.039	5	k	0.175	15	k	0.052	7
ı	0.083	9		0.214	16		0.174	1 2
r	0.112	1 0	m	0.133	1 1	r	0.051	5
W	0.071	8	S	0.167	1 4			
Х	0.200	15	t	0.063	5]		
		-	у	0.071	7]		
			Z	0.074	8			

	XJS			LDI	
Symptom	Score	Ranking	Symptom	Score	Ranking
а	0.038	4	а	0.010	1
a b	10.000	13	a g	0.182	1 4
аc	0.045	5	a h	0.036	4
q	0.036	2	ai	0.200	1 5
a d	0.200	11	aj	0.286	1 8
a e	0.286	1 2	a k	0.286	1 8
a f	0.071	8	al	0.286	18
b	0.036	3	b	0.037	5
С	0.048	6	d	0.123	11
d	10.000	13	е	0.060	6
е	0.182	1 0	f	0.083	8
f	10.000	13	g	0.143	1 3
g	10.000	13	h	0.214	17
h	10.000	13	i	0.100	1 0
i	10.000	13	j	0.069	7
j	0.050	7	k	0.086	9
k	10.000	13		0.128	12
	10.000	13	р	0.025	2
n	0.028	1	S	0.200	15
0	0.105	9	٧	0.033	3
u	10.000	13			

1. Each alphabet represents a symptom of the joint problem listed in the questionnaire.

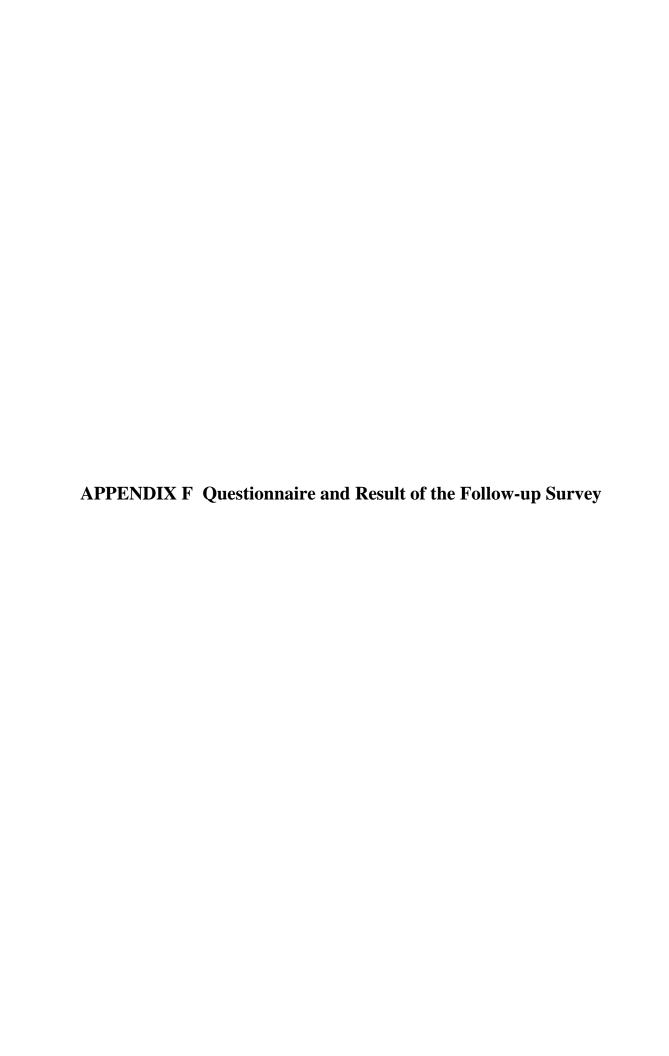
Example Data Analysis of Overall Problem Ranking (Cont.)

Symptom	B.S.	S.S.	I.A.	XJS	LDI	Total	Ranking
a	3	1	2	4	1	11	1
j	2	2	4	7	7	22	2
b	6	10	3	3	5	27	3
е	4	4	6	10	6	30	4
d	1	6	1	13	11	32	5
k	5	15	7	13	9	49	6
С	7	3	14	6	21	51	7
f	11	12	10	13	8	54	8
h	12	9	8	13	17	59	9
i	12	13	12	13	10	60	10
	9	16	12	13	12	62	11
g	12	16	9	13	13	63	12
n	16	18	14	1	21	70	13
q	16	18	14	2	21	71	14
р	16	18	14	22	2	72	15
V	16	18	14	22	3	73	16
ac	16	18	14	5	21	74	17
ah	16	18	14	22	4	74	17
r	10	18	5	22	21	76	19
af	16	18	14	8	21	77	20
0	16	18	14	9	21	78	21
t	16	5	14	22	21	78	21
ad	16	18	14	11	21	80	23
У	16	7	14	22	21	80	23
ae	16	18	14	12	21	81	25
S	16	14	14	22	15	81	25
Z	16	8	14	22	21	81	25
ab	16	18	14	13	21	82	28
u	16	18	14	13	21	82	28
W	8	18	14	22	21	83	30
ag	16	18	14	22	14	84	31
m	16	11	14	22	21	84	31
ai	16	18	14	22	15	85	33
aa	16	18	11	22	21	88	34
aj	16	18	14	22	18	88	34
ak	16	18	14	22	18	88	34
al	16	18	14	22	18	88	34
Х	15	18	14	22	21	90	38

Example Data Analysis of Follow-up Survey (Difficulty of Maintenance)

	1	2	3	4	5	6	7	Total	Weighted Total	Ranking
District	Vincennes	Crawfordsville	La Porte	Greenfield	Central Office	Seymour	Fort Wayne			
Year of Exp.	6	2	20	30	20	17	28	123		
Weight	0.05	0.02	0.16	0.24	0.16	0.14	0.23	1.00		
m	6	1	1	2	9	4	7	30	4.57	1
d	2	3	9	1	2	1	11	29	4.82	2
а	1	5	13	6	1	5	4	35	5.47	3
i	8	8	7	9	6	3	2	43	5.70	4
h	13	9	4	8	7	2	5	48	5.93	5
b	3	4	12	10	3	6	3	41	6.60	6
n	10	7	2	7	8	7	8	49	6.72	7
е	5	17	14	12	15	9	1	73	9.63	8
k	14	11	6	3	13	14	14	75	9.80	9
р	16	12	16	5	10	11	9	79	9.99	10
g	7	10	10	15	4	10	10	66	10.10	11
j	9	15	5	14	14	16	6	79	10.76	12
0	11	6	3	17	12	8	15	72	11.74	13
С	4	2	8	16	5	15	17	67	12.19	14
	15	14	15	4	16	13	16	93	12.41	15
q	17	13	17	11	11	12	13	94	12.89	16
f	12	16	11	13	17	17	12	98	13.65	17

^{1.} Each alphabet represents a symptom of the joint problem listed in the questionnaire.



Questionnaire for Ranking of Joint Problems

1.	How many years have you worked as an inspector?years
2.	How many years have you worked as an inspector for INDOT? years
3.	What kind of position do you have?
	a. Bridge Engineerb. Inspectorc. Assistant Inspectord. Others (specify)
4.	Which district are you in?
	a. Crawfordsville
	b. Fort Wayne
	c. Greenfield
	d. La Porte
	e. Seymour

The following pages list possible problems for the B.S. joint, S.S. joint, I.A. joint, Poured Dow silicone (XJS) joint, and Polymer Modified Asphalt joint. There are 17 items in total and please rank these problems using the number 1 to 17 according to its severity. 1 represents the most severe problem, 2 is the next, ..., and 17 represents the least severe problem.

f. Vincennes

Riding Quality

*	Which	problem contributes most to the poor riding quality of joints?
	a)	Loose, torn, split, cracked, damaged, hardened seals, or holes in seals
	b)	Damage of epoxy fillers or adhesive lubricants causing separation of the joint material from the joint face
	c)	Accumulation of debris and incompressible materials in the seals
	d)	Cracked and spalled concrete, and rusted or exposed reinforcement steel or structural steel in the deck joints substrate
	e)	Evidence of water leakage on the underside of the deck or at the curbline
	f)	Evidence of noise during the passage of vehicles over the joint
	g)	Restriction on freedom of joint movement causing problems such as transverse movements of the deck
	h)	Evidence of rotation, tilting, or settlement of joints
	i)	Incorrect joint opening and alignment
	j)	Deterioration along bearing areas on the pier caps and on the columns
	k)	Poor ridebility
	1)	Inadequate skid resistance
	m)	Loose, rusted, cracked, missing, or damaged steel plates, shapes, anchorage bolts, nuts, holddown bars, and other metal components
	n)	Loose, torn, split, cracked, damaged, or hardened nosing materials
	o)	Backer rods fall off
	p)	Tracking and flowing of polymer during hot weather
	 q)	Traffic comes into contact with silicone
	4 <i>)</i>	Times to mo to the tribe to the time of time of time of the time of ti

Water Leakage

*	Which	problem contributes most to the water leakage of joints?
	a)	Loose, torn, split, cracked, damaged, hardened seals, or holes in seals
	b)	Damage of epoxy fillers or adhesive lubricants causing separation of the joint material from the joint face
	c)	Accumulation of debris and incompressible materials in the seals
	d)	Cracked and spalled concrete, and rusted or exposed reinforcement steel or structural steel in the deck joints substrate
	e)	Evidence of water leakage on the underside of the deck or at the curbline
	<u>f</u>)	Evidence of noise during the passage of vehicles over the joint
	g)	Restriction on freedom of joint movement causing problems such as transverse movements of the deck
	h)	Evidence of rotation, tilting, or settlement of joints
	i)	Incorrect joint opening and alignment
	j)	Deterioration along bearing areas on the pier caps and on the columns
	<u>k</u>)	Poor ridebility
	1)	Inadequate skid resistance
	m)	Loose, rusted, cracked, missing, or damaged steel plates, shapes, anchorage bolts, nuts, holddown bars, and other metal components
	n)	Loose, torn, split, cracked, damaged, or hardened nosing materials
	o)	Backer rods fall off
	p)	Tracking and flowing of polymer during hot weather
		Traffic comes into contact with silicone
	q)	Traine comes into contact with smoone

Noise

*	Which	problem contributes most to the noise of joints?
	a)	Loose, torn, split, cracked, damaged, hardened seals, or holes in seals
	b)	Damage of epoxy fillers or adhesive lubricants causing separation of the joint material from the joint face
	c)	Accumulation of debris and incompressible materials in the seals
	d)	Cracked and spalled concrete, and rusted or exposed reinforcement steel or structural steel in the deck joints substrate
	e)	Evidence of water leakage on the underside of the deck or at the curbline
	f)	Evidence of noise during the passage of vehicles over the joint
	g)	Restriction on freedom of joint movement causing problems such as transverse movements of the deck
	h)	Evidence of rotation, tilting, or settlement of joints
	i)	Incorrect joint opening and alignment
	j)	Deterioration along bearing areas on the pier caps and on the columns
	<u>k</u>)	Poor ridebility
	l)	Inadequate skid resistance
	m)	Loose, rusted, cracked, missing, or damaged steel plates, shapes, anchorage bolts, nuts, holddown bars, and other metal components
	n)	Loose, torn, split, cracked, damaged, or hardened nosing materials
	o)	Backer rods fall off
	p)	Tracking and flowing of polymer during hot weather
	q)	Traffic comes into contact with silicone

Difficulty of Maintenance

*	Which	problem makes the joint most difficult to maintain?
	a)	Loose, torn, split, cracked, damaged, hardened seals, or holes in seals
	b)	Damage of epoxy fillers or adhesive lubricants causing separation of the joint material from the joint face
	c)	Accumulation of debris and incompressible materials in the seals
	d)	Cracked and spalled concrete, and rusted or exposed reinforcement steel or structural steel in the deck joints substrate
	e)	Evidence of water leakage on the underside of the deck or at the curbline
	f)	Evidence of noise during the passage of vehicles over the joint
	g)	Restriction on freedom of joint movement causing problems such as transverse movements of the deck
	h)	Evidence of rotation, tilting, or settlement of joints
	i)	Incorrect joint opening and alignment
	j)	Deterioration along bearing areas on the pier caps and on the columns
	k)	Poor ridebility
	1)	Inadequate skid resistance
	m)	Loose, rusted, cracked, missing, or damaged steel plates, shapes, anchorage bolts, nuts, holddown bars, and other metal components
	n)	Loose, torn, split, cracked, damaged, or hardened nosing materials
	o)	Backer rods fall off
	p)	Tracking and flowing of polymer during hot weather
	q)	Traffic comes into contact with silicone

Riding Quality

Ranking	Item	Symptom
1	d	Cracked and spalled concrete, and rusted or exposed reinforcement steel or structural steel in the deck joints substrate
2	m	Loose, rusted, cracked, missing, or damaged steel plates, shapes, anchorage, bolts, nuts, holddown bars, and other metal components
3	h	Evidence of rotation, tilting, or settlement of joints
4	i	Incorrect joint opening and alignment
5	n	Loose, torn, split, cracked, damaged, or hardened nosing materials
6	р	Tracking and flowing of polymer during hot weather
7	j	Deterioration along bearing areas on the pier caps and on the columns
8	С	Accumulation of debris and incompressible materials in the seals
9	b	Damage of epoxy fillers or adhesive lubricants causing separation of the joint material from the joint face
10	а	Loose, torn, split, cracked, damaged, hardened seals, or holes in seals
11	g	Restriction on freedom of joint movement causing problems such as transverse movements of the deck
12	f	Evidence or noise during the passage of vehicles over the joint
13	q	Traffic comes into contact with silicone
14	0	Backer rods fall off
15	е	Evidence of water leakage on the underside of the deck or at the curbline
16	-	Inadequate skid resistance

Water Leakage

Ranking	Item	Symptom
1	а	Loose, torn, split, cracked, damaged, hardened seals, or holes in seals
2	b	Damage of epoxy fillers or adhesive lubricants causing separation of the joint material from the joint face
3	d	Cracked and spalled concrete, and rusted or exposed reinforcement steel or structural steel in the deck joints substrate
4	n	Loose, torn, split, cracked, damaged, or hardened nosing materials
5	С	Accumulation of debris and incompressible materials in the seals
6	m	Loose, rusted, cracked, missing, or damaged steel plates, shapes, anchorage, bolts, nuts, holddown bars, and other metal components
7	i	Incorrect joint opening and alignment
8	q	Traffic comes into contact with silicone
9	h	Evidence of rotation, tilting, or settlement of joints
10	р	Tracking and flowing of polymer during hot weather
11	g	Restriction on freedom of joint movement causing problems such as transverse movements of the deck
12	j	Deterioration along bearing areas on the pier caps and on the columns
13	0	Backer rods fall off
14	f	Evidence or noise during the passage of vehicles over the joint
15	k	Poor ridebility
16	ı	Inadequate skid resistance

Noise

Ranking	Item	Symptom
1	m	Loose, rusted, cracked, missing, or damaged steel plates, shapes, anchorage, bolts, nuts, holddown bars, and other metal components
2	d	Cracked and spalled concrete, and rusted or exposed reinforcement steel or structural steel in the deck joints substrate
3	i	Incorrect joint opening and alignment
4	h	Evidence of rotation, tilting, or settlement of joints
5	k	Poor ridebility
6	n	Loose, torn, split, cracked, damaged, or hardened nosing materials
7	р	Tracking and flowing of polymer during hot weather
8	С	Accumulation of debris and incompressible materials in the seals
9	а	Loose, torn, split, cracked, damaged, hardened seals, or holes in seals
10	b	Damage of epoxy fillers or adhesive lubricants causing separation of the joint material from the joint face
11	g	Restriction on freedom of joint movement causing problems such as transverse movements of the deck
12	j	Deterioration along bearing areas on the pier caps and on the columns
13	0	Backer rods fall off
14	q	Traffic comes into contact with silicone
15	е	Evidence of water leakage on the underside of the deck or at the curbline
16	I	Inadequate skid resistance

Difficulty of Maintenance

Ranking	Item	Symptom
1	m	Loose, rusted, cracked, missing, or damaged steel plates, shapes, anchorage, bolts, nuts, holddown bars, and other metal components
2	d	Cracked and spalled concrete, and rusted or exposed reinforcement steel or structural steel in the deck joints substrate
3	а	Loose, torn, split, cracked, damaged, hardened seals, or holes in seals
4	i	Incorrect joint opening and alignment
5	h	Evidence of rotation, tilting, or settlement of joints
6	b	Damage of epoxy fillers or adhesive lubricants causing separation of the joint material from the joint face
7	n	Loose, torn, split, cracked, damaged, or hardened nosing materials
8	е	Evidence of water leakage on the underside of the deck or at the curbline
9	k	Poor ridebility
10	р	Tracking and flowing of polymer during hot weather
11	g	Restriction on freedom of joint movement causing problems such as transverse movements of the deck
12	j	Deterioration along bearing areas on the pier caps and on the columns
13	0	Backer rods fall off
14	С	Accumulation of debris and incompressible materials in the seals
15	I	Inadequate skid resistance
16	q	Traffic comes into contact with silicone
17	f	Evidence or noise during the passage of vehicles over the joint

Ranking of Problem (Follow-up Survey)

B.S.

Item	Symptom	Riding Quality	Water Leakage	Noise	Maintenance
	Cracked and spalled concrete, and rusted or exposed reinforcement steel or structural steel in the deck joints substrate	3	4	2	1
II I	Deterioration along bearing areas on the pier caps and on the columns	10	12	14	13
а	Loose, torn, split, cracked, damaged, hardened seals	12	2	9	3
Total		25	18	25	17

S.S.

Item	Symptom	Riding Quality	Water Leakage	Noise	Maintenance
ı a	Loose, torn, split, cracked, damaged, hardened seals, or holes in seals	12	2	9	3
II I	Deterioration along bearing areas on the pier caps and on the columns	10	12	14	13
С	Accumulation of debris and incompressible materials in the seals	11	6	10	9
Total		33	20	33	25

I.A.

Item	Symptom	Riding Quality	Water Leakage	Noise	Maintenance
	Cracked and spalled concrete, and rusted or exposed reinforcement steel or structural steel in the deck joints substrate	3	4	2	1
а	Loose, torn, split, cracked, damaged, hardened seals, or holes in seals	12	2	9	3
ı n	Damage of epoxy fillers or adhesive lubricants causing separation of the joint material from the joint face	8	3	12	8
Total		23	9	23	12

XJS

Item	Symptom	Riding Quality	Water Leakage	Noise	Maintenance
n	Loose, torn, split, cracked, damaged, hardened nosing materials	5	8	7	4
q	Traffic comes into contact with silicone	15	10	16	16
	Damage of epoxy fillers or adhesive lubricants causing separation of the joint material from the joint face	8	3	12	8
Total		28	21	35	28

LDI

Item	Symptom	Riding Quality	Water Leakage	Noise	Maintenance
	Loose, torn, split, cracked, damaged, hardened seals, or holes in seals (polymer material)	12	2	9	3
р	Tracking and flowing of polymer during hot weather	7	13	8	10
m	Loose, rusted, cracked, missing, or damaged steel plates	2	5	3	2
Total		21	20	20	15

Performance of Joints based on Each Category

Ranking	Riding Quality	Water Leakage	Noise	Maintenance
Good	XJS	S.S.	XJS	XJS & S.S.
	S.S.	LDI	S.S.	B.S.
	I.A.	B.S.	B.S.	LDI
₩	B.S. & LDI	XJS	I.A.	I.A.
Worse		I.A.	LDI	

Overall Ranking of Joint Problems (Five-State Questionnaire)

Problem	Ranking	Symptom
1.1	1	Loose seal
1.2	2	Torn seal
1.5	3	Hardened seal
1.4	4	Cracked seal
1.3	5	Split seal
3	6	Accumulation of debris and imcompressible materials in the seals
5.2	7	Spalled concrete
2	8	Damage of adhesive lubricants causing separation of the joint material from the joint face
1.6	9	Holes in seal
5.1	10	Cracked concrete
9.1	11	Evidence of water leakage on the underside of the deck
4.2	12	Anchorage of the joint is damaged
9.3	13	Evidence of water leakage at the bent cap
8.1	14	Deterioration of bearings
7.2	15	Deterioration along beam ends

Overall Ranking of Joint Problems (Follow-up Survey)

Problem	Ranking	Symptom
d	1	Cracked and spalled concrete, and rusted or exposed reinforcement steel or structural steel in the deck joints substrate
m	2	Loose, rusted, cracked, missing, or damaged steel plates, shapes, anchorage, bolts, nuts, holddown bars, and other metal components
h	3	Evidence of rotation, tilting, or settlement of joints
n	4	Loose, torn, split, cracked, damaged, or hardened nosing materials
а	5	Loose, torn, split, cracked, damaged, hardened seals, or holes in seals
i	6	Incorrect joint opening and alignment
k	6	Poor ridebility
b	8	Damage of epoxy fillers or adhesive lubricants causing separation of the joint material from the joint face
С	9	Accumulation of debris and incompressible materials in the seals
р	10	Tracking and flowing of polymer during hot weather
g	11	Restriction on freedom of joint movement causing problems such as transverse movements of the deck
е	12	Evidence of water leakage on the underside of the deck or at the curbline
f	12	Evidence or noise during the passage of vehicles over the joint
j	14	Deterioration along bearing areas on the pier caps and on the columns
0	15	Backer rods fall off
q	16	Traffic comes into contact with silicone
I	17	Inadequate skid resistance



PICTURES TAKEN IN SUMMER 1998 AND APRING 1999 FOR THE FOLLOWING JOINTS:

JOINT TYPE	LOCATION	BRIDGE CODE	PAGE
B.S.	I-465 over Fall Creek Road	I-465-123-4267B	G2
FLEXCON 2000 (1)	I-65 and Greenwood Road	I-65-100-55-59-B	G3
FLEXCON 2000 (2)	I-70 adjacent to Harding Street and Conrail	I-70-76-2385A	G4
I.A.	South Port Road over Little Buck Creek	I-65-104-55-64- DRA	G5
LDI		I-70-76-5394B	G6
MODULAR	I-65 over White River	I-65-118-4915C	G7
PAVETECH (1)	I-65 over Dr. Martin Luther King Drive	I-65-116-4913B	G8
PAVETECH (2)	I-65 at Clinton Street	I-65-117-4914C	G9
SLIDING PLATE AND TOOTH FINGER	I-70 Eastbound over Rural Street	I-70-19-2432B	G10
S.S. (1)	38 Street Eastbound Lane over I-65	I-65-118-4636B	G11
S.S. (2)	I-74		G12
XJS (1)	I-74 at east side of Indianapolis	I-74-94-4211C	G13
XJS (2)	I-59 near Carbon		G14

B.S. JOINT







FLEXCON 2000 (1)









FLEXCON 2000 (2)







I.A. JOINT







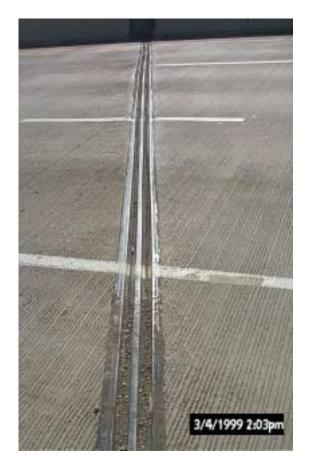
LDI JOINT







MODULAR JOINT





PAVETECH JOINT (1)









PAVETECH JOINT (2)







SLIDING PLATE AND TOOTH FINGER JOINT









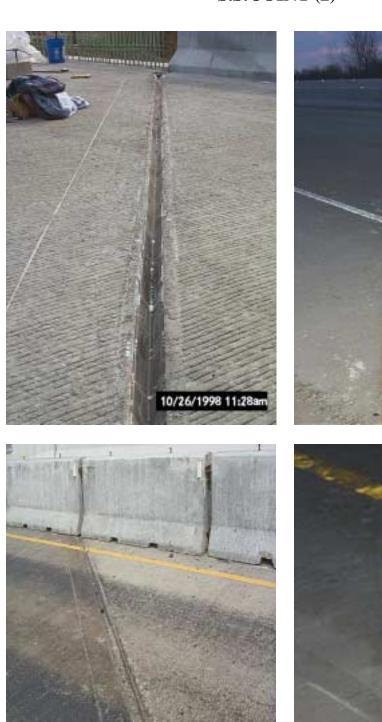
S.S. JOINT (1)







S.S. JOINT (2)





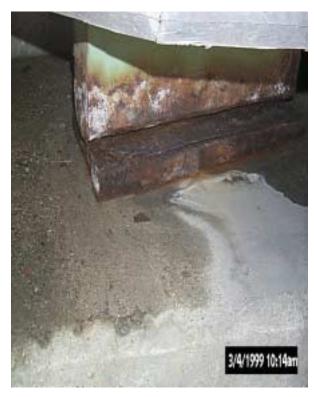


XJS JOINT (1)







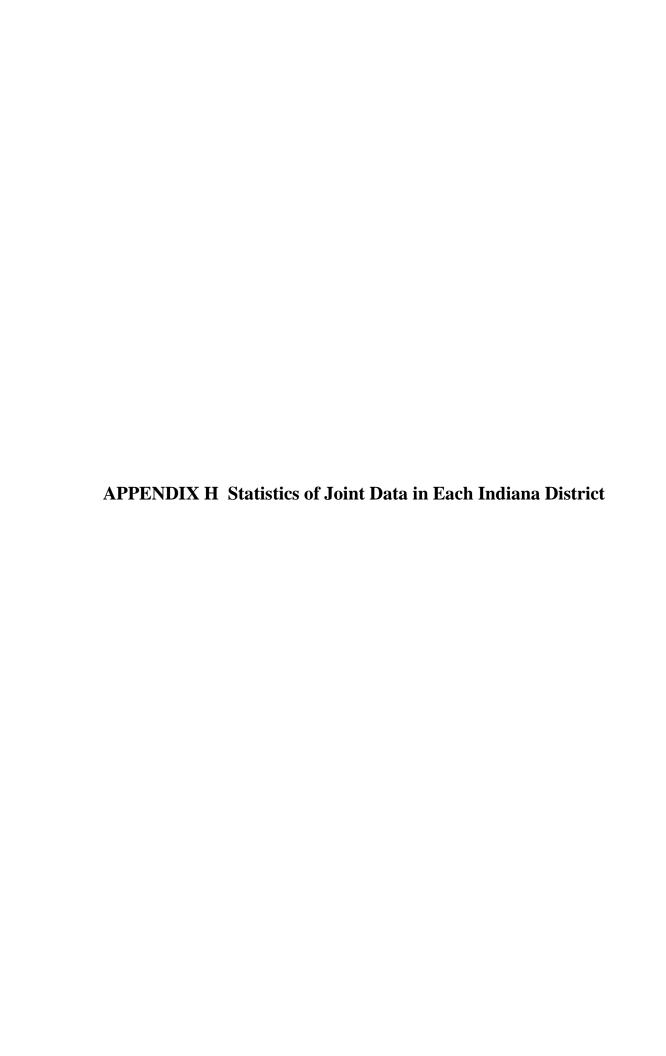


XJS JOINT (2)









Crawfordsville District (District Code: 1)

Joint Type	Code	Condition	Quantity	Percentage
		Good	298	43.00%
B.S. Type	Α	Fair	317	45.74%
		Poor	78	11.26%
		Subtotal	693	
		Good	81	37.16%
S.S. Type	В	Fair	96	44.04%
		Poor	41	18.81%
		Subtotal	218	
		Good	2	22.22%
Tooth Type	С	Fair	6	66.67%
(Finger Joint)		Poor	1	11.11%
		Subtotal	9	
		Good	2	33.33%
General Tire Type	D	Fair	1	16.67%
(Trans flex Type)		Poor	3	50.00%
, , , ,		Subtotal	6	
		Good	0	0.00%
Feldspar Type	Е	Fair	1	100.00%
		Poor	0	0.00%
		Subtotal	1	
		Good	10	27.03%
Sliding Steel Plate	F	Fair	24	64.86%
Ü		Poor	3	8.11%
		Subtotal	37	
		Good	0	0.00%
Armor Type	G	Fair	0	0.00%
(Two steel angles)		Poor	3	100.00%
,		Subtotal	3	
		Good	285	91.64%
IA Type	Н	Fair	16	5.14%
		Poor	10	3.22%
		Subtotal	311	
		Good	16	48.48%
Modular Type	I	Fair	17	51.52%
		Poor	0	0.00%
		Subtotal	33	
		Good	2	15.38%
Open Joint	J	Fair	9	69.23%
		Poor	2	15.38%
		Subtotal	13	
		Good	21	51.22%
Poured Dow Corning Silicone	0	Fair	20	48.78%
Joint (wide width)		Poor	0	0.00%
		Subtotal	41	

Crawfordsville District (District Code: 1)

Joint Type	Code	Condition	Quantity	Percentage
		Good	2	50.00%
Poured Silicone Joint	Р	Fair	2	50.00%
(narrow width - in old IA joints)		Poor	0	0.00%
		Subtotal	4	
		Good	24	75.00%
Polymer Modified Asphalt	Q	Fair	5	15.63%
Expansion Joint		Poor	3	9.38%
		Subtotal	32	
		Total	1401	

Fort Wayne District (District Code: 2)

Joint Type	Code	Condition	Quantity	Percentage
		Good	201	32.47%
B.S. Type	Α	Fair	318	51.37%
		Poor	100	16.16%
		Subtotal	619	
		Good	91	60.26%
S.S. Type	В	Fair	50	33.11%
		Poor	10	6.62%
		Subtotal	151	
		Good	0	0.00%
Tooth Type	С	Fair	0	0.00%
(Finger Joint)		Poor	0	0.00%
, ,		Subtotal	0	
		Good	0	0.00%
General Tire Type	D	Fair	0	0.00%
(Trans flex Type)		Poor	0	0.00%
,		Subtotal	0	
		Good	0	0.00%
Feldspar Type	E	Fair	1	100.00%
		Poor	0	0.00%
		Subtotal	1	
		Good	3	100.00%
Sliding Steel Plate	F	Fair	0	0.00%
-		Poor	0	0.00%
		Subtotal	3	
		Good	0	0.00%
Armor Type	G	Fair	0	0.00%
(Two steel angles)		Poor	0	0.00%
		Subtotal	0	
		Good	298	76.21%
IA Type	Н	Fair	78	19.95%
		Poor	15	3.84%
		Subtotal	391	
		Good	1	20.00%
Modular Type	I	Fair	4	80.00%
		Poor	0	0.00%
		Subtotal	5	
		Good	0	0.00%
Open Joint	J	Fair	0	0.00%
		Poor	6	100.00%
		Subtotal	6	
		Good	10	100.00%
Poured Dow Corning Silicone	0	Fair	0	0.00%
Joint (wide width)		Poor	0	0.00%
		Subtotal	10	

Fort Wayne District (District Code: 2)

Joint Type	Code	Condition	Quantity	Percentage
		Good	8	80.00%
Poured Silicone Joint	Р	Fair	1	10.00%
(narrow width - in old IA joints)		Poor	1	10.00%
		Subtotal	10	
		Good	5	100.00%
Polymer Modified Asphalt	Q	Fair	0	0.00%
Expansion Joint		Poor	0	0.00%
		Subtotal	5	
		Total	1201	

Greenfield District (District Code: 3)

Joint Type	Code	Condition	Quantity	Percentage
		Good	17	1.77%
B.S. Type	Α	Fair	161	16.77%
		Poor	782	81.46%
		Subtotal	960	
		Good	164	72.89%
S.S. Type	В	Fair	20	8.89%
		Poor	41	18.22%
		Subtotal	225	
		Good	3	15.79%
Tooth Type	С	Fair	12	63.16%
(Finger Joint)		Poor	4	21.05%
		Subtotal	19	
		Good	0	0.00%
General Tire Type	D	Fair	0	0.00%
(Trans flex Type)		Poor	4	100.00%
		Subtotal	4	
		Good	0	0.00%
Feldspar Type	E	Fair	0	0.00%
. ,,		Poor	0	0.00%
		Subtotal	0	
		Good	16	72.73%
Sliding Steel Plate	F	Fair	5	22.73%
ğ		Poor	1	4.55%
		Subtotal	22	
		Good	0	0.00%
Armor Type	G	Fair	0	0.00%
(Two steel angles)		Poor	11	100.00%
,		Subtotal	11	
		Good	166	36.24%
IA Type	Н	Fair	169	36.90%
		Poor	123	26.86%
		Subtotal	458	
		Good	4	100.00%
Modular Type	ı	Fair	0	0.00%
		Poor	0	0.00%
		Subtotal	4	
		Good	3	18.75%
Open Joint	J	Fair	4	25.00%
	_	Poor	9	56.25%
		Subtotal	16	
		Good	13	81.25%
Poured Dow Corning Silicone	0	Fair	1	6.25%
Joint (wide width)		Poor	2	12.50%
John (Mac Mac)		Subtotal	16	12.5070
		Oublotal	10	l

Greenfield District (District Code: 3)

Joint Type	Code	Condition	Quantity	Percentage
		Good	29	61.70%
Poured Silicone Joint	Р	Fair	9	19.15%
(narrow width - in old IA joints)		Poor	9	19.15%
		Subtotal	47	
		Good	28	22.58%
Polymer Modified Asphalt	Q	Fair	42	33.87%
Expansion Joint		Poor	54	43.55%
		Subtotal	124	
		Total	1906	

La Porte District (District Code: 4)

Joint Type	Code	Condition	Quantity	Percentage
		Good	330	56.60%
B.S. Type	Α	Fair	165	28.30%
		Poor	88	15.09%
		Subtotal	583	
		Good	141	71.57%
S.S. Type	В	Fair	36	18.27%
		Poor	20	10.15%
		Subtotal	197	
		Good	3	60.00%
Tooth Type	С	Fair	0	0.00%
(Finger Joint)		Poor	2	40.00%
,		Subtotal	5	
		Good	6	31.58%
General Tire Type	D	Fair	7	36.84%
(Trans flex Type)		Poor	6	31.58%
,		Subtotal	19	
		Good	0	0.00%
Feldspar Type	E	Fair	0	0.00%
, ,,		Poor	0	0.00%
		Subtotal	0	
		Good	24	100.00%
Sliding Steel Plate	F	Fair	0	0.00%
3		Poor	0	0.00%
		Subtotal	24	
		Good	0	0.00%
Armor Type	G	Fair	17	94.44%
(Two steel angles)		Poor	1	5.56%
,		Subtotal	18	
		Good	274	87.82%
IA Type	Н	Fair	36	11.54%
· ·		Poor	2	0.64%
		Subtotal	312	
		Good	11	64.71%
Modular Type	I	Fair	6	35.29%
		Poor	0	0.00%
		Subtotal	17	
		Good	7	41.18%
Open Joint	J	Fair	8	47.06%
·		Poor	2	11.76%
		Subtotal	17	
		Good	21	63.64%
Poured Dow Corning Silicone	0	Fair	12	36.36%
Joint (wide width)	-	Poor	0	0.00%
' (,		Subtotal	33	

La Porte District (District Code: 4)

Joint Type	Code	Condition	Quantity	Percentage
		Good	26	68.42%
Poured Silicone Joint	Р	Fair	11	28.95%
(narrow width - in old IA joints)		Poor	1	2.63%
		Subtotal	38	
		Good	34	89.47%
Polymer Modified Asphalt	Q	Fair	4	10.53%
Expansion Joint		Poor	0	0.00%
		Subtotal	38	
		Total	1301	

Seymour District (District Code: 5)

Joint Type	Code	Condition	Quantity	Percentage
		Good	427	63.07%
B.S. Type	Α	Fair	198	29.25%
		Poor	52	7.68%
		Subtotal	677	
		Good	92	66.19%
S.S. Type	В	Fair	33	23.74%
		Poor	14	10.07%
		Subtotal	139	
		Good	3	9.38%
Tooth Type	С	Fair	29	90.63%
(Finger Joint)		Poor	0	0.00%
		Subtotal	32	
		Good	1	12.50%
General Tire Type	D	Fair	4	50.00%
(Trans flex Type)		Poor	3	37.50%
		Subtotal	8	
		Good	0	0.00%
Feldspar Type	E	Fair	1	100.00%
		Poor	0	0.00%
		Subtotal	1	
		Good	1	4.35%
Sliding Steel Plate	F	Fair	22	95.65%
		Poor	0	0.00%
		Subtotal	23	
		Good	0	0.00%
Armor Type	G	Fair	3	60.00%
(Two steel angles)		Poor	2	40.00%
,		Subtotal	5	
		Good	181	76.05%
IA Type	Н	Fair	16	6.72%
		Poor	41	17.23%
		Subtotal	238	
		Good	9	81.82%
Modular Type	I	Fair	1	9.09%
		Poor	1	9.09%
		Subtotal	11	
		Good	15	27.78%
Open Joint	J	Fair	38	70.37%
·		Poor	1	1.85%
		Subtotal	54	
		Good	10	100.00%
Poured Dow Corning Silicone	0	Fair	0	0.00%
Joint (wide width)		Poor	0	0.00%
, , , , ,		Subtotal	10	

Seymour District (District Code: 5)

Joint Type	Code	Condition	Quantity	Percentage
		Good	0	0.00%
Poured Silicone Joint	Р	Fair	0	0.00%
(narrow width - in old IA joints)		Poor	0	0.00%
		Subtotal	0	
		Good	42	100.00%
Polymer Modified Asphalt	Q	Fair	0	0.00%
Expansion Joint		Poor	0	0.00%
		Subtotal	42	
		Total	1240	

Vincennes District (District Code: 6)

Joint Type	Code	Condition	Quantity	Percentage
		Good	137	27.24%
B.S. Type	Α	Fair	273	54.27%
		Poor	93	18.49%
		Subtotal	503	
		Good	125	68.68%
S.S. Type	В	Fair	44	24.18%
		Poor	13	7.14%
		Subtotal	182	
		Good	2	15.38%
Tooth Type	С	Fair	6	46.15%
(Finger Joint)		Poor	5	38.46%
, -		Subtotal	13	
		Good	0	0.00%
General Tire Type	D	Fair	4	66.67%
(Trans flex Type)		Poor	2	33.33%
		Subtotal	6	
		Good	0	0.00%
Feldspar Type	Е	Fair	2	100.00%
. , ,		Poor	0	0.00%
		Subtotal	2	
		Good	1	16.67%
Sliding Steel Plate	F	Fair	5	83.33%
<u> </u>		Poor	0	0.00%
		Subtotal	6	
		Good	0	0.00%
Armor Type	G	Fair	0	0.00%
(Two steel angles)		Poor	17	100.00%
,		Subtotal	17	
		Good	231	73.80%
IA Type	Н	Fair	76	24.28%
		Poor	6	1.92%
		Subtotal	313	
		Good	15	71.43%
Modular Type	I	Fair	3	14.29%
		Poor	3	14.29%
		Subtotal	21	
		Good	0	0.00%
Open Joint	J	Fair	28	80.00%
		Poor	7	20.00%
		Subtotal	35	
		Good	18	58.06%
Poured Dow Corning Silicone	0	Fair	12	38.71%
Joint (wide width)		Poor	1	3.23%
·		Subtotal	31	

Vincennes District (District Code: 6)

Joint Type	Code	Condition	Quantity	Percentage
		Good	8	100.00%
Poured Silicone Joint	Р	Fair	0	0.00%
(narrow width - in old IA joints)		Poor	0	0.00%
		Subtotal	8	
		Good	35	66.04%
Polymer Modified Asphalt	Q	Fair	11	20.75%
Expansion Joint		Poor	7	13.21%
		Subtotal	53	
		Total	1190	

APPENDIX I

Computer SAS Code and Output of Regression Analysis

SAS Code (Use B.S. Joint (Type A) as an example)

var age adt dw brw sl lms sma scn ama acn sbr sim sbs ins;
title 'Joint A with all variables';
run;
proc score data=swa score=fact out=scores; (factor analysis)
run;
proc logistic data=scores; (logistic regression)
model cond= factor1 factor2 factor3 age
/selection = stepwise
slentry=0.1
slstay=0.1
details;
/*output out=pred p=phat lower=lcl upper=ucl;*/
run;

/*proc print data=pred;

run; */

SAS Output

Joint A with all variables

453 20:09 Tuesday, September 28, 1999

Means and Standard Deviations from 1274 observations

Mean Std Dev	ADT 14849. 3399 19724. 0413	AGE 11. 5816327 5. 58192644	DW 47. 9065934 18. 701397	BRW 43. 7174254 17. 9636159	SL 221. 320251 181. 966584
Mean Std Dev	LMS 68. 9348509 24. 6822317	SMA 4. 02904239 1. 21973992	SCN 2. 23233909 1. 25881889	AMA 0. 37912088 0. 96354796	CAN 0. 42935636 0. 87477618
Mean Std Dev	SBR 6. 89638932 0. 86764455	SIM 7. 09340659 0. 74990684	SBS 7. 40973312 0. 61540789	I NS 7. 45368917 0. 60747353	

Kaiser's Measure of Sampling Adequacy: Over-all MSA = 0.68891944

SMA	LMS	SL	BRW	DW	AGE	ADT
0. 731025	0. 695165	0. 690589	0. 578267	0. 584397	0. 840510	0. 916612
INS	SBS	SIM	SBR	CAN	AMA	SCN
0. 696977	0. 696926	0.829929	0. 813145	0. 613991	0. 632429	0. 654124

Prior Communality Estimates: ONE

Eigenvalues of the Correlation Matrix: Total = 14 Average = 1

	1	2	3	4	5
Ei genval ue	3. 3403	2. 6597	2. 3675	0. 9852	0. 9029
Di fference	0. 6806	0. 2922	1. 3823	0. 0823	0. 0846
Proporti on	0. 2386	0. 1900	0. 1691	0. 0704	0.0645
Cumul ati ve	0. 2386	0. 4286	0. 5977	0. 6681	0. 7326
	Joi n	t A with all	vari abl es		

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Initial Factor Method: Principal Components

	6	7	8	9	10
Ei genval ue	0. 8184	0. 7797	0. 6247	0. 4680	0. 3647
Di fference	0. 0387	0. 1550	0. 1567	0. 1032	0. 0350

Proportion	0. 0585	0. 0557	0. 0446	0. 0334	0. 0261
Cumulative	0. 7910	0. 8467	0. 8913	0. 9247	0. 9508
Ei genval ue Di fference Proporti on Cumul ati ve	11 0. 3298 0. 1183 0. 0236 0. 9743	12 0. 2115 0. 0745 0. 0151 0. 9895	13 0. 1370 0. 1263 0. 0098 0. 9992	14 0. 0107 0. 0008 1. 0000	

3 factors will be retained by the MINEIGEN criterion.

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Initial Factor Method: Principal Components

Scree Plot of Eigenvalues

```
3. 5 ^
                     1
  3.0 ^
                           2
   2. 5
                                  3
E
i
g 2.0
e
n
v
a
I
u
e 1.5
   1.0
                                               5
                                                     6
                                                                  8
  0.5 ^
                                                                        9
                                                                               0
                                                                                            2
```

I2

Number

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Initial Factor Method: Principal Components

Factor Pattern

FACTOR1 FACTOR2 FACTOR3

	IACIONI	IACIONZ	1 40 1010	
	Settlement T	raffic Loadi	ing Structur	e Design
ADT	-0. 23364	0.80439	0. 19771	ADT
AGE	-0. 39460	-0. 12404	-0. 18757	AGE
DW	0.00931	0.88434	0. 38131	DW
BRW	0. 03581	0.89491	0. 37440	BRW
SL	-0. 32583	-0. 27922	0.56094	SL
LMS	-0. 29728	-0. 19205	0.63716	LMS
SMA	0. 48948	0. 02074	0. 22146	SMA
SCN	-0. 13433	-0. 24543	0. 42754	SCN
AMA	-0. 42908	-0. 27850	0.68870	AMA
CAN	-0. 46627	-0. 30319	0.53205	CAN
SBR	0.73583	-0. 06501	0. 29247	SBR
SIM	0.70328	-0. 21381	0. 21736	SIM
SBS	0.79118	-0. 09688	0. 27852	SBS
INS	0.78290	-0. 10027	0. 29581	INS

Variance explained by each factor

FACTOR1 FACTOR2 FACTOR3 3. 340301 2. 659723 2. 367544

Final Communality Estimates: Total = 8.367568

ADT AGE DW BRW SL LMS SMA
0. 740728 0. 206275 0. 927535 0. 942318 0. 498779 0. 531224 0. 289068

SCN AMA CAN SBR SIM SBS INS
0. 261069 0. 735979 0. 592409 0. 631210 0. 587566 0. 712920 0. 710486

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Rotation Method: Varimax

Orthogonal Transformation Matrix

1 2 3 1 0. 91091 -0. 07936 -0. 40491 2 -0. 08005 0. 92869 -0. 36211 3 0. 40477 0. 36227 0. 83960

Rotated Factor Pattern

ADT -0. 19719 0. 83720 -0. 03068 ADT AGE -0. 42543 -0. 15183 0. 04721 AGE

DW	0. 09203	0. 95867	-0. 00385	DW
BRW	0. 11253	0. 96388	-0. 02421	BRW
SL	-0. 04740	-0. 03024	0.70400	SL
LMS	0.00248	0. 07606	0. 72487	LMS
SMA	0. 53385	0.06065	-0. 01977	SMA
SCN	0.07034	-0. 06238	0.50222	SCN
AMA	-0. 08979	0. 02490	0. 85282	AMA
CAN	-0. 18510	-0. 05182	0. 74529	CAN
SBR	0. 79386	-0. 01282	-0. 02884	SBR
SIM	0. 74572	-0. 17563	-0. 02485	SIM
SBS	0. 84118	-0. 05186	-0. 05143	SBS
INS	0. 84091	-0. 04809	-0. 03233	INS

Variance explained by each factor

FACTOR1 FACTOR2 FACTOR3 3. 176564 2. 625664 2. 565339

Final Communality Estimates: Total = 8.367568

ADT	AGE	DW	BRW	SL	LMS	SMA
0. 740728	0. 206275	0. 927535	0. 942318	0. 498779	0. 531224	0. 289068
SCN	AMA	CAN	SBR	SIM	SBS	INS
0. 261069	0. 735979	0.592409	0. 631210	0.587566	0.712920	0.710486

Scoring Coefficients Estimated by Regression

Squared Multiple Correlations of the Variables with each Factor

FACTOR1 FACTOR2 FACTOR3 1.000000 1.000000 1.000000 Joint A with all variables 459 20:09 Tuesday, September 28, 1999

Rotation Method: Varimax

Standardized Scoring Coefficients

	FACTOR1	FACTOR2	FACTOR3		
ADT	-0. 05412	0. 31667	-0. 01108	ADT	
AGE	-0. 13594	-0.06264	-0. 00180	AGE	
DW	0. 04111	0. 36691	0. 01370	DW	
BRW	0.04684	0. 36891	0.00659	BRW	
SL	0. 01545	-0.00392	0. 27644	SL	
LMS	0. 03364	0. 03750	0. 28814	LMS	
SMA	0. 17072	0. 02950	0. 01638	SMA	
SCN	0.04385	-0. 01709	0. 20131	SCN	
AMA	0.00912	0. 01833	0. 33416	AMA	
CAN	-0. 02707	-0. 01338	0. 28648	CAN	
SBR	0. 25262	0.00457	0. 02337	SBR	
SIM	0. 23538	-0. 05810	0. 02094	SIM	
SBS	0. 26629	-0. 01001	0. 01605	SBS	
INS	0. 26709	-0.00835	0. 02365	INS	
	Joint A wi	th all var	i abl es		
			00 00	- .	

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The LOGISTIC Procedure

Data Set: WORK.SCORES Response Variable: COND COND

Response Level s: 2

Number of Observations: 1274

Link Function: Logit

Response Profile

Ordered Val ue	COND2	Count
1	G	841
2	Υ	433

WARNING: 530 observation(s) were deleted due to missing values for the response or explanatory variables.

Stepwise Selection Procedure

Step 0. Intercept entered:

Analysis of Maximum Likelihood Estimates

	Parameter	Standard	Wal d	Pr >	Standardi zed	0dds	Vari abl e
Variable DF	Estimate	Error	Chi -Square	Chi -Square	Estimate	Ratio	Label
			•	•			
INTERCPT 1	0. 6639	0. 0591	125. 9678	0. 0001			Intercept

Residual Chi-Square = 379.2337 with 6 DF (p=0.0001)

Analysis of Variables Not in the Model

Vari abl e	Score	Pr >	Vari abl e
	Chi -Square	Chi -Square	Label
FACTOR1	297. 7141	0. 0001	AGE
FACTOR2	39. 0210	0. 0001	
FACTOR3	8. 4209	0. 0037	
AGE	118. 5574	0. 0001	

Step 1. Variable FACTOR1 entered:

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The LOGISTIC Procedure

Model Fitting Information and Testing Global Null Hypothesis BETA=0

Cri teri on	Intercept Only	Intercept and Covari ates	Chi-Square for Covariates
AI C	1635. 146	1234. 006	
SC	1640. 296	1244. 306	•
-2 LOG L	1633. 146	1230.006	403.140 with 1 DF (p=0.0001)
Score		•	297.714 with 1 DF (p=0.0001)

Analysis of Maximum Likelihood Estimates

	Parameter	Standard	Wald	Pr >	Standardi zed	0dds	Vari abl e
Variable DF	Estimate	Error	Chi -Square	Chi -Square	Estimate	Ratio	Label
INTERCPT 1	1. 1538	0. 0892	167. 1429	0. 0001			Intercept
FACTOR1 1	1. 8588	0. 1280	210. 7571	0.0001	1. 024819	6. 416	

Association of Predicted Probabilities and Observed Responses

Concordant = 83.2%	Somers'	D = 0.665
Di scordant = 16.7%	Gamma	= 0.666
Ti ed $= 0.2\%$	Tau-a	= 0. 299
(364153 pairs)	С	= 0.832

Residual Chi-Square = 87.6357 with 5 DF (p=0.0001)

Analysis of Variables Not in the Model

Vari abl e	Score	Pr >	Vari abl e
	Chi -Square	Chi-Square	Label
FACTOR2	45. 0365	0. 0001	AGE
FACTOR3	11. 8221	0. 0006	
AGE	11. 9715	0. 0005	

Step 2. Variable FACTOR2 entered:

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The LOGISTIC Procedure

Model Fitting Information and Testing Global Null Hypothesis BETA=0

Cri teri on	Intercept Only	Intercept and Covari ates	Chi-Square for Covariates
AIC SC -2 LOG L	1635. 146 1640. 296 1633. 146	1189. 409 1204. 859 1183. 409	449.737 with 2 DF (p=0.0001)
Score	•	•	336.735 with 2 DF (p=0.0001)

Analysis of Maximum Likelihood Estimates

Odds Variable
Ratio Label
. Intercept
6. 813
0. 611

Association of Predicted Probabilities and Observed Responses

Concordant	= 84.8%	Somers'	D = 0.698
Di scordant	= 15.0%	Gamma	= 0.699
Ti ed	= 0.2%	Tau-a	= 0.313
(364153 pai	rs)	С	= 0.849

Residual Chi-Square = 44.1219 with 4 DF (p=0.0001)

Analysis of Variables Not in the Model

Vari abl e	Score	Pr >	Vari abl e
	Chi-Square	Chi-Square	Label
FACTOR3	9. 7092	0. 0018	AGE
AGE	24. 9274	0. 0001	

Step 3. Variable AGE entered:

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The LOGISTIC Procedure

${\tt Model \ Fitting \ Information \ and \ Testing \ Global \ Null \ Hypothesis \ BETA=0}$

Cri teri on	Intercept Only	Intercept and Covari ates	Chi-Square for Covariates
AI C	1635. 146	1166. 252	
SC	1640. 296	1186. 851	
-2 LOG L	1633. 146	1158. 252	474.894 with 3 DF (p=0.0001)
Score			362.134 with 3 DF (p=0.0001)

Analysis of Maximum Likelihood Estimates

Variable DF	Parameter Estimate			Pr > Chi -Square	Standardi zed Esti mate	Odds Variable Ratio Label
I NTERCPT 1 FACTOR1 1 FACTOR2 1 AGE 1	1. 9820 1. 7396 -0. 5784 -0. 0701	0. 1346	167. 0665 51. 3845	0. 0001 0. 0001 0. 0001 0. 0001	0. 959071 -0. 318914 -0. 215838	3.120 0.651 0.805 AGE

Association of Predicted Probabilities and Observed Responses

Concordant =	= 85. 2%	Somers' D	0 = 0.706
Di scordant =	- 14.7%	Gamma	= 0.706
Ti ed =	- 0.1%	Tau-a	= 0.317
(364153 pair	rs)	С	= 0.853

Residual Chi-Square = 19.0387 with 3 DF (p=0.0003)

Analysis of Variables Not in the Model

Vari abl e	Score	Pr >	Vari abl e
	Chi-Square	Chi -Square	Label
FACTOR3	12. 3739	0. 3	

NOTE: No (additional) variables met the 0.1 significance level for entry into the model.

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The LOGISTIC Procedure

Summary of Stepwise Procedure

	Vari abl e		Number	Score	Wal d	Pr >	Vari abl e
Step	Entered	Removed	Ιn	Chi -Square	Chi-Square	Chi-Square	Label
1	FACTOR1		1	297. 7		0. 0001	
2	FACTOR2		2	45. 0365		0. 0001	
3	AGE		3	24. 9274	·	0. 0001	AGE