NCHRP SYNTHESIS 319

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COOPERATIVE
HIGHWAY
RESEARCH
PROGRAM

Bridge Deck Joint Performance

A Synthesis of Highway Practice

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SUBJECT AREAS

Bridges, Other Structures, Hydraulics, and Hydrology, Material and Construction, and Maintenance

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TRANSPORTATION RESEARCH BOARD

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Systematic, well-designed research provides the most effective approach to the solution of many problems facing highway administrators and engineers. Often, highway problems are of local interest and can best be studied by highway departments individually or in cooperation with their state universities and others. However, the accelerating growth of highway transportation develops increasingly complex problems of wide interest to highway authorities. These problems are best studied through a coordinated program of cooperative research.

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The needs for highway research are many, and the National Cooperative Highway Research Program can make significant contributions to the solution of highway transportation problems of mutual concern to many responsible groups. The program, however, is intended to complement rather than to substitute for or duplicate other highway research programs.

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The members of the technical committee selected to monitor this project and to review this report were chosen for recognized scholarly competence and with due consideration for the balance of disciplines appropriate to the project. The opinions and conclusions expressed or implied are those of the research agency that performed the research, and, while they have been accepted as appropriate by the technical committee, they are not necessarily those of the Transportation Research Board, the National Research Council, the American Association of State Highway and Transportation Officials, or the Federal Highway Administration of the U.S. Department of Transportation.

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FOREWORD

By Staff
Transportation Research Board

Highway administrators, engineers, and researchers often face problems for which information already exists, either in documented form or as undocumented experience and practice. This information may be fragmented, scattered, and unevaluated. As a consequence, full knowledge of what has been learned about a problem may not be brought to bear on its solution. Costly research findings may go unused, valuable experience may be overlooked, and due consideration may not be given to recommended practices for solving or alleviating the problem.

There is information on nearly every subject of concern to highway administrators and engineers. Much of it derives from research or from the work of practitioners faced with problems in their day-to-day work. To provide a systematic means for assembling and evaluating such useful information and to make it available to the entire highway community, the American Association of State Highway and Transportation Officials—through the mechanism of the National Cooperative Highway Research Program—authorized the Transportation Research Board to undertake a continuing study. This study, NCHRP Project 20-5, "Synthesis of Information Related to Highway Problems," searches out and synthesizes useful knowledge from all available sources and prepares concise, documented reports on specific topics. Reports from this endeavor constitute an NCHRP report series, *Synthesis of Highway Practice*.

The synthesis series reports on current knowledge and practice, in a compact format, without the detailed directions usually found in handbooks or design manuals. Each report in the series provides a compendium of the best knowledge available on those measures found to be the most successful in resolving specific problems.

PREFACE

This report of the Transportation Research Board presents the state of the practice about commonly used expansion joint systems in bridges. Specifically, it summarizes performance data for each system type and contains examples of selection criteria and design guidelines. The report will be of interest to bridge engineers and designers, and any agencies responsible for bridge operation and maintenance. Topics covered include a review of the current practice, expansion joint types and features, selection criteria and design guidelines, provisions to test joint seal watertightness, and lessons for maximizing the service life of joint systems.

Information in support of this study came from the responses to a survey questionnaire from 34 states and 10 Canadian provinces. Questions addressed design procedures, use and experience, construction practices, maintenance and rehabilitation, and problems. Supplemental information relating to bridge deck selection and design criteria was provided by several states. Portions of the joint system guidelines of these states, which are considered important for purposes of comparison, are contained in the report.

A panel of experts in the subject area guided the work of organizing and evaluating the collected data and reviewed the final synthesis report. A consultant was engaged to collect and synthesize the information and to write this report. Both the consultant and the members of the oversight panel are acknowledged on the title page. This synthesis is an immediately useful document that records the practices that were acceptable within the limitations of the knowledge available at the time of its preparation. As progress in research and practice continues, new knowledge will be added to that now at hand.

CONTENTS

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Valuable assistance in the preparation of this synthesis was provided by the Topic Panel, consisting of Martin P. Burke, Jr., Bridge Consultant, Burgess & Niple Limited; Theodore Hopwood, II, Transportation Research Engineer, Kentucky Transportation Center; Vince Kazakavich, Schenectady, New York; Chris Keegan, Operations Engineer, Washington State Department of Transportation; Josef Kratochvil, Bridge Design Unit Supervisor, New Mexico State Highway and Transportation Department; Frank N. Lisle, Engineer of Maintenance, Transportation Research Board; Myint Lwin, Structural Design Engineer, Federal Highway Administration Western Resource Center; Wallace T. McKeel, Jr., Research Structure and Bridge Engineer, Virginia Transportation Research Council; Ronaldo Nicholson, Project Manager, Woodrow Wilson Bridge, Virginia Department of Transportation; Guy S. Puccio, Vice President of Engineering, Kinedyne Corporation; and George P. Romack, Senior Bridge Engineer, Office of Asset Management, Federal Highway Administration.

This study was managed by Stephen F. Maher, P.E., and Jon Williams, Managers, Synthesis Studies, who worked with the consultant, the Topic Panel, and the Project 20-5 Committee in the development and review of the report. Assistance in project scope development was provided by Donna Vlasak, Senior Program Officer. Don Tippman was responsible for editing and production. Cheryl Keith assisted in meeting logistics and distribution of the questionnaire and draft reports.

Crawford F. Jencks, Manager, National Cooperative Highway Research Program, assisted the NCHRP 20-5 Committee and the Synthesis staff.

Information on current practice was provided by many highway and transportation agencies. Their cooperation and assistance are appreciated.

BRIDGE DECK JOINT PERFORMANCE

SUMMARY

This synthesis report provides state-of-the-practice findings obtained from transportation agencies about commonly used expansion joint systems. It summarizes performance data for each system type, as well as contains examples of selection criteria and design guidelines. The report includes lessons learned for maximizing the service life of the joint systems and methods to determine if they are watertight.

Bridge deck expansion joints facilitate longitudinal movement (translation) and small amounts of rotation, which occur predictably in every bridge. The major factors that influence the movement are deck length and changes in moisture and ambient temperature. Various types of open joint systems are used to protect the edges of the concrete deck and transition traffic smoothly across the opening. The open joint system types discussed in this report are the butt, sliding plate, and finger.

- Butt joints are openings through the deck that may include armor protection against damage to concrete edges exposed to traffic. Typically, they accommodate movement of less than 25 mm (1 in.).
- Sliding plate joints are used for movements between 25 and 75 mm (1 and 3 in.) and are similar to the armored joint except that a plate is attached to one side and extends across the opening.
- The finger joint accommodates movements greater than 75 mm (3 in.) with "finger-like" plates attached to both sides, which extend across the opening and slide together. Open joints may include a drainage trough to collect the deck runoff.

Closed joint systems also protect the bridge components below the joint from damage due to water, salt, and other roadway contaminants associated with deck runoff. Closed joint system types include field-molded, compression, strip, plug, inflatable, cushion, and modular.

- Field-molded sealers are used on openings of 25 mm (1 in.) or less. They include a thick, sticky, pourable waterproof material that molds to the opening and is supported by a premolded filler. Typically, they are limited to joints with a movement range of 5 mm (3/16 in.) or less.
- Compression seals rely on a continuous premolded open cell neoprene rubber or closed cell dense foam rectangular-shaped section compressed into the joint opening to accomplish its waterproofing function. Movements range from 5 mm to 60 mm (0.25 in. to 2.5 in.).
- Strip seals consist of a premolded gland of neoprene rigidly attached to a metal facing on both sides of the joint. The joint can accommodate movements up to 100 mm (4 in.).
- Plug seals contain polymer-modified asphalt concrete compacted in a blockout centered over the joint opening. They are used for less than 50 mm (2 in.) movement.
- Inflatable neoprene open cell seals are similar to the compression seal except that compressed air is used to hold the seal in place while it is bonding to the joint face.

- Cushion seals consist of a steel-reinforced neoprene pad recessed into the deck over the joint opening and rigidly attached on both sides. Cushion seals accommodate movement up to 100 mm (4 in.).
- Modular joints are for movements over 100 mm (4 in.). They consist of sealers, separator beams, and support bars fabricated to watertight and provide structural support across the opening.

States are developing performance standards for new closed joint systems, which involve testing for watertightness. Included is a description of the testing requirements provided by some states. The minimum objective is to ensure that when it is placed, the seal is watertight.

When practical, state transportation agencies are eliminating joints on new bridges. Many are also retrofitting existing decks and superstructures to reduce the number of joints. However, these efforts have not had a significant effect on the total joint inventory, and this will not change in the foreseeable future. Most bridges have deck joints, and most deck joints have problems.

As part of this study, a questionnaire was distributed to transportation departments in all states, Canadian provinces, and other selected agencies and experts worldwide. Thirty-four states and 10 Canadian provinces responded. Questions were organized into five topics related to deck joints: (1) design procedures, (2) use and experience, (3) construction practices, (4) maintenance and rehabilitation, and (5) problems. Responses indicated a wide range of performance results and preferences, although almost all prefer closed systems, with the most popular type being the strip seal. The service life for the different type systems varied from agency to agency. Major factors contributing to joint system performance included the level of maintenance and quality control during construction. According to the survey responses, no system is without problems. Nevertheless, most agencies noted that achieving optimum joint seal performance has high priority.

Some agencies responding to the survey provided supplemental information related to their bridge deck joint selection and design criteria. This report contains portions of the joint system guidelines of these states, which are considered important for the purposes of comparison. Contributors of this information include Arizona, Colorado, Florida, Kansas, Louisiana, New Mexico, New York State, North Carolina, Ohio, and Washington State.

Lessons learned from this research included several suggestions that bridge owners could implement to improve bridge deck joint performance and extend service life, including

- Implementing a proactive deck joint maintenance program;
- Using deck joint blockouts adjacent to openings when placing a joint system;
- Supporting each replacement joint system on sound existing concrete;
- Installing each seal to match ambient temperature;
- Ensuring that the joint opening size and shape is properly constructed;
- When placing the deck overlay, installing the joint system after the overlay is placed;
- Protecting against unusual joint movement that could damage the joint seal;
- Following the manufacturer's recommendations for selection and installation;
- Avoiding splices in premolded expansion material; and
- Protecting against snowplow damage.

CHAPTER ONE

INTRODUCTION

Concrete is a common bridge deck material. It provides an impact-resistant, rigid, and tough surface that distributes vehicular loads across the superstructure. It also covers and protects critical structural members against water, contaminants, and deicing salt. However, concrete is a brittle material, which will not stretch without cracking. It has low tensile strength. Tensile stress causes the concrete to crack. Reinforcement is added to the concrete to resist tensile stress and control cracking, because cracks provide a path for salt water to reach the reinforcing steel and cause rapid corrosion. The traditional method used to control concrete cracking is to shorten the length of the deck by dividing it into separate sections (spans), leaving an opening or joint between each section.

Damage related to deck joints on existing bridges in the United States costs millions of dollars each year. This includes damage both to the joint and to the portion of the bridge beneath the joint that is exposed to debris and contaminants. To reduce the damage below the deck, designers fill, or cover, the opening with a flexible watertight material. The joint seal design tends to be problematic for a variety of reasons, which will be discussed in the following chapter. Life-cycle costing shows that improved design, installation, and maintenance of deck joints could reduce transportation agency budgets significantly, particularly where deicing salt is used.

PROBLEM STATEMENT AND SYNTHESIS OBJECTIVES

The purpose of an NCHRP Synthesis of Highway Practice is to collect and report current practice related to a highway problem area identified and considered important. There is little dispute that the performance of bridge deck joints is such a problem. *NCHRP Synthesis Report 141: Bridge Deck Joints*, published in 1989, provides useful general information concerning this topic (*1*).

Most practitioners involved in the operation of existing bridges would probably agree that the performance of joint seals is the most serious issue related to deck joints. Bridge engineers continually experiment with products and practices intended to improve the performance of bridge deck expansion joints. Although not all attempts are successful, each can provide useful information. This synthesis contains information on the use and the performance of the more commonly used bridge deck joint materials and systems. The following items for new and retrofit construction (concrete and steel bridges) are addressed:

- Design considerations (type and length of structure, span, service level, geometrics, first cost, and failure criteria),
- Joint material considerations,
- Interaction with other bridge components (settlement of abutments, bridge bearings, and secondary systems),
- Construction methods and practices (constructibility issues, nighttime operations, quality assurance, and quality control),
- Performance in various climates,
- Amount and types of traffic (average daily traffic and average daily truck traffic),
- Effect of roadway maintenance (winter activities and roadway joint maintenance),
- Effectiveness of a preventive maintenance program for bridge joints,
- Inspection and timely repair (headers, seals, and anchorage), and
- Rehabilitation strategies (including joint elimination considerations) used by various bridge owners.

State-of-the-practice information on large joints (movement range 6 in. or greater, including modular), international practice, examples of effective agency standard design details and specifications, and a glossary of terms are also included.

JOINT CLASSIFICATIONS

The performance of all common deck joints can be evaluated in-service because most states currently have a considerable number of each type. Each was considered the best choice when that bridge was built or last remodeled. Preferences change as products evolve; as bridges are rehabilitated, joint systems are often replaced with newer products. However, although deck joint technology changes rapidly, only a limited number of joints can be replaced or upgraded.

The earlier designs provided little or no sealing to prevent the passage of deck drainage and debris. In the past 50 years, flexible materials have been used to close and seal the opening, although none of the designs have been totally successful in eliminating problems, which explains why new devices and materials continue to be developed.

The goal is to have a joint that is quiet, smooth riding, watertight, capable of accommodating movement, as durable as the adjacent deck, and as maintenance free as possible. All currently available joints require preventive maintenance to keep joints functioning and avoid costly structural damage.

Construction Joints

Construction joints, also known as cold joints, are used during concrete placement to separate stop–start locations. These joints are located on construction plans at the point of contra-flexure between positive and negative moment areas, and reinforcing steel continues through the construction joint the same as if it were not there. Construction joints are commonly used in the decks of continuous spans and when concrete placement must be interrupted for a substantial period of time. If constructed properly, they are difficult to detect visually, are of little consequence, and experience minimal leakage. A construction joint is shown in Figure 1. If the two concrete faces of the construction joint do not bond together properly, water will be able to penetrate, causing the same problems presented by a crack.

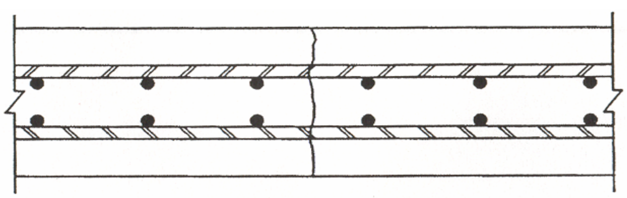


FIGURE 1 Construction joint.

Contraction Joints

Contraction joints are used to control shrinkage so that cracking occurs only at these joints. Some are detailed with a water stop. Such joints are typically found in sidewalks and retaining walls where leakage is undesirable. A contraction joint is shown in Figure 2. Contraction joints are generally not used in bridge decks. If they were used, it would be necessary to protect the reinforcement steel by sealing the top of the crack to prevent water and salt penetration.

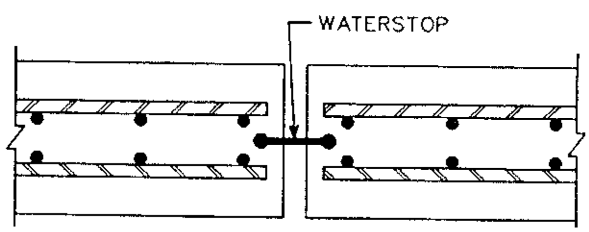
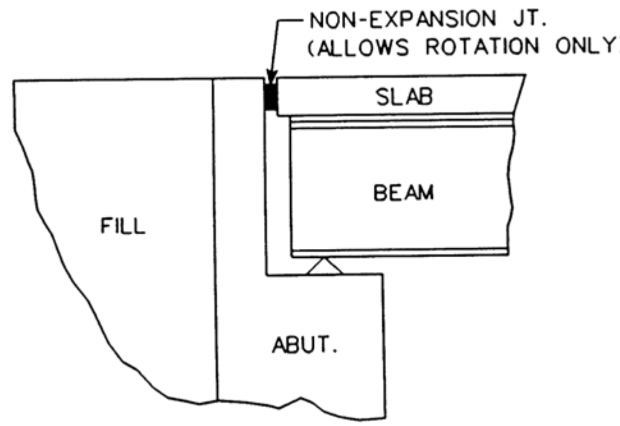


FIGURE 2 Contraction joint.

Joints Over Fixed Bearings

Joints over fixed bearings allow rotation of a beam end, but prohibit translation (longitudinal movement). The fixed bearing is attached to the beam end and anchored in the bridge seat. These joints are typically not as wide as expansion joints. A fixed joint is shown in Figure 3.

FIGURE 3 Fixed joint.



Joints Over Expansion Bearings

Joints over expansion bearings (expansion joints) accommodate several types of deck movement, including expansion. Like joints over fixed bearings, they accommodate rotational movement. Bridge decks also experience translation movement related to thermal changes. As the temperature rises, the deck expands in length, and as the temperature decreases, the deck contracts. Creep, shrinkage, and prestressing of concrete also cause permanent span length changes over time. The total movement is proportional to the span length. Movement is complicated on skewed bridges.

The bridge design engineer accounts for this movement in two ways:

1. By minimizing or eliminating joints and accommodating the stresses related to the movement in the design of the superstructure and substructure components and
2. By providing openings (expansion joints) in the deck, perpendicular to the direction of the significant movement, at each span end to accommodate longitudinal deck movement such as expansion, contraction, and rotation.

There are several types of expansion joints. Most are designed to provide a transition across the opening and prevent leakage through the joint, and they represent a variety of different technologies. This report focuses on current practice related to bridge deck expansion joints—how the current practice has evolved and how each type joint system is performing.

EXPANSION JOINT FUNCTIONS

The function of a bridge deck expansion joint is to accommodate motions that occur in the superstructure. These motions initiate from live loads, thermal changes, and the physical properties of the materials that make up the bridge. This longitudinal and transverse motion occurs as the result of thermal expansion and contraction. Concrete creep and shrinkage also contribute slightly to the movement. Live load bending causes deflection of the deck, which results in rotational movement. Substructure settlement may also cause a similar deck movement.

Traditionally, openings are provided between rigid sections of superstructure equal to or greater than the anticipated movement. These openings permit the deck to move or rotate freely within limitations to accommodate this movement. However, as a result, a discontinuity is created impairing the riding quality of the roadway in the surface of the deck. The joint opening can also act as a path through which damaging materials are deposited on supporting elements beneath the deck.

A variety of devices have been incorporated in the design of bridge deck expansion joints to protect the joint edges, to bridge the opening in the deck, and to seal the opening. There is an assortment of design details and material types, which change continually as deficiencies are identified.

Joint types and modifications frequently take years to evaluate in-service. When problems are identified, it is often difficult to distinguish between the possible causes. Typically, problems are blamed on flaws in the joint system; however, the same system can perform better for other bridge owners. Other variables, such as construction quality, maintenance neglect, environmental differences, and extraordinary traffic damage may account for this difference. Currently, there is little public-sector-sponsored laboratory research conducted to evaluate joint seal performance. Manufacturers of the products often generate the only information available.

Despite the problems and consequences, most existing bridges have expansion joints, and most agencies are concerned with keeping joints functioning properly and watertight. There are a variety of expansion joint devices and materials available to the bridge owner. Choices are made that have a significant impact on the service life of the bridge inventory. This report provides performance information related to the current alternatives. The types included are those commonly used by transportation agencies in North America. The focus is on state of the practice; there is no attempt to include systems that are unproven or systems that have failed to gain significant acceptance.

CHAPTER TWO

EXPANSION JOINT TYPES AND FEATURES

Expansion joints can be divided into two categories—open joints and closed joints. Closed joints are designed to be watertight, whereas open joints are not.

OPEN JOINTS

Common types of open joints are butt joints, either with or without armor facing (Figure 4); sliding plate joints (Figure 5); and finger joints (Figure 6). These were the first types of joints used on modern bridges. The butt joint is normally used for movement less than 25 mm (1 in.), the sliding plate bearing for movement from 25 to 75 mm (1 to 3 in.), and the finger joint (or tooth joint) for movements above 75 mm (3 in.). Open joints have lost favor with most bridge engineers, particularly in those geographical locations that require deicing salts, because they permit salt water and debris to pass through deck openings and damage critical support components.

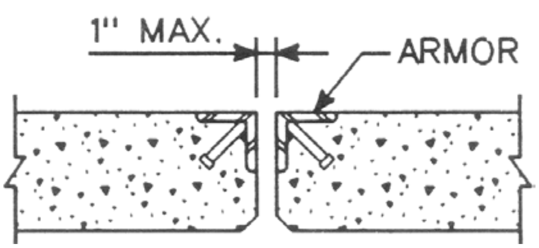


FIGURE 4 Butt joint.

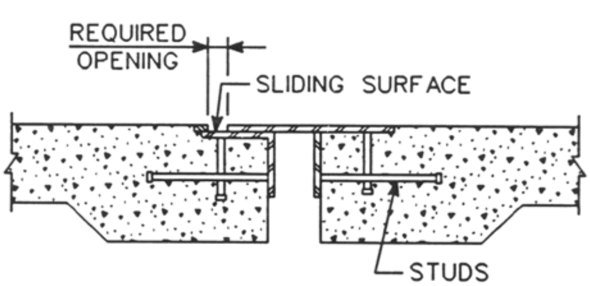


FIGURE 5 Sliding plate joint.

Drainage systems have been installed under open joints to collect and carry deck runoff away from a bridge. This prevents salt contamination runoff from damaging critical ructure and substructure components beneath the deck. The drainage system usually consists of a drainage trough (preferably noncorrosive) placed beneath the joint.

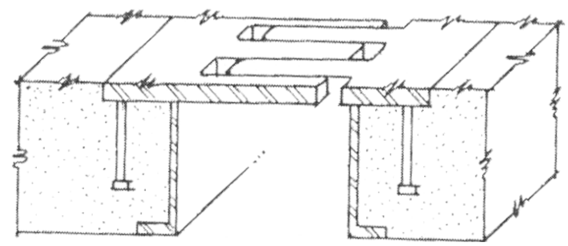


FIGURE 6 Finger joint.

The drainage troughs, however, have experienced problems. Most are poorly designed. They fill with debris, allowing runoff to overflow and spill on underlying bridge components. Cleaning and flushing are often difficult and rarely performed often enough to keep the trough open. Also, many of the older metal types have corroded, fallen apart, or been removed. Currently, many agencies use flexible troughs, which are made of noncorrosive materials such as fiberglass or neoprene. Typical details are shown in Figures 7–9. The troughs are less problematic if designed with the appropriate slope (minimum, 1%) so that debris is flushed away, if they are sufficiently accessible to be maintenance friendly, and if runoff from the trough does not spill out on the structure. Unfortunately, because of limited space, these features are difficult to achieve on most existing bridges.

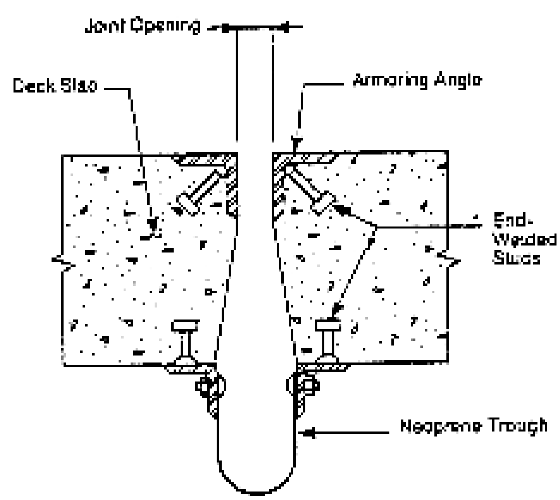


FIGURE 7 Butt joint with trough.

Butt Joint

Butt joints are commonly used where only rotation, with minor thermal movement, must be accommodated, because

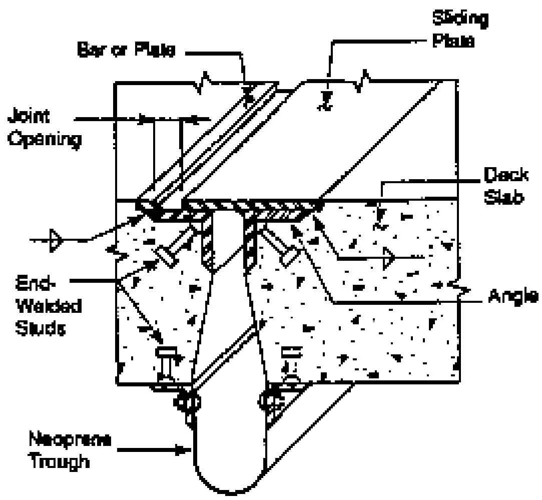


FIGURE 8 Sliding plate joint with trough.

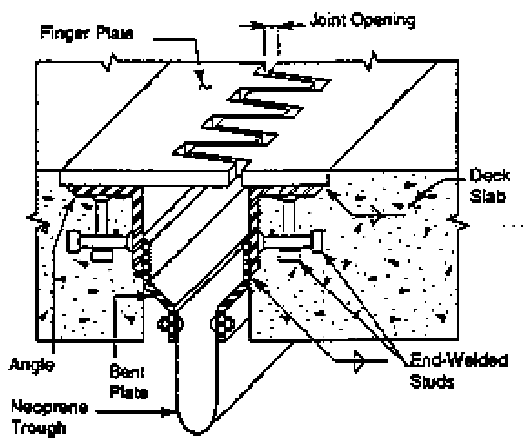


FIGURE 9 Finger joint with trough.

this joint provides no transition for traffic between adjacent edges of the deck. Armoring (metal facing of the top edge) is usually provided, although many joints are constructed without it. A typical detail is shown in Figure 4.

As with all open joints, the butt joint does not prevent drainage and debris passage through the opening. The armor is typically a metal angle embedded to protect the top edge of both sides of the joint and is anchored into the concrete with studs, bolts, or bars. It is difficult to both protect the metal facing from corrosion and to get the concrete properly consolidated under the angle. Over time, the angles may become dislodged because of inadequate support and/or fatigue of the anchor attachments. The loose metal thus becomes a traffic hazard.

Spalling or raveling of the top edge of the concrete deck often occurs on butt joints without armoring. This effect is shown in Figures 10–12. Once there is damage, deterioration will increase until repair or retrofit is implemented.

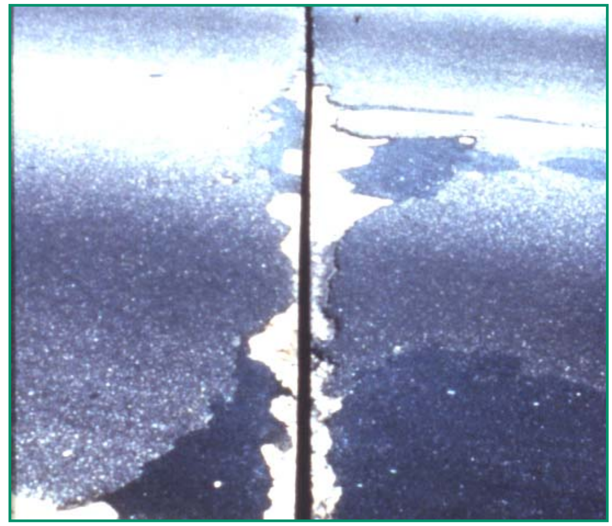


FIGURE 10 Damaged butt joints.

FIGURE 11 Butt joint with damaged edge.

FIGURE 12 Damaged joint armor.

Agencies routinely upgrade butt joints when decks are rehabilitated or replaced. The steel armor might be removed and replaced with elastomeric (polymer) concrete. The joint opening may be redesigned to hold a watertight sealer. Sealer options are discussed later in this chapter.

Sliding Plate Joint

Sliding plate joints are used for movements from 25 to 75 mm (1 to 3 in.) and were at one time the predominant type of bridge expansion joint used with steel-framed structures. This type of joint is considered an open joint by today's standards. It is not watertight, but it does prevent most debris from passing through the opening. It is similar to the armored joint except that a plate is attached to one side and extends across the opening. The unattached side of the plate rests in a slot on the other span. The assembly is anchored into the concrete with welded steel bolts, bars, or studs. A typical detail is shown in Figure 5.

It is common for plates to loosen over time and become noisy under traffic. Occasionally, they become completely detached, creating a safety hazard and source of potential vehicular damage. There are several reasons for these problems, which are often related to design and construction practices. For example, inadequate consolidation of the concrete causes loss of support and poor anchorage of the plates. Noncompressible debris accumulates in the slot at the end of the plate. Over time, the debris tends to pry up the unsupported edge of the sliding plate, making it more vulnerable to traffic impact. The anchors also corrode and are subject to fatigue from the impact of traffic. Snowplow blades can also damage the plates and anchors. At times the roadway surface around the plates deteriorates, and this deterioration increases the impact from traffic on the joint and dislodges the plates. These joints therefore are often noisy under traffic as the plates loosen. Sliding plate joints have been found particularly unsatisfactory on highways with a significant amount of truck traffic. In most places, other types of joints have replaced these joints.

Finger Joint

Accommodation for movements greater than 75 mm (3 in.) is provided by a finger (also called tooth) joint. A typical detail is shown in Figure 6. There are varying opinions regarding the use of this joint type. As with all other open joints, initial costs are considerably less than for a closed joint. This difference is much more significant with a finger joint than with a modular joint system, which is discussed later in this report. Also, modular joint systems have experienced significantly more durability problems. Consequently, many agencies have opted to specify finger joints on longer bridge spans with a drainage trough to collect the deck runoff and corrosion agents. A finger joint with drainage trough can be seen in Figure 13.

Finger joints tend to have fewer problems than many other joints. A few have anchorage problems or problems with the ends of the fingers bending upward, which results in increased noise, a rough riding surface, and occasionally broken fingers. The effects are shown in Figure 14. The most common problem is deterioration of the concrete around the joint, as shown in Figure 15. Because the joint is open, the only protection for the bridge elements below the joint is a properly maintained drainage trough.

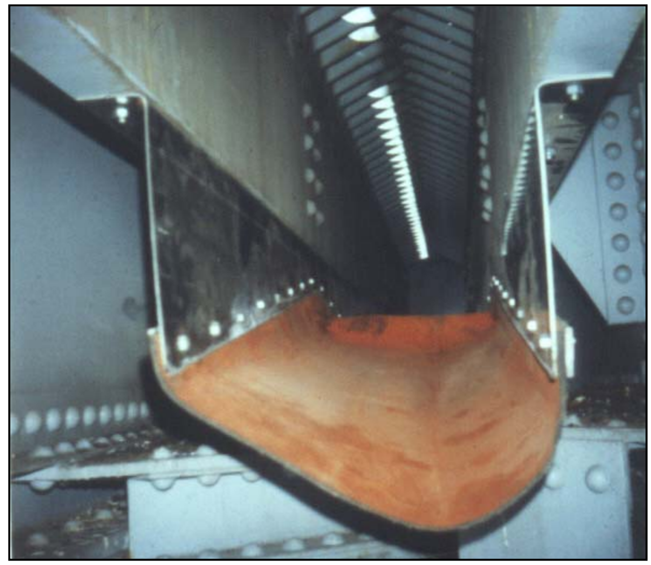


FIGURE 13 Finger joint with trough.

FIGURE 14 Damaged finger joint.

CLOSED JOINTS

Over the past five decades, the public's expectations about the quality of bare pavement have grown, which has resulted in the increased use of deicing salt. With the increasing use of salt, the popularity of open joints has decreased accordingly. Salt accelerates the corrosion and dramatically decreases the service life of both steel and reinforced concrete bridge members. Deicing chemicals, sand, and abrasives contribute to the problem by spilling through the joint

FIGURE 15 Damaged concrete around finger joint.

FIGURE 16 Debris on bridge cap.

FIGURE 17 Corroded steel diaphragms under joint.

and piling up on beam flanges, bearings, and bridge seats. This debris retains moisture and salt on the surface of bridge members and accelerates corrosion. Illustrations are shown in Figure 16 (debris on pier cap), Figure 17 (corroding steel diaphragms), Figure 18 (corroded steel beam end),

FIGURE 18 Corroded steel beam end.

FIGURE 19 Frozen bearing and damaged bridge seat under joint.

and Figure 19 (damaged seat from frozen bearing). Transportation agencies that use salt recognize the need to have watertight bridge deck joints. In some states, leaking joints are considered an environmental issue.

The challenge is to develop a durable, watertight joint that can withstand pounding traffic on a bridge deck. Manufacturers continually seek to develop cost-effective, low-maintenance, watertight joint systems that are as durable as bridge decks. Agencies continue to experiment with the current options, which are improving, but not yet ideal. Special challenges include damage from traffic impacts, noncompressible debris lodged in joint openings, and snowplowing. Examples are shown in Figures 20 and 21.

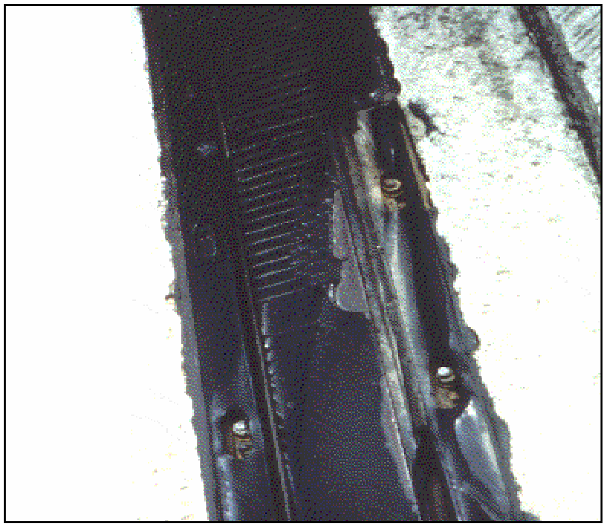


FIGURE 20 Snowplow damage to cushion joint.

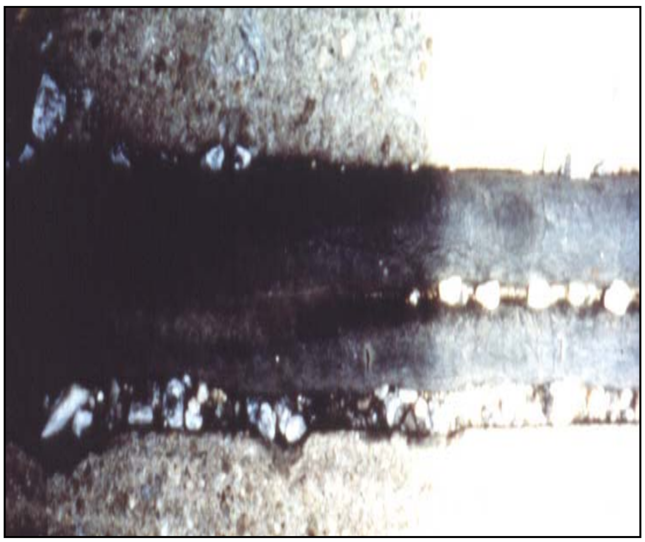


FIGURE 21 Debris lodged in joint seal.

Agency wide, there is no consensus as to which type of closed joints work best. Most systems have evolved over several decades. Sealer materials have improved, anchors are stronger and better designed, and installation methodology has been refined. Also, the deck blockout material holding some systems in place has changed. Other variables among locations include climate, traffic volume and size, snow-removal techniques, construction skills, and level of maintenance. Agencies are slow to return to a system that performed unsatisfactorily in the past. Current closed joint system types used by transportation agencies that responded to the survey include field-molded, compression, strip, plug, cushion, and modular.

Field-Molded Sealer

The field-molded (poured-in-place) sealer was one of the first types used when transportation agencies began attempting to make deck joints watertight. Traditionally, it is used on shorter spans where the joint movement is 5 mm (3/16 in.) or less. However, newer systems are suggested by manufacturers for larger movements depending on the type of sealant material. This system normally includes a thick, sticky, and pourable waterproof material placed near the top of the joint as a sealant. Silicone is probably the most common sealant used today. A premolded filler material (backer rod) is placed under the sealant to prevent it from flowing through the joint. After the sealant molds to the opening, it remains flexible and bonds to the sides of the joint. The first poured seal materials were heated asphalt or coal tar products, which did not perform satisfactorily for many transportation agencies. Earlier polymer materials had many of the same problems, including debonding, splitting, and damage from noncompressible debris. Damage to the deck edge also caused the joint sealant to fail, as shown in Figures 22 and 23. Agencies report

FIGURE 22 Removing failed poured-in-place sealant.

FIGURE 23 Damaged poured-in-place seal.

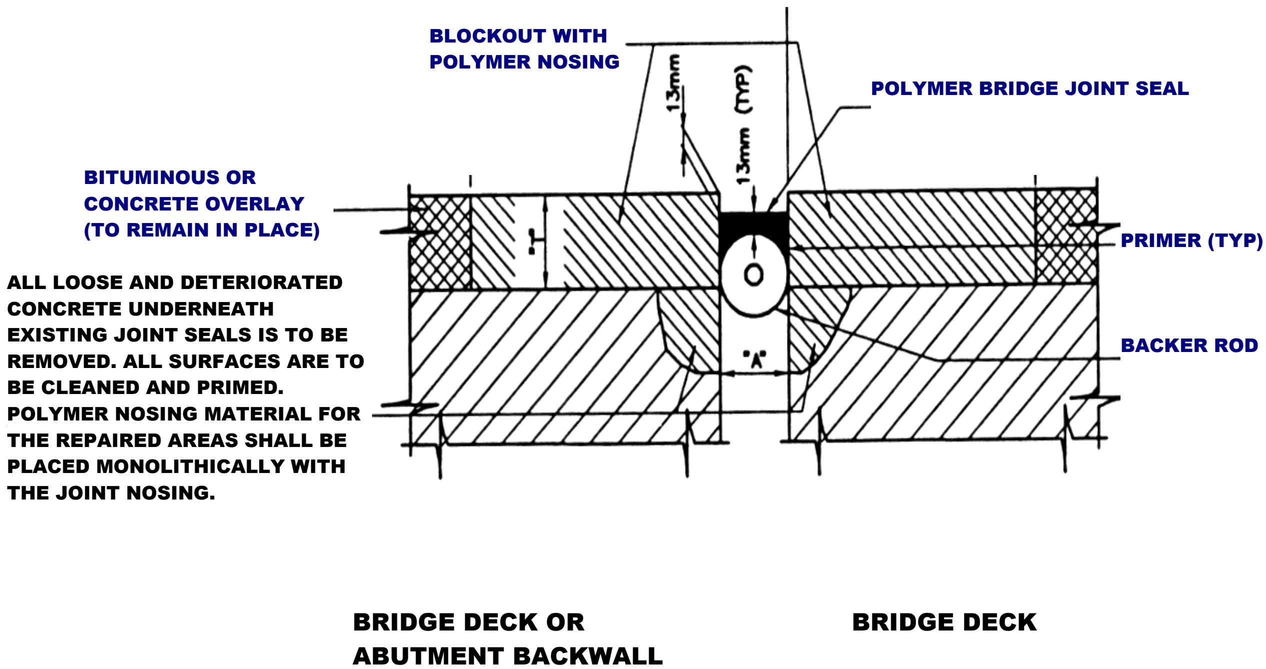


FIGURE 24 Polymer poured-in-place seal.

that, when installed properly, the newer systems are serving well. As a consequence, this type joint is returning to widespread use.

The systems used today typically include an elastomeric header with pourable silicone sealer and polyethylene foam backer rod as joint filler. The silicone is a self-leveling, rapid-curing, two-component polymer material. The backer rod is squeezed into the joint to keep the sealant from spilling through the joint opening and to form the shape of the sealer. The silicone sealant is poured in the opening on top of the backer rod. It is important that the joint edges be clean and sound so that the silicone bonds tightly. The thickness of the silicone at the center should be no more than half the width of the joint. It is important that the bottom of the silicone does not bond to the material below. It performs best if the seal is poured when the ambient temperature (which must be above 40ºF) is at the middle of the historical range or the joint opening is at the midpoint. Agencies have also had success with elastomeric blockout materials to reinforce the edge of the deck. A typical detail is shown in Figure 24.

There are certain advantages to this type of seal. Unlike many premolded seals, its performance is generally unaffected by joint walls that are not perfectly parallel or perfectly vertical. It is also relatively easy to repair. If a short portion of the seal fails, it is easy to remove the seal, clean the walls, and quickly refill the joint. This activity minimizes traffic disruption and work zone hazards.

Compression Seal

Compression seals rely on a continuous preformed neoprene elastomeric rectangular-shaped section compressed into the joint opening for the total width of the bridge deck, to accomplish its waterproofing function. Movements from 5 mm to 60 mm (0.25 in. to 2.5 in.) can be accommodated with this type of joint. Open cell compression seals are extruded with a semihollow cross section with internal diagonal and vertical neoprene webbing, resembling a truss, to allow the joint seal to compress freely while providing stability and pressure against the joint face during movement. The joint face may or may not be strengthened with armor or polymer concrete material. A typical detail is shown in Figure 25.

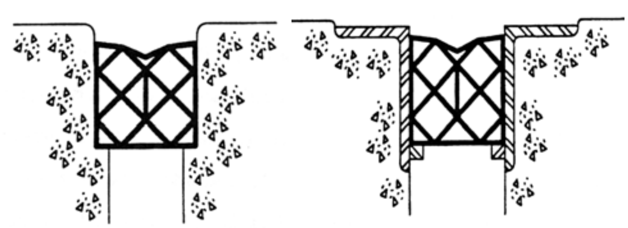


FIGURE 25 Open cell compression seal.

Some agencies also use a closed cell (foam) compression seal. For example, the North Carolina Department of Transportation (DOT) specifies the closed cell compression seal, with the open cell neoprene seal as an alternate. Both the open or closed cell seals accommodate approximately

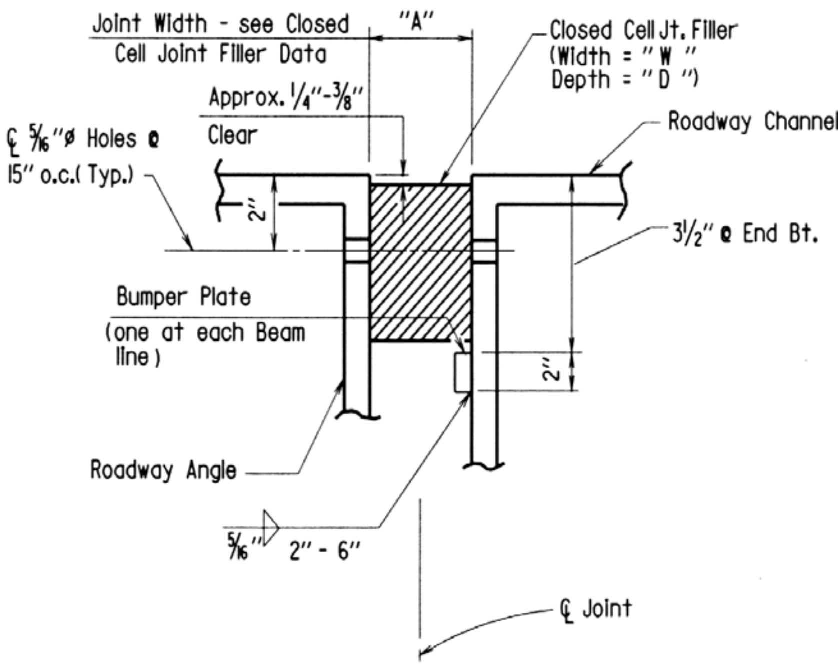


FIGURE 26 Closed cell compression seal.

FIGURE 27 Placement of closed cell compression seal.

the same range of movement. The seal is a low-density closed cell polymer with a foam-like appearance. One manufacturer describes its product as cross-linked ethylene vinyl acetate polyethylene copolymer material. This material relies heavily on an adhesive bond to the joint sidewall. In a free state, heat may cause shrinkage, especially if the material is not properly ventilated. It is reported that large sustained compressive movement forces air from the seal material, which may not recover when the joint opening expands. The closed cell seal is shown in Figure 26. Figure 27 shows the installation of closed cell sealer material.

The sides of the compression seal are squeezed together and inserted into the joint using a lubricant that also serves as an adhesive that bonds the seal in place. That seal must always be in compression to ensure that it stays in place and remains watertight. Splices should be avoided. Typically, the sides of the joint include an offset or stop bar at the bottom of the seal to hold it in place.

Agencies report mixed reviews regarding compression seals. Some, such as New York and Illinois, report that these are effective seals that require minimal maintenance with a reasonable life span. Others, such as Louisiana and Colorado, report unreliable performance; problems included damage from debris, traffic, and snowplows. Seals are reported to leak shortly after installation and to become dislodged and lose compression over time. Some practitioners feel that this type of joint seal works best in areas with moderate temperature extremes; the wider the range of temperature, the more total distance a joint material must expand or contract.

Several selection and installation issues are particularly important when using compression seals. The seals must be sized properly for the actual joint opening range. Joint openings must be constructed properly with a uniform width, vertical sides, and no edge spalling. Also, the seal must be set the proper distance below the top of the deck. Seals are more difficult to install and subject to damage if not placed when the temperature is relatively low. Over time, the compression seal is reported by some to experience decreased capability to retain its initial compression recovery due to loss of resilience, particularly if the movement range is large.

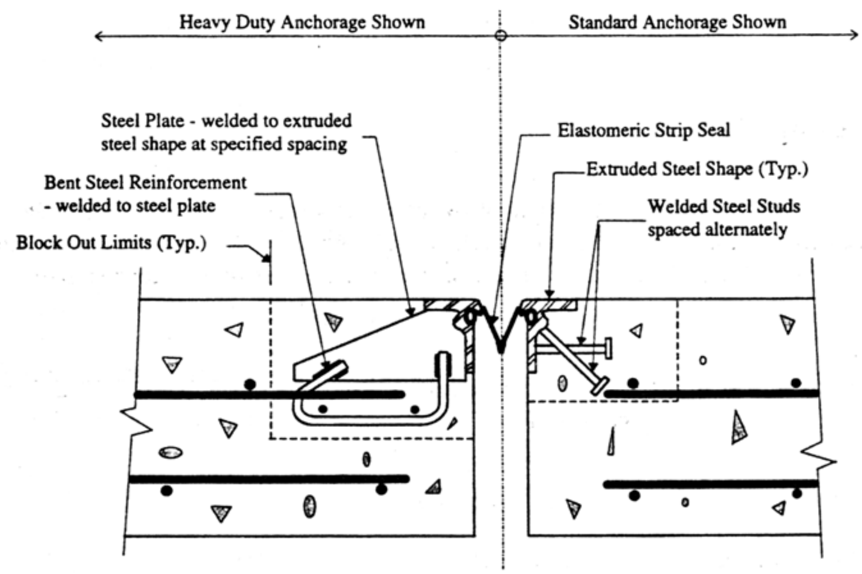


FIGURE 28 Strip seal.

Strip Seal

A strip seal consists of a membrane (gland) of neoprene rigidly attached to a metal facing on both sides of the joint. The material is premolded into a "V" shape that opens as the joint width increases and closes as the joint width decreases. The joint can accommodate movements up to 100 mm (4 in.). A typical detail is shown in Figure 28.

This type of seal received the most positive appraisals by agencies surveyed during this study. Minnesota, New Jersey, and Pennsylvania are among the states that like the strip seal. These seals are watertight when properly installed. Under the best conditions, the life of a strip seal tends to be longer than that of other joint seals. However, these seals are difficult to replace, and splices in the membrane should be avoided. They are damaged by snowplows, particularly if the skew is 20° or greater and should be avoided if the skew angle and snowplow blade angle are the same.

Problem areas are found at gutter lines and places where sharp breaks in the horizontal and vertical deck cross section occur. Membrane tears usually occur as the result of noncompressible materials lodged in membrane crevices when it is expanded. As the joint closes, these materials become wedged in the crevice and can cause rupture with loss of watertightness. Breakdown can also occur as a result of traffic movement over debris-filled joints. The seals also occasionally pull out of their groove in the metal facing. An example of strip seal damage is shown in Figure 29.

FIGURE 29 Damaged strip cell.

Plug Seal

The asphalt plug joint system (plug) is becoming popular with some agencies. This seal is used for expansion joint openings with less than 50 mm (2 in.) movement. The system can be used on concrete decks, particularly if an overlay is being added. A popular application is on decks where a waterproof membrane, topped by bituminous (asphalt) concrete overlay, has been added.

The joint requires a blockout centered over the joint. Typical dimensions of the blockout are 570 mm wide by 60 mm (minimum) deep (20 in. × 2 in.). A backer rod is squeezed into the remaining joint below the blockout. A polymer-modified asphalt binder material heated to 190°C (380°F) is used to coat the blockout and fill the joint above the backer rod. A steel plate approximately 230 mm (8 in.) wide is centered over the joint, bridging the opening, for its entire length.

The blockout is filled with an open-graded aggregate coated with the asphalt binder. The aggregate is heated to the same temperature as the binder. After placement, the

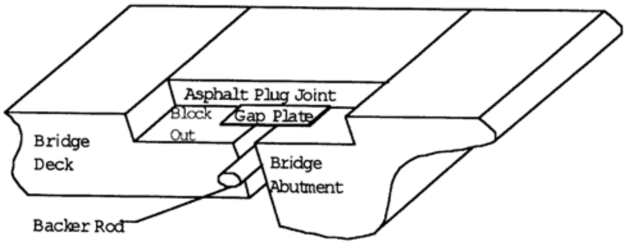


FIGURE 30 Asphalt plug joint system.

material is consolidated with a vibrating plate compactor. Finally, the binder material is poured over the top of the compacted material until all the voids are filled and a fine aggregate is used to coat the surface for traction. A typical detail is shown in Figure 30.

The primary advantage of this system is ease of installation and repair. Other advantages include the low cost of installation and repair, low instance of snowplow damage, and that it can be cold milled. The major disadvantage of this system is that it was developed almost exclusively for bridge deck joints without curbs, barriers, parapets, etc. This system does not provide an effective method of sealing joint upturns, especially for longer decks and skewed deck joints where joint movement will degrade the system, resulting in early system failure. Problems have been reported on some installations, including softening in hot weather, debonding of the joint-pavement interface, and cracking in very cold weather. Over time they may rut or delaminate in certain heavy traffic situations. It is also reported that they cannot adjust to a rapid change in temperature without damage. Experience or research may find that this system works best in restricted climate conditions.

Inflatable Neoprene Seal

The inflatable neoprene open cell seal has been used by several transportation agencies, with mixed results. This type of joint system is known by the trade name Jeene Structural Sealing Joint System and manufactured by Hydrozo/Jeene, Inc. Unlike the other preformed neoprene seals, this one is available through only one source. The seal is shown in Figure 31.

The inflatable neoprene seal is installed in the joint and coated with a bonding material on both sides. Elastomeric concrete is normally used to form the joint blockout. Once in place, the seal is inflated, compressing the neoprene to the sides of the joint to help achieve a watertight bond. The seal is deflated approximately 24 h after the bonding material

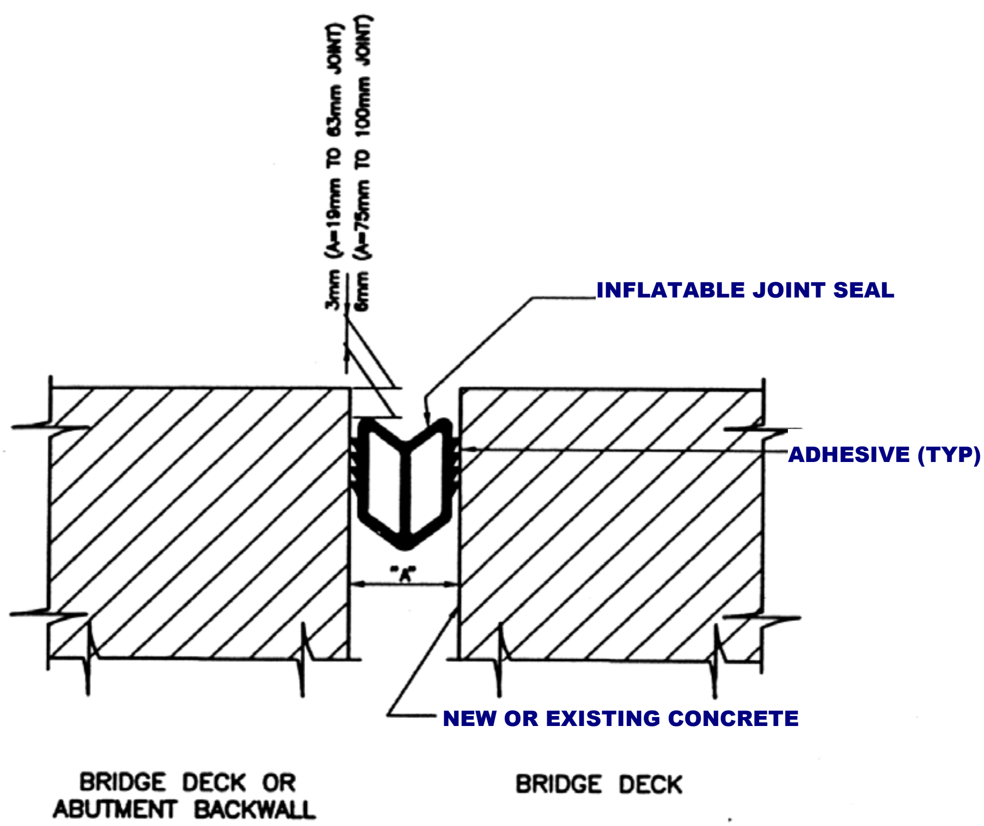


FIGURE 31 Inflatable neoprene seal.

is set; however, traffic is permitted to cross the joint while the seal is inflated.

The advantage of the inflatable seal is that it can be put in place rapidly, with only minor inconvenience to the highway user. Unlike the compression seal it can accommodate minor irregularities in the joint opening. Disadvantages include that once it is deflated it totally relies on the bond with the joint edge to remain watertight. It will also fail if the joint edge is damaged after the seal is installed. Although several agencies reported problems with this type of seal, Pennsylvania reported acceptable performance on two bridges where the material was monitored over a 3-year period. This seal is used primarily on rehabilitation and repair work.

Cushion Seal

The cushion (plank) seal consists of a steel-reinforced neoprene pad recessed into the deck over the joint opening and rigidly attached on both sides. The attachment is accomplished with rods anchored in the deck and threaded on top with nuts holding the pad down. A typical detail is shown in Figure 32. If the seal is properly installed, the neoprene stretches as the joint opens and shrinks as the joint closes. Internal reinforcement with thin steel plates embedded in the neoprene makes this seal more durable. Cushion seals are used to accommodate movement up to 100 mm (4 in.).

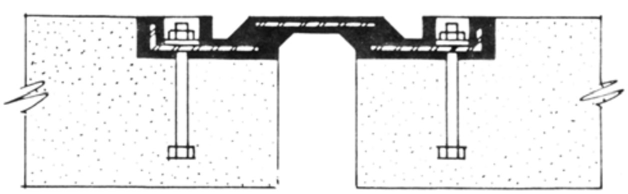


FIGURE 32 Cushion seal.

These joints were popular several decades ago, but have since diminished in favor, particularly among those agencies that use snowplows. Snowplows cut into the material and occasionally destroy complete sections. Because these seals normally require total replacement when damaged, cost is a consideration in this choice. Splice failure is another problem. Anchor failure is no longer a significant problem, because epoxy anchors are now used. However, caps, covering the anchor nuts, can dislodge due to adhesive failure and traffic. The joint edge spalls, making the seal more vulnerable to leakage and traffic or snowplow damage. Figure 33 shows an example of a cushion seal failure. Another common problem is that the cushion seal must be set when the bridge deck is at the proper temperature. Only then it is capable of expanding and contracting for the full range of movement. If the ambient temperature

FIGURE 33 Damaged cushion seal.

is too cold when the seal is set, the pad will buckle up in the middle and be damaged by traffic when the temperature gets hot. If the weather is too warm when the joint is set, excess stretching during cold weather will damage the seal material or the anchors.

Modular Joint Sealing Systems

Modular joints are fabricated to accommodate larger movements over 100 mm (4 in.). The joint components are sized according to the magnitude of movement, which dictates the opening width. Modular joints have been designed for use on very long span bridges with the capability of more than 2 m (7 ft) movement. The typical movement is between 150 mm (6 in.) and 600 mm (24 in.). The system consists of three main components: sealers, separator beams, and support bars. A typical detail is shown in Figure 34. Sealers and separator beams form a watertight joint at the riding surface. Separator beams often are extruded or rolled metal shapes, and they allow joining of the seals in series. The separator beams are supported on support bars at frequent intervals.

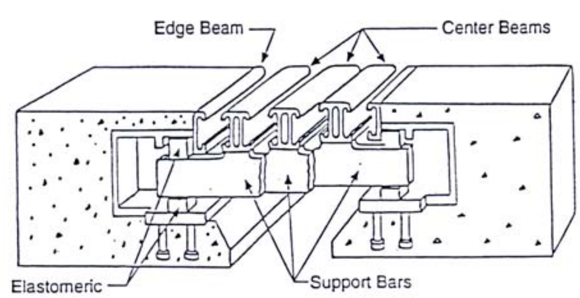


FIGURE 34 Modular joint system.

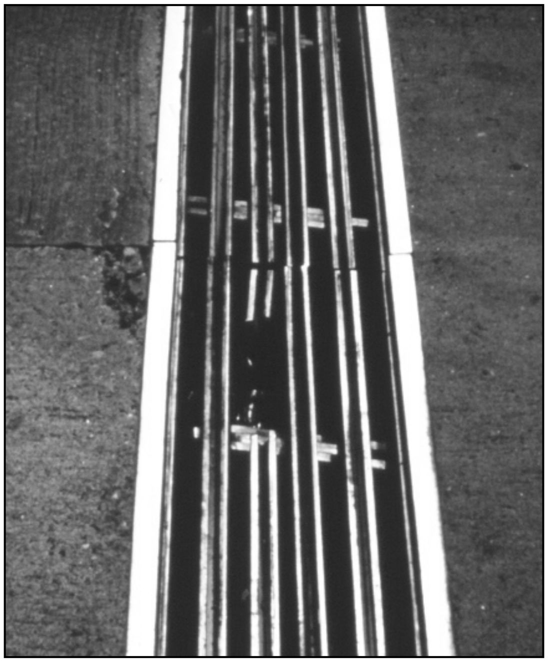


FIGURE 35 Damaged modular joints.

Modular joint systems have experienced their share of problems, including fatigue cracking of welds, damage to equalizing springs, damage to the neoprene sealer material, damage to the supports, and damage from snowplows. An example is shown in Figure 35. Most agencies object to their high initial costs and high maintenance cost. Many agencies have returned to using finger joints at openings with a larger range of movement, placing more emphasis on drainage troughs.

Designing a modular expansion joint system is similar to designing another very short span on a long bridge. The difficulty is that the joint system must be capable of expanding and contracting 100 times more than the other spans, must remain watertight, and must be supported by a movable framing system. The most difficult issues to resolve are related to durability. The sealer material must be very tough and the framing system must be designed to resist very large fatigue stresses.

Modular joint seals have improved and are continuing to improve. Designers understand more about the need to provide fatigue resistant details. Some agencies use them exclusively for large movements, and others use them just for the very large movements. An excellent resource for information about modular joint systems is *NCHRP Report 402: Fatigue Design of Modular Expansion Joints* (*2*).

Joint System Anchorage

This study does not focus on the design of joint anchorage systems except as it applies to the general performance of the seal. Anchorage designs often vary between agencies for the same type seal. Anchor performance is influenced by the vehicle size and volume, snowplow damage, and concrete construction quality around the joint. Designers develop more heavy-duty anchorage systems as older systems exhibit problems. Anchorage systems should be designed based on the type of traffic using the bridge. It should not be assumed that the anchors shown in the figures are necessarily the best or those recommended.

CHAPTER THREE

REVIEW OF CURRENT PRACTICES

A questionnaire was developed to collect state-of-the-practice information from transportation agencies (see Appendix A). The questionnaire was sent to all state DOTs, all Canadian provinces, and selected agencies and individuals worldwide. There were 35 responses from state DOTs and 49 total responses. A list of questionnaire responders is given in Appendix B. This chapter summarizes the information contained in the responses and the follow-up telephone interviews of selected state and provincial DOT officials and bridge designers.

The questionnaire is divided into five parts: (1) design procedures, (2) use and experience, (3) construction practices, (4) maintenance and rehabilitation, and (5) problems.

PART 1—DESIGN PROCEDURES FOR BRIDGE DECK JOINTS

1. *What specifications are used by your agency for the design of bridge deck expansion (movements) joints?*

State transportation agencies use AASHTO specifications, with modifications based on their experience and preferences. For issues not covered by AASHTO, or for new products, agencies tend to include manufacturers recommendations as part of the special provisions for the project. Canadian provinces use a variety of specifications, including those of AASHTO, Canada, and specifications developed internally. Consultants use client specifications when available; otherwise project-specific specifications are developed.

Often, new joint types are introduced to an agency as part of a rehabilitation or maintenance activity. It is not uncommon for the manufacturer to participate in the installation. Devising initial specifications is a team effort of the agency and the manufacturer. If the use of the joint continues, specifications are refined based on performance.

2. *What factors are considered when designing and specifying a particular expansion joint?*

According to the questionnaire responses, the most common factor considered when designing and specifying a particular expansion joint is "movement range." These factors are listed here in the order of importance.

- Movement range
- Bridge span
- Type of bridge
- Joint performance and previous experience
- Durability
- Maintenance requirements
- Bridge alignment
- Joint details at curbs, concrete barriers, or deck edges
- Initial costs
- Climate conditions
- Expected joint life
- Installation time
- Life-cycle costs
- Type of bridge supports
- Service level
- Other.

3. *Does your agency try to minimize or eliminate the use of deck joints for new construction? If so, what considerations are made in the design of the other bridge components?*

Eliminating deck joints is a high priority for many of the responding transportation agencies. Only three respondents indicated that minimizing joints was not a consideration when designing new bridges. A few provided their maximum continuity length, which ranged from 90 to 150 m (300 to 500 ft), although much longer continuous spans have been constructed.

A bridge deck must be designed differently to accommodate a continuous span configuration. Eliminating a joint usually requires that the design of other parts of the bridge be modified. The largest number of respondents listed integral abutments as a modification. Other modifications listed included turning piles to their weak axis, using a single row of piles, using a more flexible substructure, changing the bearings, and adjusting the approaches. The movement that takes place at the expansion joint on noncontinuous bridges is transferred to another location, which might be off the bridge.

PART 2—USE OF AND EXPERIENCE WITH DECK JOINTS

1. *Historically, what has been your agency's overall experience with open deck joints, such as formed joints or fingerplate joints?*

Only two respondents indicated satisfaction with their open joint experience. Another 10 indicated good to fair experience only with finger joints. A large majority indicated that their experience was poor because of damage from drainage through the joint.

2. *Are there particular types of open deck joints and/or joint materials that are avoided? Please explain.*

   Responses were consistent with those provided for the previous question. Two respondents indicated that they did not avoid any open joint types. The majority avoided all open joints. Apparently, many consider a finger joint with a trough as a closed system.

3. *Does your agency presently specify the use of open deck joints?*

   Approximately one-half of the respondents do not specify open deck joints. The remainder specify only finger joints. Most of those that use finger joints use them only with drainage troughs.

4. *Historically, what has been your agency's experience with closed deck joints, such as poured seals, strip seals, compression seals, elastomeric seals, and sliding plate?*

   Several respondents commented that closed joints were normally assumed to be watertight, and the sliding plate type is not intended to be watertight and should be included in the open joint category. Although most indicated that all joint types have problems, their experience with the strip seal was cited as the least problematic of the alternatives. The compression seal was the next most popular. New silicone field-molded joints and the asphalt plug joints are being tested by several agencies.

5. *Are there particular types of closed deck joints and/or joint materials that are avoided? Please explain.*

   The joint type avoided most was the sliding plate. The next appeared to be the cushion, although respondents used several different terms, including elastomeric, neoprene, and cushion. The results of the questionnaire show that every type of closed joint is avoided by some agency.

6. *Does your agency presently specify the use of closed deck joints?*

   The only agency reporting that it does not specify closed joints was the Mississippi DOT. Based on the results of the questionnaire, closed joint systems specified most often for movements less than 150 mm (6 in.) include, in order of preference, strip seal, compression seal, silicone field-molded, and asphalt plug.

7. *Does your agency presently specify the use of modular bridge joint systems?*

   Approximately 60% of the respondents reported that they do specify modular joint systems. Of those that said no, the most common reason was the high cost. Several respondents also experienced poor performance with such systems.

   The following are additional findings:

   - D. S. Brown and Watson Bowman are the primary suppliers of modular joint systems.
   - Deck joints are used on all types of long-span bridges.
   - Although there were a few smaller exceptions, the predominant minimum movement for modular joints is 100 mm (4 in.). The maximum is controlled by the agency's continuous span limitations.
   - Several problem areas were reported, including weld failures, anchor failures, support beam failures, spring failures, and gland/neoprene failures.
   - Agencies reported mixed experiences with modular systems, the consensus being that these are the best of current alternatives for large movement bridge decks, and that the system has been improved with experience and research.

PART 3—DECK JOINT CONSTRUCTION PRACTICES

1. *Are there any specific installation practices that your agency has found to influence, either positively or negatively, the performance, general durability, or life of deck expansion joints? If yes, please explain and reference or attach the relevant specifications.*

   The responses to this question demonstrated the wide variety of occasionally conflicting preferences among transportation agencies. For example, from their experience, various agencies suggested that it is best to use elastomeric headers, to avoid elastomeric headers, to use armor joint headers, and to not use armor joint headers. Other notable suggestions included

   - To achieve a smoother riding deck, use a closure pour or blockout to install and/or replace a joint system.
   - On a closed joint system, ensure that the sealer is installed so that it is in the relaxed position at the median ambient temperature for the location.
   - Consolidate concrete properly under and around armor plates.
   - Use strong, fatigue-resistant, anchors.
   - Install plates to protect against snowplows.
   - Follow manufacturers' recommendations when installing joint systems.

- Do not permit joints in premolded joint seals.
- Set seals at proper elevations.
- Install troughs under closed seals to handle inevitable minor leakage.

2. Does your agency require quality control and assurance procedures for the construction of deck joints? If yes, please explain and reference or attach the relevant specifications.

Generally, the responses included the following

- Testing materials;
- Shop testing fabrication (when applicable);
- Field inspection, by inspectors who are assigned to the construction project;
- When appropriate, using a manufacturer's representative for additional inspection; and
- Using high-pressure water and/or air to ensure that the joint is watertight.

3. What specifications and/or types of joint materials are required for acceptance?

For transportation agencies, the primary sources for established joint systems are their specifications and standard special provisions. For new systems, special provisions are based on manufacturer's recommendations, research recommendations, and specifications from other agencies. Other responses included

- Approved product lists,
- Standard materials specifications (i.e., ASTM),
- Manufacturer's certifications,
- Materials certifications, and
- Mill certifications.

4. Do you allow field splicing of joint seals?

Thirty respondents reported that they do not permit field splicing on premolded joint seals. Another four permit it only for staged construction. Only 10 responded yes without including exceptions.

5. What types of anchorage details for deck joints does your agency use? Please explain and reference or attach the relevant specifications.

Welded studs are the most commonly used devices used for anchorage of joint systems. Steel straps were also mentioned by many of the respondents, as were rebars. Many agencies have standard details for routine situations. Special situations are custom designed.

6. Does your agency have special requirements for the concrete in the blockouts surrounding the deck joints? Please explain and reference or attach the relevant specifications.

Most agencies do not have special requirements for the concrete in the blockouts surrounding the deck joints. For those that do, the most commonly used product is elastomeric (polymer) concrete.

7. Does your agency require any specific weather conditions for the installations of deck joints? Please explain and reference or attach the relevant specifications.

The responses to this question were mixed. Some mentioned the weather requirements for concrete placement, such as 7°C (45°F) and dry. A significant number indicated that their concern is to make sure that the seal is placed at, or adjusted for, the appropriate midrange temperature so that a full range of movement is possible. Others reported that the weather restrictions, if any, contained in the manufacturer's recommendations are their primary consideration.

8. Are special practices employed to handle joint installation at deck ends, curbs, and parapet walls? Please explain and reference or attach the relevant specifications.

The majority of the respondents reported that their agencies turn the seal up at the ends. Some shape the seal up the curb and/or parapet. A few extend the seal through the curb and/or parapet at the same slope as the roadway. This approach is the best for flushing debris out of the joint; however, there are potential problems with drainage discharged from the end of the joint.

PART 4—DECK JOINT MAINTENANCE AND REHABILITATION PRACTICES

1. Does your agency conduct periodic inspection and maintenance of bridge deck expansion joints? If so, please describe (how often, what is looked for, what is the most common problem area).

Most responding agencies in the United States report that deck joints are inspected, normally at 2-year intervals, as part of the national bridge inspection program mandated by law. Many agencies outside the United States have similar inspection requirements. When asked what inspectors look for during the inspection, the most common response was physical damage. A few agencies reported that inspectors also looked for maintenance needs.

Most of the responses to this question were not clear. It cannot be determined whether inspectors are looking for preventive maintenance needs, such as debris deposits on the seal and leaking joint seals, or whether they report only advanced problems that are potential safety hazards. Follow-up interviews with some of the agencies indicated that they tend not to respond to joint problems unless there is a safety hazard or when the deck is being rehabilitated or replaced.

2. *If your agency has a deck joint maintenance program, what is your opinion of the overall effectiveness of the program? Is maintenance of joints considered to be cost-effective?*

Each of the 10 positive responses to having a deck joint maintenance program considered it to be cost-effective. The remaining respondents either do not have a program or did not answer the question. Interviews indicated that many more agency employees feel that a joint maintenance program would be cost-effective, but that they do not receive adequate maintenance funding to implement one.

3. *Does your agency have a strategy for rehabilitating bridge deck joints? If so, please explain.*

Responses varied; half of the respondents have a strategy and half do not. However, the final results were not that different. Often, the strategy was to react to problems, which those without a strategy reported that they did. Other than reactive efforts, joint repair and rehabilitation, in most agencies, is associated with deck rehabilitation.

4. *Does your agency attempt to reduce and/or eliminate deck joints as part of rehabilitation? If so, please explain.*

Sixty-five percent of those responding try to reduce deck joints when bridge decks are rehabilitated.

5. *As part of bridge rehabilitation, does your agency replace one type of deck joint with another? Please explain.*

The state of Maine and the province of Alberta were the only two agencies reporting that they do not replace one type of deck joint with another as part of deck rehabilitation. Comments from those agencies reporting that they do replace one joint with another included

- Replacing steel plate and finger joints with strip,
- Replacing compression joints with asphalt plug, and
- Replacing, if necessary.

6. *Do you have any recommendations for improving the service life of deck joints? Please explain.*

The responses included, in order of frequency

- Ensuring proper installation,
- Providing proper maintenance,
- Developing improved designs,
- Improving joint system modular design,
- Developing a self-cleaning seal,
- Using galvanized armor,
- Converting to asphalt plug,
- Minimizing joints,
- Developing more durable materials, and
- Adding troughs under all seals.

PART 5—PROBLEMS WITH BRIDGE DECK JOINTS

1. *Does debris commonly collect in your deck joints? If yes, does the debris have adverse effects on joint performance?*

Almost all respondents reported that their deck joints commonly collect debris, with 80% noting that the debris has adverse effects on joint performance.

2. *(a) What percentage of your closed joints leak?*

- Ten respondents reported that between 75% and 100% of their joints leak.
- Eight reported that between 50% and 75% leak.
- Six reported that between 25% and 50% leak.
- Seven reported that between 0% and 25% leak.
- More than one-third of the respondents chose not to estimate.

(b) Typically, how long after installation does this leaking occur?

- Fifteen respondents reported that it takes between 0 and 5 years for closed joints to begin leaking.
- Ten reported between 5 years and 10 years to begin leaking.
- One reported more than 10 years to begin leaking.

(c) What do you attribute the leakage to?

- Improper installation,
- Poor maintenance,
- Puncture/damage by debris,
- Depends on joint type,
- Defective product,
- Damage by traffic,
- Damage by snowplow, and
- Temperature extremes.

3. *Have you observed any problems associated with inadequate movement capacity in your deck joints? Please explain.*

Responses were evenly divided between yes and no.

Reasons for yes included

- Installation at the wrong temperature,
- Substructure movement,
- Skewed bridge,
- Jammed joint, and
- Designed incorrectly.

2. *How does your agency define failure of a deck joint? Please explain for each failure case and joint type, as applicable.*

More than half of the respondents reported that leakage defines failure of the joint, although traffic hazard is the only criterion for some agencies. Physical damage was also included by some agencies.

3. *Please provide a list of observed performance problems, not mentioned above, for bridge deck expansion joints in your agency's inventory.*

More than 80% of the respondents did not provide any additional information. Of those that did, the following were noteworthy:

- Compression failure when a joint closes,
- Snowplow damage,
- Substructure movement,
- Debris in joints causing lengthening of the deck and substructure damage, and
- Poorly formed headers.

CHAPTER FOUR

SELECTION AND DESIGN GUIDELINES

Transportation agencies often develop design guidelines to reflect their performance experience with alternative products. These guidelines serve as supplements to the AASHTO design specifications. Some states provided a copy of their joint system guidelines when responding to the questionnaire. These guidelines are used by their staff and by consultant engineers when designing bridges in state. States differ in their performance for joint types and products. Typically, these guidelines are for the systems that are approved for different types of bridges. Some also listed the approved products and manufacturers. No joint system currently in use should be expected to last the life of the bridge deck; the actual life depends on several factors, including level of maintenance.

Not all agencies provided guidelines; therefore, no attempt was made to draw general conclusions related to overall design requirements, other than the results provided in chapter three from the questionnaire responses. Nevertheless, selected portions of these guidelines are included in this chapter to demonstrate a variety of preferences based on in-house testing and performance experience. They generally tend to reinforce findings contained elsewhere in the report. Note that jointless bridges and watertight joint seals are high priorities in all the guideline samples.

ARIZONA

The required movement rating is equal to the total anticipated movement; that is, the difference between the widest and the narrowest opening of a joint (including thermal movement, shrinkage, and creep).

The movement rating for joints for steel structures shall be based primarily on the thermal expansion and contraction characteristics of the superstructure, whereas for concrete structures the effects of shortening due to creep and shrinkage and where applicable, prestressing, shall also be added. Movement ratings shall be based on temperature variations as measured from the assumed mean temperature.

Other factors which should be considered in determining the required movement rating included consideration of the effects of any skew, anticipated settlement, and rotations due to live loads and dead loads, where appropriate.

Items requiring attention included

1. Type of anchorage system to be used;
2. Method of joint termination at the ends;
3. Method of running joints through barriers, sidewalks, and/or medians;
4. Physical limitation on size of joints;
5. Susceptibility of joint to leakage;
6. Possible interference with post-tensioning anchors;
7. Selection of appropriate modular proprietary systems that meet design requirements; and
8. Forces applied to the surrounding concrete by the joint.

Available types of joints include compression seals, strip seals, and modular joints. Compression seal joints and strip seal joints are generic and should be detailed on the plans, by standards, and/or covered in the special provisions. Modular joints are proprietary and require that the designer specify allowable joint types and styles in the special provisions. It is the responsibility of the designer to review the proprietary joint literature and related manufacturer's specifications to ensure that the selected joint types are properly specified and compatible with the design requirements.

- Compression seals—The compression seal element should have a shape factor of 1:1. Effective movement ratings for this type of joint range up to 60 mm (2.50 in.). The advantages of this joint type include its low cost, proven performance, and acceptance for use of pedestrian walkways. However, this type of joint cannot be unbolted and easily raised, generates pressure, and is not good for high skews or horizontal directional changes.
- Strip seals—Effective movement ratings for this type of joint range up to 100 mm (4 in.). This type of joint is best used when the movement rating is beyond the capacity of compression seals and for large skews. Strip seal joints will require cover plates for pedestrian walkways.
- Modular joints—Modular joints are very complex joint systems. Effective movement ratings range from 100 mm (4 in.) up to 750 mm (30 in.). Modular joints are the best choice for movement ratings over 100 mm (4 in.), but are very costly and should be avoided whenever possible.

COLORADO

Expansion joint devices are designed to accommodate structure movement, provide smooth and quiet passage of traffic, and prevent water runoff (particularly deicing chemicals) from damaging the structural elements.

Bridge deck expansion joints should not be used when the superstructure and substructure can be economically designed to accommodate the resulting thermal, creep, and shrinkage deformations and forces.

Except as provided for below, strip seal devices shall be used on expansion joints designed to accommodate a range of translation, normal to joint length, from 0 to 100 mm (0 to 4 in.). Modular expansion devices shall be used when the range of translation normal to joint length exceeds 4 in.

The Koch BJS and the Thorma-Joint systems (asphalt plug systems) have been approved by the staff bridge engineer for replacing failed expansion devices on existing bridges where the movement at the joint is 2 in. or less. They can be specified as an equal alternate to the strip seal with elastomeric concrete devices that we have been using. For retrofit in situations with greater movement, the strip seal with elastomeric concrete devices should be used exclusively.

The Hydroxo/Jeene (inflatable type) 4-in.-wide device, with armored corners, shall be allowed as an equal alternate to strip seals on approach slab joints.

FLORIDA

The engineer of record shall minimize the use of joints by providing deck slab continuity at intermediate bents or piers. Deck joints shall be designed to resist loads and accommodate movements at the service and strength limit states and to satisfy the requirements of the fatigue and fracture limit states.

Shop drawings are required for all expansion joints except poured rubber seals and open joints.

In some instances, open joints may be acceptable; however, such joints must have provision for diverting drainage without causing damage to the bridge bearings, other structural elements, or the environment, and must have the prior approval of the department.

Strip seals, silicone seals, or joints other than the compression seals should be used to the maximum extent possible. Sliding plate, finger joints, etc., should be used only for very large movements, that is, bridges with span lengths greater than 60 m (200 ft) or where movements of continuous units result in a maximum joint opening width greater than 75 mm (3 in.).

When an expansion joint is required, the joint shall satisfy the following criteria as applicable:

- Proprietary joints shall be designed and installed in strict accordance with load and resistance factor design (AASHTO bridge design specifications) and the manufacturer's limitations and/or design values, particularly at maximum joint opening.
- The joint must provide a good riding surface, relatively free from vibration and noise.
- Frame rails must be designed as necessary to resist all anticipated loads, including dynamic load allowance.
- The joint must not transfer undue stresses to the structure.
- Elastomers for joint seals shall provide a service life warranty for a period of five (5) years minimum.
- The joint shall be designed for minimum maintenance and ease of access and parts replacement.
- The joint shall be leak-proof with a continuous sealing element for the entire joint length.
- The joint materials shall be resistant to both corrosion and ultraviolet rays, and shall not be a catalyst or vehicle for electrolytic action.

From the results of 2-year performance tests, the following joint systems were approved for use by Florida DOT (*3*):

1. Dow 902 RCS Joint Sealant (field-molded silicone with armored edges),
2. XJS Expansion Joint System (field-molded silicone with polymer blockout),
3. Ceva 300 Joint System (closed cell compression seal with armored edges),
4. Expandex Buried Joint System (asphalt plug joint),
5. KOCH BJS Joint System (Asphalt plug joint),
6. Delcrete Elastomeric Concrete/Steel Flex Strip Seal System (strip seal with polymer blockout), and
7. Jenne Structural Seal (inflatable seal only, not the system).

KANSAS

The type of expansion joint selected for bridges is dependent primarily on the length of the structure and whether or not the joint is to be sealed. Because the use of an expansion device may result in a maintenance problem, it is Kansas DOT policy not to provide expansion devices on steel bridges up to 90 m (300 ft) in length, and concrete bridges up to 150 m (490 ft) in length, although there may be unusual conditions that would require an expansion device. For most projects, it is preferred to design an expansion device that will be watertight to prevent deck drainage through the deck.

For small movements 25–50 mm (1–2 in.), compression seals with armored faces may be used. All compression seals should have a stop bar placed below the seal.

For movements in the range of 50 to 100 mm (2 to 4 in.), a strip seal type expansion device with steel armoring is preferred. Strip seals should be placed as a single unit if at all practical. Large roadway widths or staged construction may make a single unit impossible. If so, a note allowing a hot vulcanized splice of the strip seal should be placed on the plans. Expansion devices composed of solid elastomeric material are not recommended.

For larger movements, steel finger type expansion devices with a fabric trough to collect drainage are preferred. However, sliding plate or modular expansion devices may be used in certain instances.

The compression seals and strip seals shall be carried through the railings where possible. The devices should extend 150 mm (6 in.) beyond the outside of the rail. This helps clean the units of roadway debris. The overflow drainage may be handled in an open gutter or by providing riprap protection of the berms.

Some features to be considered in the design of expansion devices are as follows:

- Air vents should be provided in the flat surfaces of the device to prevent voids from forming during concrete placement.
- The device should include snowplow guards and be recessed about 5 mm (0.25 in.) below the deck surface to prevent damage from snowplow operation.
- All glands and seals should be continuous across the width of the bridge, with watertight joints.

LOUISIANA

For prestressed girder spans there are two types of joints currently being used: open joints and strip seal joints. Open joints are used at intermediate bents in rural areas and for stream crossings in urban areas where aesthetics are not as critical. For urban overpasses and interchanges exposed to the public view, strip seal joints are used to prevent unsightly staining and debris accumulation from drainage effluent. Strip seals are used at all end bents to prevent erosion. Both strip seal and open joints are capable of handling the expansion of up to 80 m (260 ft) of prestressed girder span [75 mm (3 in.) maximum opening]. For a single continuous span unit in which all of the expansion occurs at the abutments, the distance between joints could theoretically be doubled. However, bent restraint must be taken into account at continuity bents with span fixity.

All steel girder spans will have sealed joints. Strip seal joints are capable of handling the expansion of up to 56 m (180 ft) of steel girder span. A 112-m (370-ft) continuous unit can be handled if abutments are at each end with the unit fixed at midpoint. For longer spans, finger joints will generally be employed with a trough (at 8% minimum slope) provided to divert the drainage away from the steel superstructure. Generally, thick finger plates without stiffeners are more desirable than thinner plates with stiffeners, for the thick plates add more inertia to the joint as well as provide a better detail for fatigue resistance. For finger joints on curved girder spans, the designer is advised to refer to AASHTO's *Tentative Guide Specifications for Horizontally Curved Highway Bridges* (*4*) regarding the orientation of the fingers and the bearings.

Joints shall be furnished in one piece without butt welds unless it is impractical due to plate length availability, in which case only one shop butt weld will be permitted.

The bridge design engineer must approve the use of prefabricated or modular expansion joints in lieu of finger joints. The use of steel reinforced elastomeric joint seals is prohibited. In gore areas of new construction or in severely skewed spans, portions of the joint may have severe kinks and the designer is advised to confer with the joint manufacturer to ensure a proper fit of the strip seal.

NEW MEXICO

During the design process, designers must select which one (or more) system type should be used for each joint location on the bridge (see Table 1).

TABLE 1
SYSTEM TYPES

System	Movement (in.)	New Construction: Deck Joints	New Construction: Approach Slab to Sleeper	New Construction: Sealing Stationary Joints	Rehabilitation and Repair: Joint Reconstruction	Rehabilitation and Repair: Replace Compression Joints	Rehabilitation and Repair: Replace Bolt-Down Joints
Strip	0–4	X	X		X		X
Polymer	±2			X		X	X
Inflatable	±2	X	X	X	X	X	X
Plug	±2						X

NEW YORK STATE

The advantage to using bridges with jointless decks is the considerable benefit gained by eliminating the deck expansion joint system. Leaking deck joint systems are one of the most significant causes of bridge deterioration. Although deck joint design has improved considerably in recent years, it is unlikely that any deck joint system will ever be completely reliable. Therefore, there is strong motivation to eliminate all deck joints whenever possible.

Jointless bridge decks at abutments can be used under the following criteria:

- Maximum skew of 30º at the expansion end of the span.
- Maximum expansion length at the abutment of 60 m (200 ft). (Expansion length is defined as the distance from the abutment to the nearest fixed bearing.)
- Abutments with U-wingwalls may be used at the fixed end of the span or at the expansion end, if the approach slab does not meet the U-wingwall. A bond breaker is usually not effective in allowing an approach slab to slide past a U-wingwall. If a jointless deck is used at an expansion end with U-wingwalls, adequate provision must be made for movement of the deck slab where it meets the wingwall.
- Approach slabs must be used.
- Jointless deck details may only be used at the fixed end of a bridge with curved girders.
- Jointless deck details may be used at the fixed end of the span with a conventional expansion joint at the expansion end.
- When the expansion length at an abutment exceeds 30 m (100 ft), provisions for expansion must be provided at the end of the approach slab by using the appropriate sleeper slab detail.

For deck expansion joints there have been many deck joints and details used over the years. Some types have worked better than others, but the one thing learned is that their use should be avoided whenever possible through the use of continuous spans, jointless abutment, and integral abutment details.

If expansion joints need to be used, the following types should be specified:

- Use armored joints with compression seal when distance to fixed bearing ranges from 0 to 60 m (0 to 200 ft) for steel superstructures and from 0 to 96 m (0 to 320 ft) for concrete superstructures. Skew limitations on the expansion end are 45º, except for the largest seal, which is 30º.
- Use the single cell modular joint system when there is less than 80 mm (3.25 in.) movement.
- Use the multicell modular joint system when there is over 80 mm (3.25 in.) movement.

NORTH CAROLINA

The length of expansion and the skew angle of the joint generally determine the type of expansion joint or seal to be used at a deck joint. The range of temperature for thermal movement shall be from −18º to 49ºC (0º to 120ºF) for steel beams with a concrete slab and from −7º to 38ºC (20º to 100ºF) for concrete beams with a concrete slab. The total movement shall be computed (in inches) by multiplying the thermal movement by the appropriate factor as follows:

- For steel beams and girders
  Total Movement = 1.25 × Thermal Movement
- For concrete girders
  Total Movement = 1.50 × Thermal Movement

Provide #16 (#5) G bars parallel to the joint and extending the full width of the bridge. The G bar shall be located as close to the joint edge as possible. Care should be taken to ensure that the G bar can be tied to other reinforcing steel.

- Evazote joint seal (closed cell compression seal)—For a maximum joint opening of 89 mm (3.5 in.) normal to the centerline of the joint at −7ºC (20ºF) for concrete superstructures or at −18ºC (0ºF) for steel superstructures, use an evazote joint seal at both interior bents and end bents. The joint shall be sawed prior to the casting of the barrier rail or sidewalk.

For projects with a design average daily truck traffic of 2,500 or more, the evazote joint seal shall be armored from gutterline to gutterline. The formed opening shall be detailed with the seal turned up into the sidewalk or barrier rail. The width of the formed opening shall match the computed sawed opening.

- Optional compression joint seals—At joints where the skew is between 70º and 110º, the contractor shall have the option to use a compression joint seal. A maximum joint opening of 89 mm (3.5 in.) normal to the centerline of the joint should not be exceeded. The joint shall be sawed prior to the casting of the barrier rail or sidewalk.

Optional compression joint seals shall be armored consistent with the criteria for evazote joint seals.

- Expansion joint seals—When compression or evazote joint seals cannot be utilized, use the standard expansion joint seal or the strip seal expansion joint.

For total movement over 65 mm (2.50 in.) use the modular expansion joint seal. Maintain a 25-mm (1-in.) minimum joint opening normal to the centerline of joint when fully expanded.

- Standard expansion joint seal—Cover plates will be required over expansion joint seals. Care should be taken in orientation of the cover plates with respect to traffic. The bolts on the cover plate shall be on the side of the approaching traffic.
- Strip seal expansion joints—Where the total movement is within the range for the standard expansion joint seal but t*he average daily truck traffic is less than 500, use a strip seal expansion joint.* Cover plates are required over strip seal expansion joints. The cover plate must be oriented so that the bolts are on the side of the approaching traffic.
- Modular expansion joint seals—The contractor will submit detailed drawings and specifications for the proposed modular expansion joint seal. Special snowplow protection of modular expansion joint seals will be necessary on bridges meeting the following criteria:
  - Being located in areas that require snowplow protection.
  - The skew angle is between 50º and 70º or between 110º and 130º.

OHIO

- Integral design—Integral construction involves attaching the superstructure and substructure (abutments). The longitudinal movements are accommodated by the flexibility of the abutments (a capped pile abutment on a single row of piles). These abutment designs are appropriate for bridge expansion lengths up to 250 ft (400 ft total length, assuming two-thirds of the movement could occur in one direction) and a maximum skew of 30º. The superstructure may be structural steel, cast-in-place concrete, prestressed concrete box, or I-beam*. Integral design shall be used where practical.* This design should used for symmetrical, uncurved structures.
- Semi-integral design—*Semi-integral design should be considered and is preferred to abutments with a deck joint.* These abutment designs are appropriate for bridge expansion lengths up to 250 ft (400 ft total length, assuming two-thirds of the movement could occur in one direction). The foundations for these designs must be stable and fixed in position. These designs are not applicable when a single row of piles is used. The expansion and contraction movement of the bridge superstructure is accommodated between the end of the approach slab and the roadway. This design should be used for symmetrical, uncurved (straight beam) structures.

To use this design, the geometry of the approach slab, the design of the wingwalls, and the transition parapets, if any must be compatible with the freedom required for the integral (beams, deck, backwall, and approach slab) connection to translate longitudinally. The expansion and contraction movements of the bridge superstructure will be transferred to the end of the approach slabs.

- Expansion joints using polymer modified asphalt binder—This device is generally for use on structures with concrete or asphalt overlays and where expected expansion is 0–40 mm (0–1.50 in.).
- Compression seal expansion devices—Maximum allowable seal size is 100 mm (4 in.). A 125-mm (5-in.) wide seal shall not be used because installation problems have been encountered. Compression seal expansion devices are limited to structures with a maximum skew of 15º. Movement should be limited so the seal is not compressed greater than 60% or less than 20%. The compression seal shall be of one piece across the total width of the structure. No splices are acceptable.
- Strip seal expansion devices—The seal size is limited to a 125-mm (5-in.) maximum. Unpainted A588M weathering steel should not be used in the manufacture of this type expansion device, because A588M does not perform well in the atmospheric conditions to which an expansion device is subjected. The strip seal shall be of one piece across the total width of the structure. No splices are acceptable.
- Modular expansion devices—Modular expansion devices may be required for structures when total required movements exceed movement capacity of a strip or compression seal. Use of modular devices requires approval of the Bureau of Bridges and Structural Design. Modular devices, main load-bearing beams, support beams, and welds shall be designed for fatigue. The manufacturer of the expansion device shall be required by plan note to submit design calculations showing that the device can meet the impact requirements.

Modular devices have been known to fail at connections due to faulty welding and fatigue. Therefore, it is recommended that the following general requirements be included in any project plan notes:

- Spacing of support beams shall be limited to 1000-mm (40-in.) centers under main load-bearing beams unless fatigue testing of the actual welding connection details has been performed to show that a greater spacing is acceptable.
- Shop or field welds, splicing main beams, or connections to the main beams shall be full-

penetration welded and 100% nondestructively tested in accordance with the AWS D1.5 Bridge Welding Code. Any required field splices or joints and nondestructive testing shall be located and defined in the plans.
  - Fabricators of modular devices shall be certified American Institute of Steel Construction, Category III.
  - Approved manufacturer/fabricator shall supply a qualified technical representative to the jobsite during all installation procedures.
  - Seals shall be one continuous piece through the total length of the structure.

- Tooth type, finger type, or nonstandard sliding plate expansion devices—An alternate type of expansion device for structures where movements exceed the capacity of either strip of compression seal devices. *Not generally recommended,* because this device has sealing, construction, fabrication, support, and installation problems. Use of this type of device requires approval by the Bureau of Bridges and Structural Design.

WASHINGTON STATE

Use L-abutments with expansion joints at ends for multiple-span bridges. Expansion joints may be eliminated for single-span bridges with the approval of the bridge design engineer. Consult expansion joint specialist or bridge design engineer for skews over 30º. Specific manufacturers may be specified, if necessary, to satisfy the design criteria.

- Small movement joint (less than 1.75 in.)—Use continuous compression seals with silicone poured and asphalt plug as alternates. Polymer headers are recommended with compression and silicone-poured seals.
- Medium movement joint (movement greater than 1.75 in. but less than 5 in.)—Use continuous strip seals armored and anchored with steel parts.
- Large movement joint (movement greater than 5 in.) —Use modular expansion joints with continuous strip seals and movement greater than 3 in. per sealing element. The maximum gap between support beams is 3.50 in. The design sealer is to be replaceable and provide access to joint for repair of all elements. Finger joints may be used with approval in special situations.

CHAPTER FIVE

PROVISIONS TO TEST JOINT SEAL WATERTIGHTNESS

Several respondents indicated that it was not uncommon to have leaking expansion joints on a new bridge. To address this problem, agencies are including performance standards as part of their specifications for new joint seals. The requirement may include a special test to ensure that the new joint does not leak before it is accepted from the construction contractor. Testing methods are being developed to identify seals that are not watertight. This chapter discusses performance provisions from four state DOTs for testing in-place deck seals.

IOWA

The Iowa Vacuum Joint Seal Performance Test (IA-VAC) Method—This test method describes the procedure for determining the performance of contraction joint seals by applying a vacuum above the seal and observing for air bubbles, which indicate seal leakage between pavement slabs or bridge deck sections.

Apparatus–IA-VAC

1. Chamber—150 mm (6 in.) × 1220 mm (48 in.) × 50 mm (2 in.);
2. Vacuum pump—Fisher, 246 watt (0.33 hp) 128 L (4 ft^3)/minimum airflow;
3. Vacuum reserve tank—14 L (0.5 ft^3);
4. Vacuum hoses—one 6 mm (0.25 in.) × 3 m (10 ft) and one 6 mm (0.25 in.) × 1 m (3 ft);
5. Sprayer—12 L (3 gal) with shampoo/water solution;
6. Portable electric generator—Honda, 1400 (1.9 hp); and
7. Two pieces of impermeable foam shaped to block the openings above the seal at each end of the IA-VAC chamber.

Test Procedure

1. Select the test location at random or as best suited for general coverage evaluation.
2. Spray wet the road surface area to be covered by the test chamber and double spray over the sealed joint with the water/shampoo solution.
3. If the joint seal is more than 3 mm (1/8 in.) lower than the road surface, place a short piece of impermeable foam in the joint under each end of the chamber to assist in chamber sealing.
4. Place the test chamber over the joint gland; press it onto the road surface by having the operator stand on it (until a vacuum indication is observed).
5. Observe and record the test location, vacuum reading, number of leaks, and cause of leak.
6. Close the vacuum line valve; open the vacuum release valve.

NEW YORK STATE

The New York State Watertight Integrity Test requirements are as follows:

- At least 5 work days after the joint system has been fully installed, the contractor shall test the entire (full-length) joint system for watertight integrity. A method shall be employed satisfactory to the engineer. The entire joint system shall be covered with water either ponded or flowing for a minimum duration of 15 min. The concrete surface under the joint shall be inspected during this 15-min period and also for a minimum of 45 min after the supply of water has stopped for any evidence of dripping water or moisture. Watertightness shall be interpreted to be no free dripping water on any surface on the underside of the joint. Patches of moisture shall not be the cause of nonacceptance. The contractor shall locate the place(s) of leakage and shall take any and all measures necessary to stop the leakage. This work shall be done at the contractor's expense.
- Should the joint system exhibit evidence of water leakage at any place whatsoever, the contractor shall locate the place(s) of leakage and shall take any and all measures necessary to stop the leakage. This work shall be done at the contractor's expense.
- Any water integrity test performed subsequent to the contractor's previously described corrective measures shall carry the same responsibility as the original test.
- In the event that measures to eliminate leakage have to be taken, a subsequent water integrity test shall be performed subject to the same conditions as the original test.

NORTH CAROLINA

Upon completion of an expansion joint seal, the top surface shall be subjected to a water test to detect any leakage. The roadway section of the joint from curb to curb, or barrier rail to barrier rail, shall be covered with water, either ponded or flowing, of not less than 1 in. above the roadway surface at all points. Sidewalk sections shall be diked and an unnozzled water hose delivering approximately 1 gallon of water per minute shall be secured to the inside face of the bridge railing trained in a downward position about 6 in. above the sidewalks, such that there will be continuous flow of water across the sidewalk and down the curb face of the joint.

The ponding or flowing of water on the roadway and continuous flow across sidewalks and curbs shall be maintained for a period of 5 h. At the conclusion of the test, the underside of the joint shall be closely examined for leakage. The expansion joint seal shall be considered watertight if no obvious wetness is visible on the engineer's finger after touching a number of underdeck areas. Damp concrete that is not enough to impart wetness to the finger will not be considered a sign of leakage.

Should the joint system exhibit evidence of water leakage at any place whatsoever, the contractor shall locate the place(s) of leakage and shall take any and all measures necessary to stop the leakage. This work shall be done at the contractor's expense. In the event that measures to eliminate leakage have to be taken, a subsequent water integrity test shall be performed subject to the same conditions as the original test. The subsequent water integrity test shall be done at the contractor's expense.

UTAH

Watertight test—Ensure that joint areas can hold water for 2 h without leakage.

CHAPTER SIX

LESSONS FOR MAXIMIZING JOINT SEAL SERVICE LIFE

Not all agencies achieve the same service life from watertight joint systems. This study suggests that there are some common factors that account for these differences. Several factors, such as climate (particularly temperature range), volume of truck traffic, use of snowplows, and use of deicing materials are not controllable. However, the difference between the satisfactory and unsatisfactory performance of an expansion joint seal is often controllable by the bridge owner. The state-of-the-practice survey for this study provided some examples, which are given in this chapter.

IMPLEMENT A PROACTIVE MAINTENANCE PROGRAM

In some agencies, bridge maintenance is reactive; that is, restricted to reacting to the failure of some part of the structure. However, to maintain is to preserve, and this requires a proactive strategy. Unfortunately, the resources allocated to bridge maintenance are often inadequate for crews to respond to anything other than immediate problems. Such a strategy is justified because funds are limited. Neglecting maintenance is not cost-effective. The appropriate level of maintenance extends the service life of the bridge and reduces the total life-cycle costs.

A proactive maintenance program stresses preventive maintenance. Preventive maintenance involves using maintenance-friendly products and designs, which may initially cost more. Maintenance-friendly joint systems are durable, accessible, repairable, and replaceable. Preventive maintenance activities include washing decks, keeping drains open, removing debris, and fixing small problems before they result in system failure. Experience has shown that for preventive maintenance to occur, it must be agency policy and promoted by top management.

Some preventive maintenance procedures, such as deck washing, are performed at regular intervals. Others, such as the repair of a loose anchor or an unbonded seam, must be identified by a thorough inspection program and given a high repair priority. Although agencies are only beginning to keep the kind of records necessary to quantify the benefits, questionnaire responses indicate that preventive maintenance is considered cost-effective, particularly when it is applied to a bridge deck expansion joint seal.

Preventive maintenance extends the life of joint seals. To say that a leaking joint seal may be better than no seal is like saying a leaking roof is better than no roof. The objective of preventive maintenance should be to maintain a watertight seal. The seal should be repaired if any part is leaking. Debris and gravel should be removed from the surface to prevent damage to the seal. Preventive maintenance includes improving the approach roadway pavement surface or draining to keep debris off the deck. Figure 36 shows a watertight compression seal on a bridge over the New York State Thruway near Albany. The seal was installed in 1986. Figure 37 shows the excellent condition of the seats and beam-ends under the joint. Figures 38 and 39 show the top and bottom, respectively, of a strip seal in similar condition, from the same general area. The service life of the joint can be improved when an agency enforces a proactive maintenance strategy.

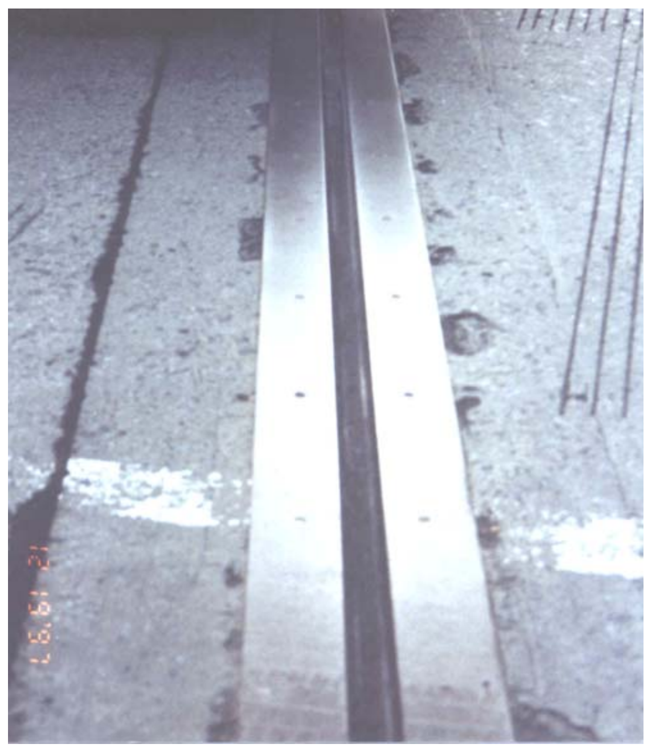


FIGURE 36 Watertight compression seal installed in 1986.

USE DECK JOINT BLOCKOUTS

A blockout is a rectangular section of bridge deck, adjacent to the joint, which is removed (or not cast). Figure 40 shows a blockout on one side of the joint. The blockout is used to facilitate proper sizing of the opening and positioning

FIGURE 37 Seats and beam-ends under watertight compression seal installed in 1986.

FIGURE 38 Top of watertight strip seal, New York State Thruway.

FIGURE 39 Under watertight strip seal, New York State Thruway.

FIGURE 40 Blockout for joint replacement.

and anchorage of the seal assembly. It also permits the use of a more durable joint edging material. The blockout is often required if the joint system is replaced in an existing deck. Concrete is removed when a joint system is replaced, and anchors are positioned before concrete is recast.

Blockouts are also used when certain types of joints are being placed in new decks and deck overlays. It is much easier to control the joint width and shape when the blockout is cast after the deck is cast. This permits the joint to be cast after the dead load deflection and concrete shrinkage have occurred. It is also easier to install the joint system at the proper elevation for optimum riding surface and minimum traffic damage when the blockout is cast after the deck is cast, particularly for those systems that are cast into the deck.

The material placed in the blockout is important. Many joint systems fail because of the failure of the deck material around the joint. Blockouts permit the use of more expensive and durable material to support the joint system and provide more durable joint edges to resist damage from high-impact truck traffic. Many agencies are pleased with the performance of elastomeric (polymer) concrete to cast joint blockouts. An example of a polymer concrete blockout with a poured-in-place silicone seal is shown in Figure 41.

FIGURE 41 Watertight poured-in-place seal with polymer material in blockout.

BOND THE JOINT SYSTEM TO SOUND CONCRETE

A newly replaced joint system is no better than the adjacent bridge deck concrete. It is important that the adjacent existing concrete be sound. Failed joint systems can result from a maintenance crew's attempting to bond the material in a newly cast joint blockout to existing salt contaminated or unsound concrete. Figure 42 provides an example of this type of failure. It performs in the same way as a good-quality deck patch surrounded by poor quality existing deck concrete. The patch will fail because the interface between the old and new concrete weakens and fails. Corrosion engineers tell us that corrosion cells develop when salt-contaminated and new concrete are cast at adjacent locations. This difference in the old and new concrete accelerates the corrosion of the reinforcing steel, which results in subsurface deck delimitation.

Although it is always important that new concrete be placed and consolidated properly, it is particularly important to provide a good-quality support and anchorage for the joint system. If metal plates and armor are not completely supported, because of voids in the concrete, they will flex under traffic. Such flexing accelerates metal fatigue and anchorage failure. Also, anchors should be recessed below the deck surface to protect against snowplow damage.

FIGURE 42 Effect of poor quality blockout material.

POSITION THE SEAL TO MATCH AMBIENT TEMPERATURE

Expansion joint seals must be capable of expanding, without damage, to accommodate the maximum opening that occurs in the winter when the bridge superstructure is cold. Similarly, they have to contract or buckle, without damage, to accommodate the smallest opening that occurs on the hottest day of summer. A properly designed seal should accommodate the full temperature range, assuming that the opening is the correct width and the seal is positioned properly at time of installation to reflect the ambient temperature.

To ensure the most efficient use of the seal material, it is important that quality control procedures be implemented to ensure that the seal is set, or anchored, in the proper position to reflect the ambient temperature. For example, if the seal is set in a midrange position on a very hot day, it may not be capable of expanding to accommodate the opening on a very cold day without damaging the seal or anchors, and compromising the waterproofing capability.

CONSTRUCT THE PROPER SIZE JOINT OPENING

The sizes of joint seals are determined based on the range of movement. The size of the opening is designed to keep the seal watertight at all times without damage from tearing or crushing. For optimum service life of the joint seal, the opening must be constructed properly. It is critical to the seal performance that the opening be the correct size for the deck temperature at the time it is measured. The sides of the opening must be vertical and the opening must be straight, with parallel edges, for the total joint width. This construction is particularly important when compression seals are used.

FIGURE 43 Saw cutting a joint opening.

If a compression seal is being replaced, the actual opening should be measured and deck temperature recorded to ensure that the new seal is properly sized. If an existing deck is being saw cut to accommodate a new compression seal, a template should be securely attached to the deck surface to ensure that the saw cut is straight. A two-blade saw should be used in the sawing to ensure a uniform width. Figure 43 shows a joint opening being saw cut.

INSTALL THE JOINT AFTER PLACING THE OVERLAY

Various methods are used to reinstall joint systems when an overlay is placed on a bridge deck. Some agencies have relocated the joint system first by casting a concrete dam around the joint and placing the overlay up to the face of the dam. On rare occasions, joint systems have been anchored in place and installed as part of the overlay by consolidating the overlay material around the joint system anchors. Both of these methods tend to result in a rough riding surface over the joint. A smoother riding surface is achieved by placing the overlay across the joint opening and then installing the joint seal to match the overlay surface. Saw cutting and removing the overlay material around the joint creates blockouts. The new joint system is then cast into the blockout with concrete or polymer material. This is a better method of achieving a smooth riding surface.

PROTECT AGAINST UNUSUAL MOVEMENT

Joint seals occasionally fail because of unexpected substructure movement. Embankment pressure, settlement, scour, or a seismic event might be the cause. Such movement might cause the joint to open or close beyond the design assumptions. Seals may tear or crush, or anchors may fail. To correct the problems, the substructure must first be stabilized and the bearings repositioned, then the joint opening may be restored either by saw cutting or recasting the concrete. Occasionally, if the width of the opening has increased, a wider seal can be used to avoid recasting of the joint.

FOLLOW THE MANUFACTURER'S RECOMMENDATIONS

Contractors or maintenance crews often use familiar methods to install new products. It is helpful for them to have a representative of the manufacturer present the first time a new product is installed. If this is not possible, the manufacturer's recommendations should be followed unless there is a very good reason to do otherwise. It is in the manufacturer's best interest that its products perform satisfactorily.

AVOID SPLICES IN PREMOLDED EXPANSION SEALS

Most agencies prohibit splices in premolded expansion seals, which limits their use—particularly certain types, such as a cushion joint. It is important to ensure that the premolded material is available in the required length to seal the total length of the joint. Special planning is necessary when replacing a bridge under traffic using stage construction. The seal must be installed after the total width of the new deck is constructed. One method is to wait to saw cut the blockouts. To reduce costs, some agencies permit splices in the curb, sidewalk, or rail area, because those portions rarely require replacement.

Seamless full-length seals are also possible with modular joints. The entire width of the framework is installed in sections. Seamless seals are then installed across the entire deck.

PROTECT AGAINST SNOWPLOW DAMAGE

Considerable damage is inflicted on joint seals by snowplow blades. This is more of a problem in states that receive large amounts of snow, because they usually have larger plows and use them often during the snow season. Joints that experience the most damage are those that are skewed at the same angle as the angle of the blades. States such as Minnesota and Wyoming have installed special metal plates over seals to reduce joint seal damage. They are installed on bridges that are skewed at the same angle as the snowplow blades. Metal extrusions or strips are attached to the joint edge over the opening to keep the blade from damaging the seal. The extrusions are recessed slightly below the deck surface.

CHAPTER SEVEN

CONCLUSIONS

Although the current trend is to eliminate deck joints in bridge decks whenever possible, the vast majority of existing bridges have joints, a situation that will continue for many years. As a result, damaged and leaking bridge deck joints remain a significant problem for most transportation agencies. Therefore, it is important to minimize the leakage to avoid serious damage to the bridge structural support system. Almost all transportation agencies interviewed for this report favored closed (watertight) deck joint systems to reduce damage, although such joints historically have had problems related to the anchorage of the metal plates and angles. The primary reason that most transportation agencies do not use open joints, such as the butt, sliding plate, and finger joints, is because they permit corrosive contaminants to drain through the deck. Although drainage troughs may help, on most bridges they introduce another set of problems.

The types of currently available closed (watertight) joint systems include poured in place, asphalt plug, compression, inflatable, strip, and modular. Some closed systems perform better than others, and performance varies among agencies. All closed systems have a limited leakproof service life. Factors that influence the leakproof service life include quality control during construction and the level of preventive maintenance that is provided.

Both open and closed systems have problems with damage to the concrete adjacent to the joint system, including edge raveling, anchorage failure, and a rough transition from the deck to the joint system. This problem can be remedied by installing the joint system after the deck is cast. A blockout is detected around the joint and either very high-quality concrete or polymer material is cast into the blockout to support the joint system.

Transportation agencies are increasingly designing bridges without joints. In addition, some agencies are retrofitting existing decks and superstructures to reduce the number of joints. However, this effort has not yet had a significant effect on the total joint inventory; most bridges still have deck joints, and most deck joints have problems. Those surveyed during this project expressed a wide range of opinions regarding the best joint treatment.

The premolded neoprene strip seal is the joint system favored for short-to-moderate length continuous spans by most bridge owners. Other favorites include the premolded compression seal, the field-molded polymer seal, and the asphalt plug joint system. Although all of these treatments can pose problems, they are the preferred choices of the agencies contacted as part of this survey.

For longer spans there are only two expansion joint choices: the finger joint or the modular system, which are favored by an approximately equal number of respondents. For those who give cost a high priority, the finger joint is preferred, with a trough to collect material passing through the opening. For those who demand watertightness, the modular system is the choice.

Lessons learned from this research included several suggestions that bridge owners could implement to improve bridge deck joint performance and extend service life, including

- Implementing a proactive deck joint maintenance program;
- Using deck joint blockouts adjacent to openings when placing a joint system;
- Supporting each replacement joint system on sound existing concrete;
- Installing each seal to match ambient temperature;
- Ensuring that the joint opening size and shape is properly constructed;
- When placing the deck overlay, installing the joint system after the overlay is placed;
- Protecting against unusual joint movement that could damage the joint seal;
- Following the manufacturer’s recommendations for selection and installation;
- Avoiding splices in premolded expansion material; and
- Protecting against snowplow damage.

This report also provides suggestions for further research and operational actions.

- Bridge owners would be more likely to make better decisions if more objective performance data related to the life-cycle cost of the joint treatment alternatives were accessible. These data should include the cost of damage that joint problems cause to other parts of the bridge. Most agencies do not currently have this type of data available. This information could be collected and compared best by a bridge management system. However, current bridge management system implementation has not advanced to the point where this can be done. More research is recommended to advance the technology for a bridge management system so that this type of assessment can be made by project-level decision makers.

- It is also important to identify the factors that influence joint system service life, given that systems that perform well for one agency can perform poorly for another. There is little information currently available to identify and evaluate the factors that lead to these differences in performance. A technology transfer program could be used to collect and distribute information on uniform performance for the different types of deck joints. Such a program might be expanded to collect performance data for other important bridge preservation alternatives as well. Research is needed to study how this can best be accomplished.
- Included in the research should be selection criteria, design and construction requirements, quality control recommendations, and maintenance requirements. Appropriate cautions might also be suggested about avoiding certain joint seals in situations where they are not likely to be successful.
- Another research topic for consideration is to identify a test method for evaluating the long-term durability of flexible joint systems. Durability consideration would include
  - Seal of joint material with concrete deck,
  - Mechanical wear resistance,
  - Tear or cut resistance,
  - Anchorage, and
  - Resilience.

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3. Issa, M., B. Robinson, and M. Shahawy, *On-Site Evaluation of Bridge Deck Expansion Joints*, Florida Department of Transportation, Structures Research Center, Tallahassee, February 1996, 182 pp.
4. *Tentative Guide Specifications for Horizontally Curved Highway Bridges*, American Association of State Highway and Transportation Officials, Washington, D.C., 1993, 121 pp.

GLOSSARY

ADT—Average daily traffic.
ADTT—Average daily truck traffic.
Blockout—A rectangular portion of a concrete deck adjacent to the joint and extending the length of the joint. It is left unfilled when the deck is cast or removed from an existing deck. The blockout is cast after the deck to form the joint edge and anchor some expansion joint systems.
Creep—A characteristic of concrete members that results in the members growing slightly shorter over time.
Delaminate—To separate below the surface.
Elastomeric concrete—A two-part polymer product mixed with graded aggregate, which can be used to in a joint blockout.
Evazote—The brand name for a type of closed cell elastomer joint seal.
Gland—A thin strip of waterproof material.
Live load—The portion of a load that does not remain constant; for example, the load caused by vehicles crossing a bridge.
Modular—Composed of similar segments.
QA/QC—Quality assurance and quality control.
Scour—The removal of particles of material protecting or supporting a substructure unit by the force of water flowing under the bridge.
Service level—A category of predefined characteristics associated with minimum condition and functional limitations used to measure the serviceability of a highway system component.
Silicone—A flexible polymer waterproofing material created from mixing two components. Used in a joint seal, it shapes into the opening and sticks to the sides.
Transverse—A direction perpendicular to the direction of traffic.

APPENDIX A

Survey Questionnaire

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Project 20-5, Topic 30-08

Bridge Deck Joint Performance

QUESTIONNAIRE

Name of respondent: ____________________

Title: ____________________

Agency: ____________________

Address: ____________________

____

Phone no.: ____________________

E-mail address: ____________________

Attached is a questionnaire seeking information on the current use, design, maintenance, rehabilitation, and observed field problems with respect to bridge deck expansion (movement) joints. Several of the questions included in this survey request information that is quite specific. If the requested information is not known or easily available, please provide your best estimate. Feel free to provide information on deck joints that is not addressed in the survey.

Please return the completed questionnaire and any supporting documents to:

David I. McLean
Department of Civil and Environmental Engineering
Washington State University
Pullman, WA 99154-2910

If you wish, you may fax your response to (509) 335-7632. If you have any questions, please contact me by phone at (509) 335-3110.

We would appreciate your response by June 1, 1999.

THANK YOU FOR YOUR TIME AND EFFORT!

PART 1 DESIGN PROCEDURES FOR BRIDGE DECK JOINTS

1. What specifications are used by your agency for the design of bridge deck expansion (movement) joints?

2. What factors are considered when designing and specifying a particular expansion joint?

- ❑ Type of bridge
- ❑ Bridge span
- ❑ Movement range
- ❑ Service level
- ❑ Climate conditions
- ❑ Expected joint life
- ❑ Bridge alignment
- ❑ Type of bridge supports
- ❑ Installation time
- ❑ Joint performance/previous experience
- ❑ Durability
- ❑ Maintenance requirements
- ❑ Initial costs
- ❑ Life-cycle costs
- ❑ Joint details at curbs, concrete barriers, or deck edges
- ❑ Other factors—please list ____
  ____
  ____

As applicable, please reference or attach the pertinent design provisions from your specifications for the factors checked above.

3. Does your agency try to minimize or eliminate the use of deck joints for new construction? If so, what considerations are made in the design of the other bridge components?

PART 2 USE OF AND EXPERIENCE WITH DECK JOINTS

1. Historically, what has been your agency's overall experience with open deck joints, such as formed joints or finger plate joints?

2. Are there particular types of open deck joints and/or joint materials that are avoided? Please explain.

3. Does your agency presently specify the use of open deck joints?

- ❑ Yes—Please answer the questions listed on the following page for each type of open joint in use.

- ❑ No—If no, please answer in the space below why open joints are not used, and proceed to Question 4 of this questionnaire.

COPY THIS PAGE AND PROVIDE RESPONSES FOR EACH TYPE OF OPEN JOINT

Type of open deck joint in use: ____

- List common manufacturers who provide this type of joint in your bridges and/or attach drawings as relevant.
- In what type(s) of bridges and/or for what level of service are these joints specified?
- Note any skew limitations for use of these joints.
- For what movement ranges are these joints used?
- Do you utilize troughs with these open deck joints, either as new construction or as retrofit?
- Do you employ armor or other measures to protect this type of joint? Please explain and attach relevant design details.
- What has your agency's experience been with this particular type of open joint?

4. Historically, what has been your agency's overall experience with closed deck joints, such as poured seals, strip seals, compression seals, elastomeric seals, and sliding plates?

5. Are there particular types of closed deck joints and/or joint materials that are avoided? Please explain.

6. Does your agency presently specify the use of closed deck joints?

   ❑ Yes—Please answer the questions listed on the following page for each type of closed deck joint in use.

   ❑ No—If no, please answer in the space below why closed deck joints are not used, and proceed to Question 7 of this questionnaire.

COPY THIS PAGE AND PROVIDE RESPONSES FOR EACH TYPE OF OPEN JOINT

Type of open deck joint in use: ____

- List common manufacturers who provide this type of joint in your bridges and/or attach drawings as relevant.

- In what type(s) of bridges and/or for what level of service are these joints specified?

- Note any skew limitations for use of these joints.

- For what movement ranges are these joints used?

- Do you employ armor or other measures to protect this type of joint? Please explain and attach relevant design details.

- Are there components of this particular type of closed deck joints that your agency has found to be problematic? If so, please explain and attach drawings describing the details as appropriate.

- What has your agency's experience been with this particular type of closed joint?

7. Does your agency presently specify the use of modular bridge joint systems?

   ❑ Yes—Please answer the questions listed further down the page.

   ❑ No—If no, please answer in the space below why modular bridge joint systems are not used, and proceed to Part 3 on page 8 of this questionnaire.

- List common manufacturers who provide the modular bridge joint systems in your bridges and/or attach drawings as relevant.

- In what type(s) of bridges and/or for what level of service are these joints specified?

- Note any skew limitations for use of these joints.

- For what movement ranges are these joints used?

- Are there components of the modular bridge joint systems that your agency has found to be problematic? If so, please explain and attach drawings describing the details as appropriate.

- What has your agency's experience been with modular bridge joint systems?

PART 3 DECK JOINT CONSTRUCTION PRACTICES

1. Are there any specific installation practices that your agency has found to influence, either positively or negatively, the performance, general durability, or life of deck expansion joints? If yes, please explain and reference or attach the relevant specifications.

2. Does your agency require quality control and assurance procedures for the construction of deck joints? If yes, please explain and reference or attach the relevant specifications.

3. What specifications and/or types of tests on joint materials are required for acceptance.

4. Do you allow field splicing of joint seals?

❑ Yes
❑ No

If yes, please describe the procedures and any special materials or equipment required.

5. What types of anchorage details for deck joints does your agency use? Please explain and reference or attach the relevant specifications.

6. Does your agency have special requirements for the concrete in the blockouts surrounding the deck joints? Please explain and reference or attach the relevant specifications.

7. Does your agency require any specific weather conditions for the installation of deck joints? Please explain and reference or attach the relevant specifications.

8. Are special practices employed to handle joint installation at deck ends, curbs, and parapet walls. Please explain and reference or attach the relevant specifications.

PART 4 DECK JOINT MAINTENANCE AND REHABILITATION PRACTICES

1. Does your agency conduct periodic inspection and maintenance of bridge deck expansion joints? If so, please describe (how often, what is looked for, what is the most common problem area?).

2. If your agency has a deck joint maintenance program, what is your opinion of the overall effectiveness of the program? Is maintenance of joints considered to be cost-effective?

3. Does your agency have a strategy for rehabilitating bridge deck joints? If so, please explain (attach relevant documents as appropriate).

4. Does your agency attempt to reduce and/or eliminate deck joints as part of bridge rehabilitation? If so, please explain.

5. As part of the bridge rehabilitation, does your agency replace one type of deck joint with another? Please explain.

6. Do you have any recommendations for improving the service life of deck joints? Please explain. Use additional pages as necessary.

PART 5 PROBLEMS WITH BRIDGE DECK JOINTS

1. Does debris commonly collect in your deck joints? If yes, does the debris have adverse effects on joint performance?

2. What percentage of your closed joints leak? Typically, how long after installation does this occur? What do you attribute the leakage to?

3. Have you observed any problems associated with inadequate movement capacity in your deck joints. Please explain.

4. How does your agency define failure in a deck joint? Please explain for each failure case and joint type, as applicable.

5. Please provide a list of observed performance problems, not mentioned above, for bridge deck expansion joints in your agency's inventory. For each problem listed, please include

- A description of the type of problem
- Extent of the problem
- Probable cause of the problem
- Type of joint for which the problem occurs most
- Type of bridge for which the problem occurs most
- Service conditions
- Other relevant factors (such as the presence of snow removal activities, climatic conditions)
- Steps taken to remediate the problem

Please use additional pages as necessary.

APPENDIX B

Questionnaire Respondents

Agency	Title
Arizona Department of Transportation	State Bridge Engineer
Arkansas Department of Transportation	Bridge Engineer
Colorado Department of Transportation	Prof. Engineer II
Connecticut Department of Transportation	Dir. Research & Materials
Florida Department of Transportation	Senior Str. Design Engr.
Illinois Department of Transportation	Br. Std. & Spec. Engr.
Indiana Department of Transportation	Br. Rehab. Engineer
Iowa Department of Transportation	Br. Maint. Engr. & Chief Str. Engr.
Kansas Department of Transportation	Br. Inspec. Engr. & Br. Maint. Engr.
Kentucky Transportation Cabinet	Dir. Div. Bridge Design
Louisiana Department of Transportation	Br. Design Admin./Br. Maint. Engr.
Maine Department of Transportation	Shop Drawing Engr. & Engr. Tech.
Minnesota Department of Transportation	State Bridge Engineer
Mississippi Department of Transportation	Bridge Engineer
Missouri Department of Transportation	Research Director
Montana Department of Transportation	Bridge Design Engineer
Nevada Department of Transportation	Principal Bridge Engineer
New Hampshire Department of Transportation	Design Chief
New Jersey Department of Transportation	Manager Str. Engineer
New Mexico Department of Transportation	Engineer III
New York State Department of Transportation	Assoc. Civil Engineer
North Carolina Department of Transportation	Transp. Engineer III
Oklahoma Department of Transportation	State Bridge Engineer
Oregon Department of Transportation	Interim Br. Oper. Mgr. Engr.
Pennsylvania Department of Transportation	Chief Bridge Engineer
Rhode Island Department of Transportation	Senior Civil Engineer
South Carolina Department of Transportation	Bridge Design Engineer
South Dakota Department of Transportation	Bridge Maintenance Engineer
Tennessee Department of Transportation	Director Structures Division
Texas Department of Transportation	Br. Const. & Maint. Engr. III
Utah Department of Transportation	Bridge Inspector
Virginia Department of Transportation	Str. Engineer Supervisor
Washington State Department of Transportation	Str. Engineer
Wyoming Department of Transportation	State Bridge Engineer

Agency	Title
Alberta Infrastructure	Fabrication Standards Engr.
British Columbia	
Province of Manitoba Transp. & Government Services	Director Bridges & Strs.
Newfoundland Dept. of Works, Services, & Transp.	Senior Engineer
New Brunswick Department of Transportation	Asst. Director Strs. Branch
Northwest Territories Department of Transportation	Head Structures Section
Nova Scotia Department of Transportation	Design Engineer
Ontario Ministry of Transportation	Str. Rehab. Engr. & Chair Exp. Jt. Ct.
Quebec Ministry of Transportation	Director Structures Division
Saskatchewan Highways & Transportation	Bridge Preservation Engineer
D. S. Brown Co.	General Manager Engineering
Modjeski and Masters, Inc.	Senior Associate
Parsons Brinckerhoff	Sr. Engr. Manager
University of Minnesota	Grad. Research Assistant

Abbreviations used without definition in TRB Publications:

AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
APTA	American Public Transportation Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
CTAA	Community Transportation Association of America
CTBSSP	Commercial Truck and Bus Safety Synthesis Program
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
IEEE	Institute of Electrical and Electronics Engineers
ITE	Institute of Transportation Engineers
NCHRP	National Cooperative Highway Research Program
NCTRP	National Cooperative Transit Research and Development Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
SAE	Society of Automotive Engineers
TCRP	Transit Cooperative Research Program
TRB	Transportation Research Board
U.S.DOT	United States Department of Transportation