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REPORT 467

NATIONAL
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PROGRAM

Performance Testing for Modular Bridge Joint Systems

TRANSPORTATION RESEARCH BOARD

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Performance Testing for Modular Bridge Joint Systems

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

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FOREWORD

By Staff
Transportation Research Board

This report contains the findings of research performed to develop performance requirements for modular bridge joint systems. The report includes recommended testing specifications; material, fabrication, and construction guidelines; and a joint anchorage design example. The material in this report will be of immediate interest to bridge designers.

Bridge deck joints are used to accommodate the longitudinal expansion and contraction of a bridge superstructure. Modular joints permit large movements and prevent corrosive roadway runoff from leaking onto the bridge beams and substructure. Modular bridge joint systems are complex and expensive mechanical devices. These systems are composed of various combinations of metal rails and metal support bars and elastomeric sealing systems. Many of these devices provide marginal performance, resulting in failures in the structural support and sealing system. Substantial maintenance is generally necessary to keep these devices operating. In many instances, these joints perform so poorly that they are removed and replaced prematurely. To assist transportation agencies in the selection and installation of these systems, performance requirements are needed.

Under NCHRP Project 10-52, the University of Minnesota developed performance requirements for modular bridge joint systems and developed test methods and test equipment for the prequalification and acceptance of such systems to meet these requirements. In addition, critical issues relating to design, fabrication, installation, and construction inspection were identified to ensure that these requirements provide a suitable service life. This report provides full details of the research methods. Recommended performance test specifications; materials, fabrication, and construction guidelines; and an anchorage design example are included in appendixes. Many of the guidelines are also applicable to strip seals.

CONTENTS

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Robert Dexter, Associate Professor of Civil Engineering, University of Minnesota, was the principal investigator. The other author of this report was Mark Mutziger, Graduate Research Assistant, University of Minnesota. Mark is currently employed at TKDA in St. Paul. Carl B. Osberg was the Graduate Research Assistant for the first half of the project and an author of the interim report. His work is also discussed in this final report.

The researchers would like to thank Robert Connor, Lehigh University, and Michael Irwin, Modjeski and Masters, Inc., for their help in developing this report. The authors appreciated the patience and direction of David Beal of NCHRP and the planning, review, and suggestions of the project panel. Paul Bergson, Structural Laboratory Manager, provided valuable help with the laboratory testing.

William J. Moreau, P.E., Chief Engineer for the New York State Bridge Authority, and Vince Kazakavich, State of New York Department of Transportation, provided invaluable help with the field visit access and information. The Minnesota, Colorado, Idaho, and Washington Departments of Transportation also provided significant help.

PERFORMANCE TESTING FOR MODULAR BRIDGE JOINT SYSTEMS

SUMMARY

When functioning properly, modular bridge joint systems (MBJS) provide good performance and can help protect the structure from deck drainage. If deck drainage falls freely through an open joint or spills over from a blocked trough, this drainage can cause costly excessive corrosion. However, no uniform national specifications for the design, performance, or construction installation of MBJS exist. Without specifications, the low-bid process results in less durable products because manufacturers design and fabricate these complex devices to achieve the lowest initial cost. Consequently, as with many other types of expansion joints, some MBJS have provided marginal performance, exhibiting premature failures in the structural supports, movement systems, and sealing systems. In addition, durability and even functional problems have occurred because of inadequate installation of MBJS.

A survey of transportation agencies and extensive observations of service performance of MBJS were used to develop a prioritized list of performance problems and to develop required performance levels. The premature failures were evaluated and it was found that failures are often a chain reaction (i.e., the failure of one component leads to the destruction of other components). Eventually, this chain reaction leads to a failure or loss of serviceability or functioning. On the basis of these evaluations, it is postulated that most of the premature failures can be avoided in the future if the following activities and guidance are implemented:

- Design specifications;
- Materials, fabrication, and construction guidelines; and,
- Performance testing.

When the root cause of an overall failure is a failure of the structural supports (i.e., the centerbeams and the support bars), it is usually the result of fatigue cracking. Research was previously conducted on this problem, and fatigue design and testing specifications were proposed in *NCHRP Report 402.* It is believed that implementing the design and testing specifications proposed in *NCHRP Report 402* can substantially reduce the occurrence of fatigue cracking.

The research described in this report focussed on the remaining performance problems. Relatively prescriptive materials, fabrication, and construction guidelines were developed

to address as many of these problems as possible. The proposed guidelines are based on the present best practices and specifications of the manufacturers, the states, and other agencies, and, therefore, should be easily implemented by bridge designers, MBJS manufacturers, contractors, and bridge owners. However, several performance factors could not be addressed through these guidelines because:

- No accepted materials specifications or tests exist;
- The diversity of MBJS designs precludes such prescriptive guidelines; or,
- The cause of the performance problem is not well understood and, therefore, a prescriptive solution is not available.

Two performance tests were developed that attempt to address these remaining performance problems that could not be addressed through the guidelines. These performance tests are an Opening Movement Vibration (OMV) test and a Seal Push Out (SPO) test. The OMV test simulates the movement demands on the MBJS while subjecting the specimen to vibration similar to that resulting from truck traffic. The SPO test measures the ability of the seals to remain attached to the metal separation beams while subjected to a vertical load simulating the effect of compacting debris in the seals.

The tests produce performance problems and failure modes similar to those observed in service. The tests reveal present design and material deficiencies and/or limitations of the MBJS, discriminate between different types and manufacturers of MBJS, and allow the MBJS to be rated on the basis of strength and durability. Most of the durability problems now associated with MBJS can be significantly reduced, if not eliminated, by implementing the following guidance:

- The OMV and SPO performance tests to prequalify MBJS;
- The proposed “Materials, Fabrication, and Construction Guidelines for Modular Bridge Joint Systems and Strip Seal Bridge Joint Systems” presented as Appendix B and;
- The fatigue design and testing specifications proposed in *NCHRP Report 402*.

CHAPTER **1**

INTRODUCTION AND RESEARCH APPROACH

1.1 MODULAR BRIDGE JOINT SYSTEMS DESCRIPTION AND USE

Expansion joints are placed in bridge decks or abutments to accommodate relative movement between superstructure segments of the bridges and movement between superstructures and abutments as a result of thermal expansion and contraction, creep and shrinkage of concrete, substructure settlement, live load, and other causes. Some expansion joints have also been designed to resist earthquakes. Such designs have successfully accommodated earthquake movement and remained functional, resisted earthquake forces, and helped provide damping.

Expansion joints can be broadly grouped into two categories: open and closed. Open joints (e.g., finger or tooth joints) allow water and debris to pass through the deck joint. This deck drainage often causes various problems, including corrosion of the bridge superstructure and substructure elements near the joint.

Finger joints can be made with drainage troughs to collect and redirect deck drainage. Although these troughs can be designed to be effective, experience shows that, typically, drainage troughs are poorly conceived and designed and, therefore, are ineffective and, in some cases, may even be counterproductive (*1, 2*). For example, Figure 1.1 shows finger joints with troughs filled with debris to the point where the debris has begun to inhibit proper movement of the joint.

Closed, or sealed, expansion joints offer corrosion protection to the underlying bridge superstructures by eliminating drainage through the deck joint. If a sealed expansion joint remains effective, this protection against corrosion extends the useful life of both concrete and steel bridges and reduces the need for coatings as well as coating maintenance and replacement. For example, weathering steel can be used under the joint without additional coatings, provided that the expansion joint can be relied on to remain sealed. Figure 1.2 shows 20-year-old weathering steel girders under a well-maintained expansion joint near Albany, New York.

Under the Section, "Location of Joints," the *AASHTO LRFD Bridge Design Specifications* state:

> Closed or waterproof deck joints should be provided where joints are located directly above structural members and bearings that would be adversely affected by debris accumulation. Where deicing chemicals are used on bridge decks, sealed or waterproofed joints should be provided. (*3*)

The commentary on that same section further states that:

> Open joints with drainage troughs should not be placed where the use of horizontal drainage conductors would be necessary. (*3*)

Much of the nation is dependent on deicing chemicals to keep roadway surfaces safe. Given the unreliability of troughs, sealed expansion joints are a better option than finger joints fitted with troughs.

One type of sealed expansion joint, a strip-seal expansion joint, uses elastomeric seals to flex between "edgebeams" embedded in the haunches of the concrete deck slab or abutment as shown in Figure 1.3. Strip-seal joints have been manufactured that have a total movement range of 127 mm (5 in.), but the *AASHTO LRFD Bridge Design Specifications* limit the total opening to 100 mm (4 in.) (*3*). Current design practice focuses on minimizing the number of movable deck joints. By eliminating intermediate joints, the movement requirements of the remaining joints is increased proportionally.

For greater movements, multiple elastomeric seals may be combined to form a modular bridge joint system (MBJS). An MBJS uses one or more transverse "centerbeams" parallel to the edgebeams to separate two or more elastomeric seals and, therefore, increase the total possible movement range to multiples of a single seal range. In a common MBJS design, longitudinal "support bars" span the expansion gap between superstructure units or abutments and support the transverse centerbeams. Figure 1.4 shows a cutaway view of this type of MBJS. These support bars slide in and out of support boxes embedded in the haunches of the bridge deck or abutment. The support bars usually slide between polytetrafluoraethylene (PTFE), commonly referred to as Teflon, surfaces that are bonded to elastomeric bearings and springs. The bearings and springs are typically precompressed and hold the support bar in place in the support boxes. Elastomeric springs or other control devices must be provided to ensure that the centerbeam spacing remains approximately equal.

MBJS are classified by the number of longitudinal support bars and how they are connected to the transverse centerbeams. The most common type of MBJS is the welded multiple-support-bar (WMSB) system. In this system, shown in

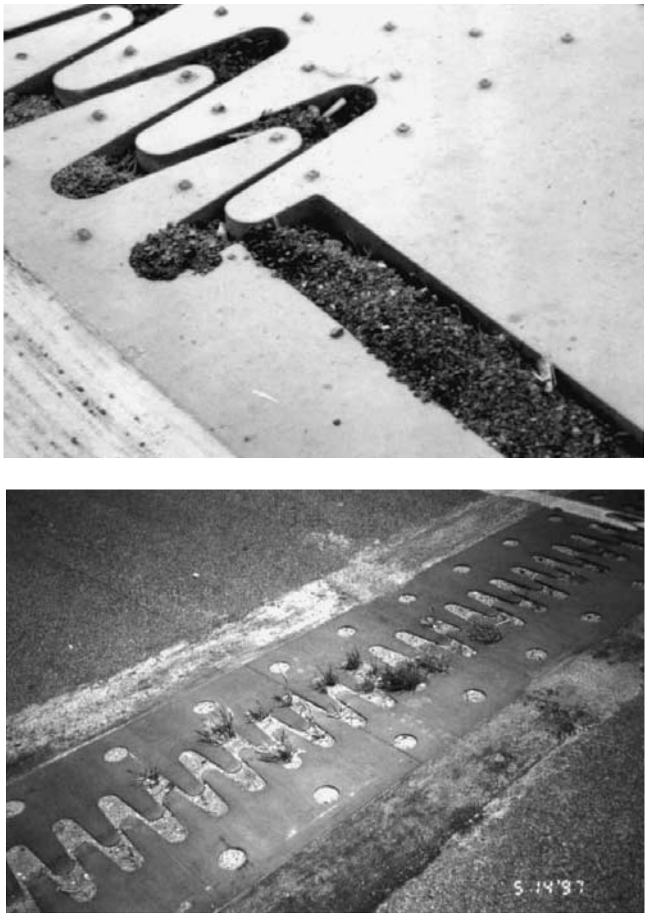

Figure 1.1 (Top and Bottom). Examples of finger joint troughs full of debris.

Figure 1.5, each support bar is welded to only one centerbeam. Given typical present centerbeam sections, the centerbeam span is limited to about 1,200 mm (48 in.) by the fatigue limit state (*4*). Therefore, there is a limit on the maximum width and number of bars in a support box. Although some large multiple-support-bar systems have been built and are perform-

Figure 1.2. Weathering steel and clean piertops under Hoosic St. Bridge near Albany, NY.

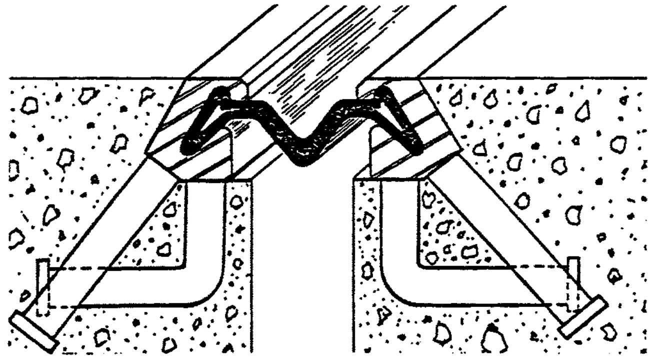

Figure 1.3. Strip-seal bridge joint system.

ing well, usually, multiple-support-bar systems are impractical for more than eight support bars (i.e., nine seals) or for movement ranges much larger than 700 mm (27 in.).

Single-support-bar (SSB) systems do not have to accommodate multiple support bars in each support box and, therefore, may be used for movements greater than 700 mm (27 in.). In an SSB system, only one support bar is connected to all of the centerbeams, as shown in Figure 1.6. The centerbeam/support bar connection typically consists of a yoke through which the support bar slides. Modern SSB systems typically have precompressed elastomeric springs and bearings in the yoke around the support bar.

In a special type of SSB system called the swivel joist or swivel joint system, the support bars (joists) also swivel about the centerbeam support bar yoke connection and, therefore, move laterally in the support box, in addition to sliding longitudinally as shown in Figure 1.7. In comparison with WMSB systems, the swivel joint system allows larger movements in the 5 deg of freedom other than longitudinal, particularly large transverse movements. For example, large swivel joints are used on the floating Lake Washington bridges in Seattle, Washington, on Interstate 90. The swivel joints on the Lacey V. Murrow Bridge have a 915-mm (36-in.) movement range and the swivel joints on the Third Lake Washington Bridge have a 1,220-mm (48-in.) movement range—the largest single support bar MBJS in the United States (*5*).

There is also a unique MBJS on the Hoosic Street, or Collar City, Bridge in Albany, New York (*6, 7*). This MBJS was manufactured in Europe and has a scissor mechanism that doubles as both the support bar and the equidistant mechanism. Figure 1.8 depicts this type of joint. Variations on this design now use the scissor, or trellis, mechanism only as an equidistant device and have a single-support-bar to support the centerbeams.

1.2 PROBLEM STATEMENT

Unfortunately, MBJS are typically procured on the lowest-bid basis. Although some states have developed individual specifications, most notably the State of Washington (*8*), no

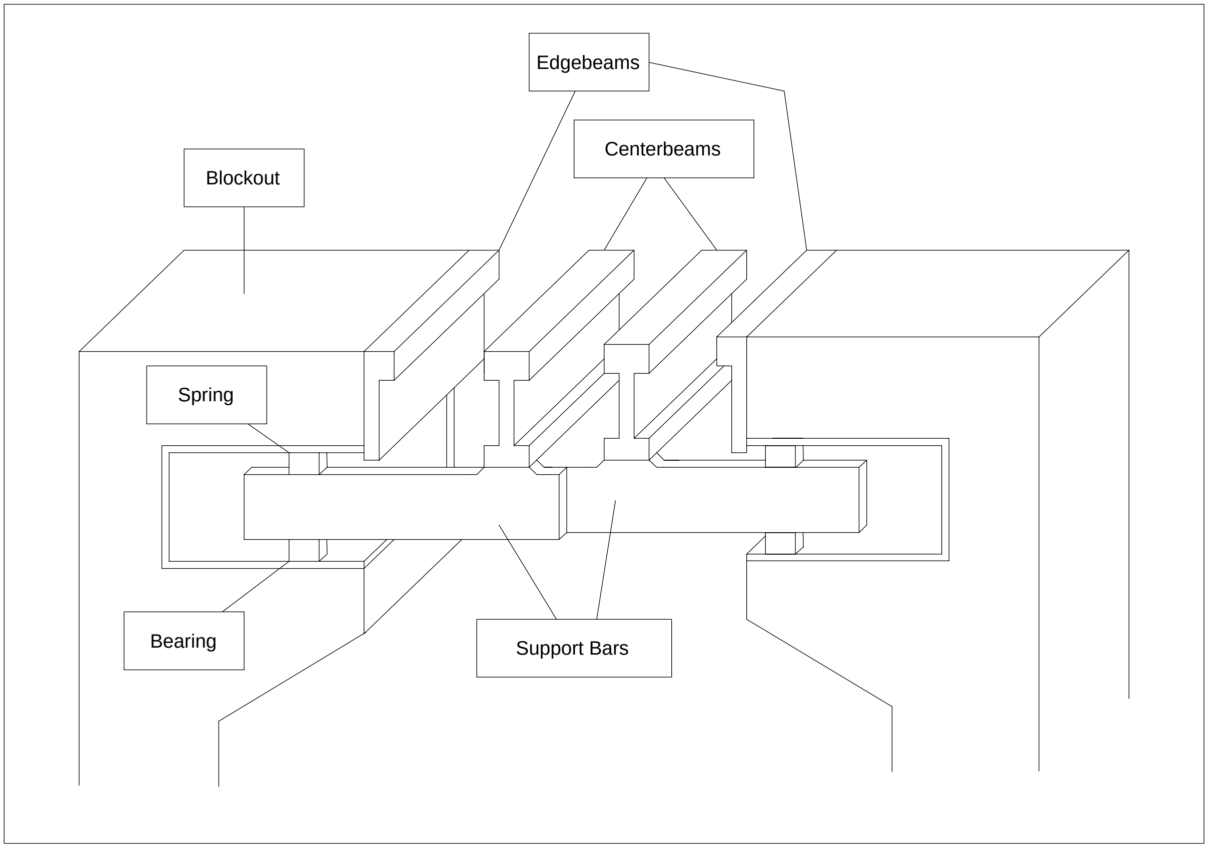

Figure 1.4.   Multiple-support-bar MBJS.

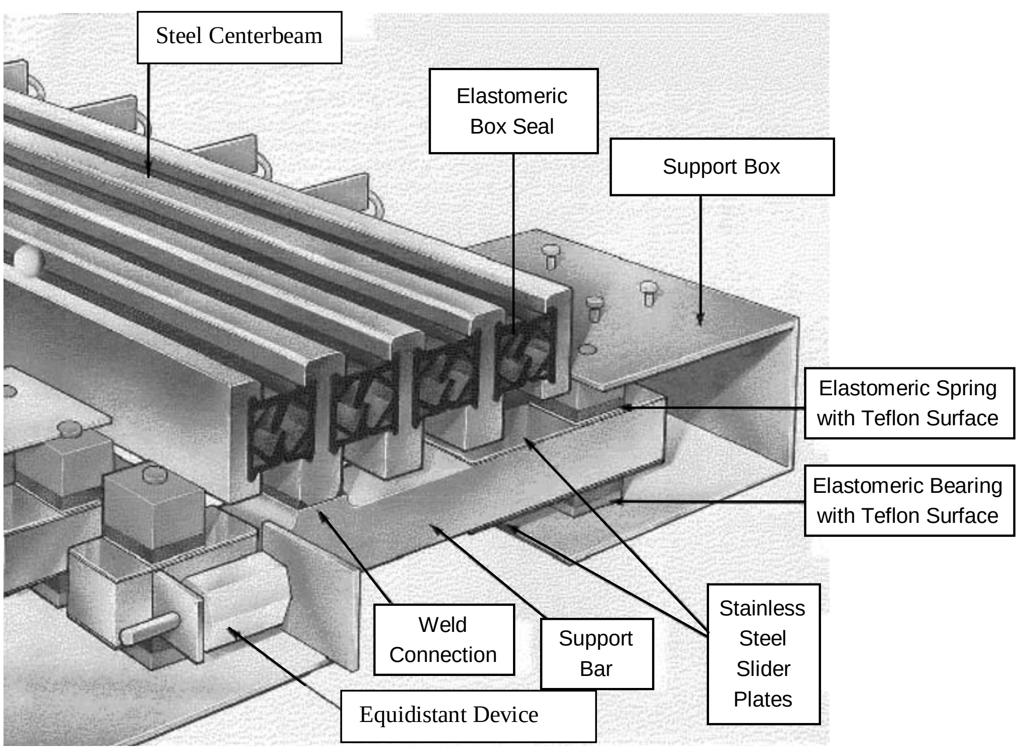

Figure 1.5.   Multiple-support-bar MBJS showing components.

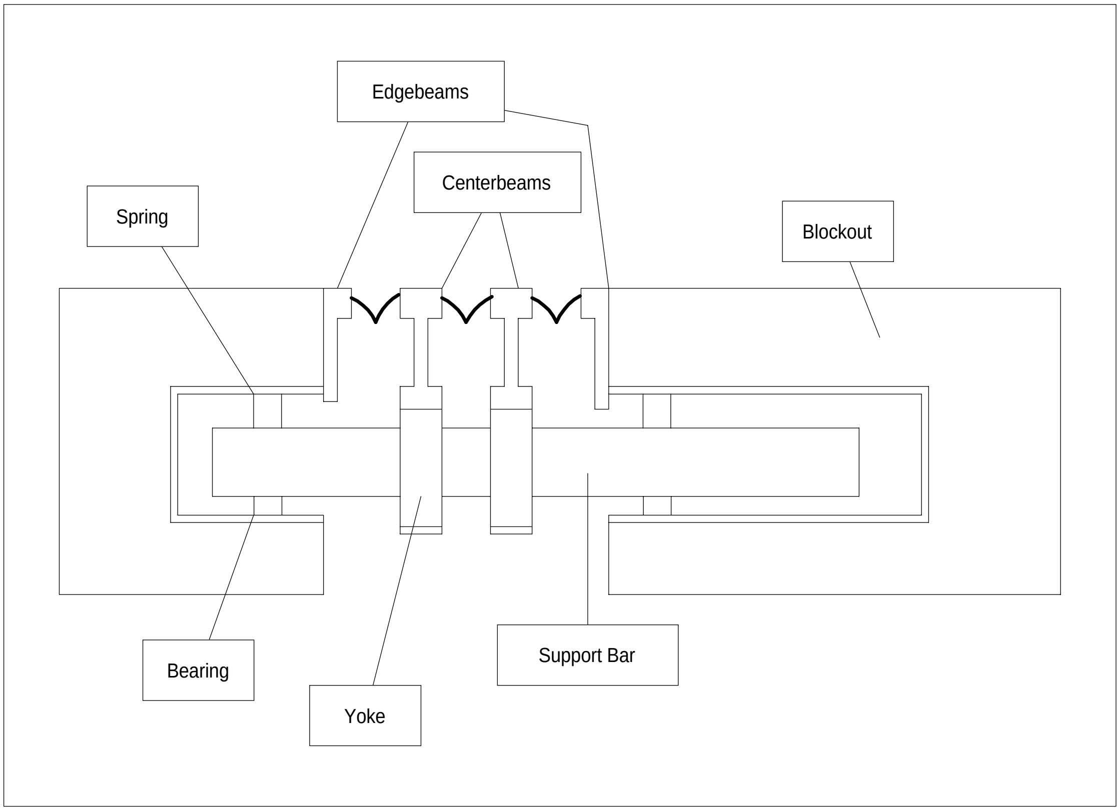

Figure 1.6. Single-support-bar MBJS.

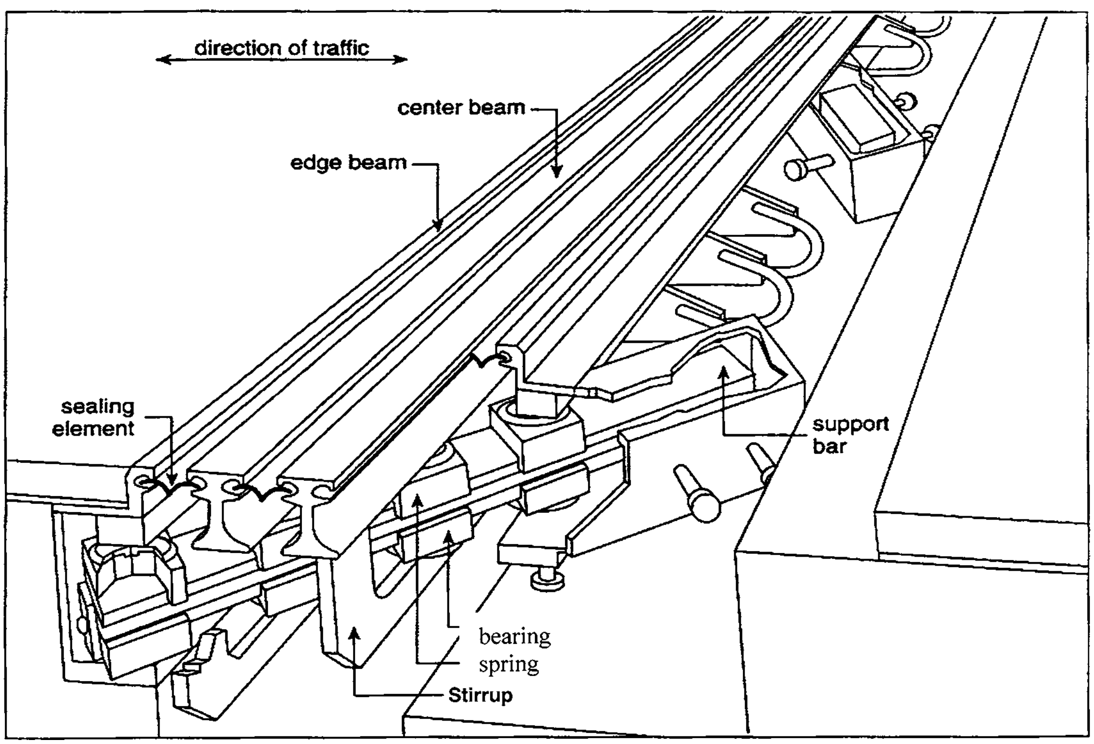

Figure 1.7. Swivel-joint type MBJS.

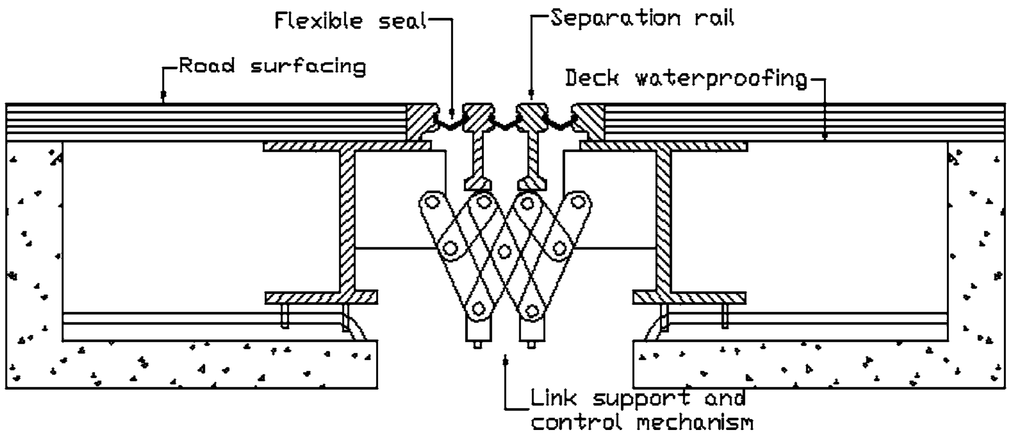

Figure 1.8. Scissor-type MBJS.

uniform national requirements exist for the design, performance, construction, and installation of MBJS. Without any specifications, the low-bid process inevitably results in increased durability problems as manufacturers endeavor to design and fabricate these complex devices with a lower initial cost. In addition, durability and even functional problems have occurred because of incorrect installation of MBJS.

Consequently, many MBJS have provided marginal performance, exhibiting failures in the structural supports, movement systems, and sealing systems. Substantial maintenance is generally necessary to keep these poorly performing MBJS operating. In many instances, MBJS have performed so poorly that they have been removed and replaced before their anticipated design life. Durability problems with MBJS can be broadly grouped into four categories:

- Poor detailing of the bridge or poor overall joint design,
- Problems that can be traced to improper installation,
- Wear and tear of the elastomeric parts, and
- Fatigue cracking of steel parts and their connections.

NCHRP sponsored a research project to address the fatigue-cracking problem. The results from this project are presented in *NCHRP Report 402* (*4*), including performance-based specifications and commentary for the fatigue testing and design of MBJS. MBJS that are designed and tested in accord with these specifications proposed in *NCHRP Report 402* should not experience fatigue cracking or other failure of the structural supports. However, the other durability problems have not yet been adequately addressed. In order to substantially reduce or eliminate these other problems, additional design, material, and fabrication guidelines; performance testing specifications; and installation guidelines are needed. The performance requirements and test methods must account for the complex behavior of an MBJS as a system, while being economical and reasonably easy to apply. These requirements and test methods must be general so that innovative designs for MBJS are not excluded.

1.3 OVERVIEW OF NCHRP PROJECT 10-52

The scope of this research (Project 10-52, "Performance Testing for Modular Bridge Joint Systems") was the performance and durability of the overall MBJS as a system. In particular, the focus was on the durability of the seals, bearings, springs, and other nonmetallic components. The objectives for NCHRP Project 10-52 were as follows:

- Identify and rate the importance of MBJS service problems and factors that significantly affect MBJS performance;
- Develop material, fabrication, construction, and installation guidelines; and
- Develop and verify prequalification requirements and tests.

To meet these objectives, the research included the following:

- A review of all literature on this subject and a survey of current manufacturers, U.S. and Canadian transportation agencies, contractors, consultants, researchers and others with MBJS experience;
- Field visits to MBJS to document in-service performance and failure modes; and
- Laboratory testing of complete full-size representative sample MBJS.

Minimum performance requirements are proposed, which can be specified by transportation agencies and bridge designers. Among these proposed requirements are a pair of prequalification and acceptance tests. In addition, guidelines for

the materials, fabrication, construction, and installation of MBJS are proposed.

1.4 ORGANIZATION OF THE REPORT

Chapter 2 discusses the research findings, including the performance factors for MBJS on the basis of the literature review, survey responses, and field visits. Chapter 2 also discusses the design and rationale for the proposed performance tests, as well as the results from the tests performed. (An interim report for this project covers the literature review, the survey, and field visits in detail and documents and ranks the various performance factors (*9*).) This report focuses primarily on the laboratory testing and development of the material, fabrication, construction, and installation guidelines. The data and discussion from the interim report will be referenced in this report only if relevant to these primary topics.

Chapter 3 presents the development of the proposed performance test specifications, as well as material, fabrication, construction, and installation guidelines. Chapter 4 contains final conclusions and suggestions for further research. The performance test specifications are presented in Appendix A, the materials, fabrication, and construction guidelines for MBJS and strip seal bridge joint systems are presented in Appendix B, and the anchorage design and calculations are presented in Appendix C.

CHAPTER 2

FINDINGS

Significant findings of the literature review, survey of transportation agencies and other knowledgeable individuals, field visits, and laboratory testing are summarized in this chapter. The information from the literature review, survey, and field visits was used to determine the performance factors and their relative importance. The performance factors were then separated into

- Those that can be adequately addressed through the proposed material and fabrication guidelines,
- Those that can be addressed through the proposed installation guidelines, and
- The remaining performance factors, the effects of which should be incorporated into the performance tests.

The rationales for the material and fabrication guidelines and the installation guidelines are presented in Chapter 3. The development of and results from the performance tests are discussed in this Chapter.

The performance tests were designed to evaluate the performance factors that cannot be addressed through the material and fabrication guidelines and the installation guidelines. Performing the tests on six different MBJS refined the procedure for the tests. The results of these tests are summarized and discussed in Section 2.2.

2.1 PERFORMANCE FACTORS

Considerable research has been done to define the performance factors for bridge joints. For example, the State of Florida conducted research on various bridge joint systems (*10*). Although MBJS were not included, many of the performance factors relevant to other bridge joints can be applied to MBJS. Using information from design and district engineers, along with the State's structure's design guidelines, the State of Florida's Structure Research Center established criteria for evaluation of MBJS performance. MBJS must

- Accommodate the full range of structural movements, without exceeding the manufacturer's recommended clear span at deck surface level when at maximum opening;
- Provide a proper anchorage and structural capacity to resist the anticipated loads;
- Have an acceptable riding surface;
- Be reasonably quiet and vibration free;
- Facilitate inspection, maintenance, repair, removal, and replacement;
- Be leak-proof with the sealing element continuous for the entire structure width; and
- Be corrosion-resistant.

In addition, MBJS must not

1. Restrict structure expansion and contraction, which may impart undue stress to the structure or
2. Be a catalyst or vehicle for electrolytic action.

In addition, the study reported that the following factors should be considered when selecting bridge expansion joints:

- System life, for mechanical integrity and integrity of a seal;
- Material cost;
- Installation cost;
- Installation time (time and extent of traffic interruption);
- Mechanical failure mechanisms that may present a danger to traffic;
- Construction tolerance (i.e., the skill or care required for installation—e.g., can typical road crews perform consistently good installations?);
- Expansion/contraction movement range; and
- Availability of parts and repair (e.g., are the parts and repairs available from the supplier only?).

The Transport Road and Research Laboratory (TRRL) in the United Kingdom investigated bridge joint performance factors and did include MBJS (*11*). The authors produced a list of performance requirements for bridge joints that is nearly identical to the State of Florida's requirements. In the TRRL report, it is concluded that the initial MBJS costs are "insignificant" when compared with the cost of maintenance, especially when user costs resulting from closure are included. It is also indicated that MJBS perform better than other types of bridge joints. The TRRL study found that traffic loading, faulty installation, poor detailing, or movements cause most joint failures to occur much sooner than the design life indicated.

Research into MBJS in-service use has shown that the performance of these systems is dependent on many factors. Based on the research described in the interim report, the performance factors for MBJS are listed in Table 2.1 with their respective desired performance level. Each of these performance factors will be discussed in detail in the following section.

2.1.1 Whole Life Cost

MBJS are typically used for longitudinal movements greater than 100 mm (4 in.). For this level of movement, there are only a few alternatives to using MBJS, and all have unsatisfactory characteristics that have, in some cases, resulted in high whole life costs.

An open joint, such as the finger joint, can be used in place of a sealed joint. However, these joints allow runoff to pass through the joint. This runoff, if not properly contained and handled, may cause corrosion of the bridge. There are documented cases of runoff through open joints causing corrosion severe enough to necessitate expensive corrective measures or even structural failure and bridge replacement (*12*). Finger joints have been specified with a trough or flexible "diaper" to collect the drainage and route it to downspouts. However, there are few reports of these systems working successfully without frequent cleanout. Some troughs have filled with debris within a few weeks of opening the bridge. Lack of maintenance often leads to clogged scuppers and unanticipated drainage paths. Again the runoff may leak or be diverted onto the bridge and cause deterioration.

MBJS are complex and expensive devices. Although the cost of MBJS have decreased substantially over the last decade, the installed cost is still on the order of $14 per meter for each millimeter of movement capacity ($100 per foot for each inch of movement capacity). For a larger bridge, multiple lanes and larger required movement, the cost can approach one million dollars. For example, the total installed cost for two MBJS each with a movement capacity of 915 mm (36 in.) was $800,000 or 1.2 percent of the $63 million total cost of the Lacey V. Murrow floating bridge in Seattle (*5*). However, the initial cost of MBJS is insignificant compared with the potential costs for maintenance and replacement if the MBJS per-

TABLE 2.1 MBJS performance factors and levels

Performance Factor	Desired Performance Level
Whole Life Cost	Minimal maintenance costs other than annually cleaning the debris from the seals
Service Life	75 years total, 25 years elastomeric components
MBJS and Bridge Design	Accessible for inspection and repair, not overly sensitive to installation procedures and tolerances, acceptable failure mode, traffic safety
Movement Range	Capable of providing specified movements and unanticipated movements in all six degrees of freedom without undue stress. Proposed minimum movement ranges are listed in Table 2.2
Installation	Temperature settings provided by manufacturer, proposed tolerances included in Appendix B, good consolidation of concrete
Metallic Components	Fatigue tested and designed, tolerate worst-case loading proposed in Report 402, corrosion resistant
Elastomeric Components (springs, bearings, seals)	Resilient, stay in place, resistant to environment, no leakage
Anchorage System	Durable, tolerate worst-case loading proposed in Report 402 , proper consolidation
Traffic and Snowplow	Pavement not excessively rutted, skew different than plow angle, recessed edgebeams, vertical resonant frequency greater than traffic loading frequency, debris resistant seals

forms poorly, especially when the user costs associated with a temporary bridge closing are included. The initial cost of MBJS is comparable to the initial cost of finger joints. As a result of implementing the proposed test specifications and guidelines, the whole life cost should be much better than that of most other bridge joints, including finger joints.

2.1.2 Service Life

Service lives for various components are suggested in the proposed specifications in Appendix A, although the decision on design life is left to the discretion of the engineer or owner. Significant consideration has been given to determining the appropriate design life for MBJS. The longer an MBJS exists, the greater potential for failure. It was determined from the survey data that the average life for MBJS currently in use, eliminating obviously poor systems that failed soon after installation, is approximately 15 to 20 years, with an average seal life of 10 years.

Current AASHTO LRFD bridge design code (*3*) requires that bridge decks and any elements contained within be designed for a 75-year service life. It is widely believed that recent bridge decks with epoxy-coated reinforcing bars can actually achieve this service life. Therefore MBJS must also be designed to function properly for 75 years.

Alternatively, MBJS could be designed for replacement each time the bridge deck is overlaid. In that case, the service life would be approximately 25 years. However, survey responses and field visits indicated that many MBJS have lasted longer than 30 years, with the seals lasting over 20 years without incident. The survey responses also indicated that many bridge engineers would like to have an MBJS service life of at least 50 years.

However, it is not realistic to expect seal life to achieve more than 25 years. Therefore, it is recommended that seal life be set at 25 years. Seal replacement is a more easily achievable and economical task than complete MBJS replacement. The seals can be replaced from the bridge deck surface in a short time.

Although these service life requirements are not met, for the most part, by current MBJS, the NCHRP project panel and the researchers believe these goals are attainable.

2.1.3 MBJS and Bridge Design

NCHRP Report 402 recommended the first specific fatigue design requirements. The functional design for the movement system is left to the discretion of the manufacturer. Although MBJS are complex devices, their performance must not be overly sensitive to installation procedures and tolerances. MBJS performance also depends on installation details, such as blockout requirements and gap spacing at installation. Specific dimensions are usually not known until after most of the bridge superstructure has already been designed and sometimes, even constructed. Problems also may result from the engineer's unfamiliarity with these systems and their respective needs and capabilities. Greater detail on design requirements can be found in the following sections, especially the section on Detailing.

2.1.3.1 Movement Range

The first step in designing an MBJS is to determine the movement capacity required. For most bridges, this is done only for the longitudinal direction. The AASHTO LRFD design code provides guidance on temperature extremes for design. The code also provides information on thermal expansion coefficients for concrete, steel, and wood (*3*). In addition, modifications to the equations for calculating bridge movement and modifications of the extreme temperatures to use with those equations have been recommended (*13*).

Often, the only component of bridge movement that is calculated is the longitudinal translation. However, unusually wide bridges will have a significant transverse movement component. Movement should be calculated along the cross-corner diagonal of such bridges. This movement can then be resolved into longitudinal and transverse movement. Highly skewed bridges can also exhibit significant movement in the transverse direction. The movement of curved bridges should be calculated along the chord through the fixed bearing locations.

All other types of expected movement ranges should be calculated or estimated, including concrete creep and shrinkage, settlement, and effects of prestressing. Measurements have shown that movements from traffic loading are small in comparison with thermal movements and can typically be ignored (*4*).

The MBJS must be able to accommodate movement in all six degrees of freedom, three translations and three rotations as shown in Figure 2.1. The maximum observed movement ranges (total movement range is twice the plus or minus movement) from the literature review and the survey are summarized in Table 2.2. The movement ranges summarized in Table 2.2 are proposed as minimum requirements until more accurate information becomes available.

Each seal in an MBJS is normally capable of at least 75 mm (3 in.) of longitudinal movement. Although the AASHTO LRFD specification (*3*) limits this movement to 75 mm (3 in.), all domestic MBJS manufacturers use seals that are capable of 80 mm (3.2 in.) movement, and several can provide special seals capable of 100 mm or even 125 mm of movement. Although there is not much experience with these larger opening seals, there is no reason to suspect allowing 80 mm (3.2 in.) of movement would be detrimental and it is recommended that the LRFD specification be changed to allow 80 mm (3.2 in.) of movement.

It is highly unlikely that the required longitudinal movement is exactly a multiple of 75 mm (3 in.). The MJBS must always

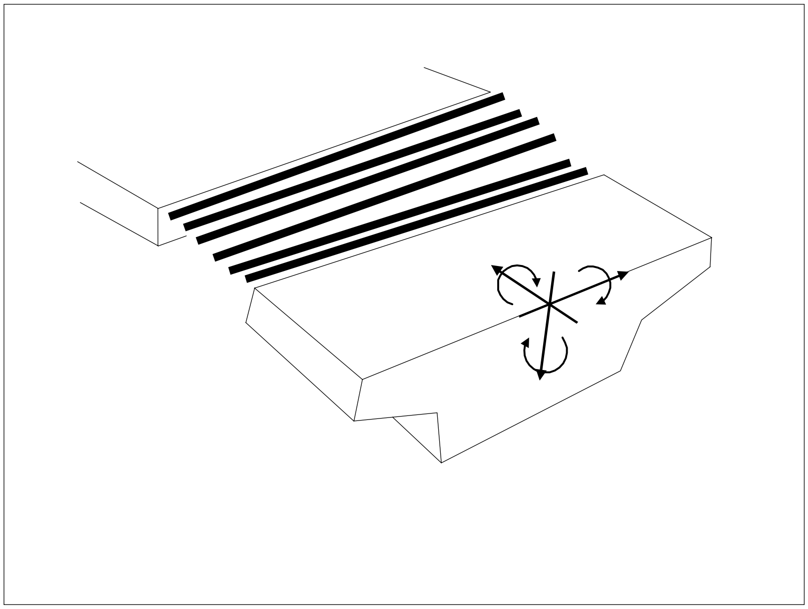

Figure 2.1. Six degrees of freedom.

be oversized rather than undersized. So it is almost certain that it will contain reserve movement capacity that will never be used. However, the methods of calculating thermal expansion are imprecise and this reserve movement capacity may be a favorable safety feature. As shown in Table 2.2, the maximum observed longitudinal movement was 50 mm (2 in.) beyond what was calculated. The required longitudinal movement capacity of the MBJS is recommended to be at least 25 mm (1 in.) more than what is calculated using conservative but reasonable assumptions. The designer should not add more than 25 mm (1 in.) if it means adding another seal.

2.1.3.2 Detailing

Performance factors related to detailing are discussed in Appendix B. Selecting the MBJS before the bridge design is finalized is desirable so that the MBJS can be incorporated into the engineering drawings. As engineers have become more familiar with MBJS, they have begun to get more involved in their design and specification; however, the MBJS is usually a bid item left to the contractor's discretion, and there are several qualified manufacturers. Because MBJS are proprietary, the configurations of the various manufacturers' models vary significantly.

The blockout is usually formed in the bridge deck or abutment to allow for the MBJS to be installed after most of the superstructure has been constructed. This is the preferred installation method because it allows for prestressing shrinkage, settlement of the foundations, movement from the pouring deck, and so forth. to occur before the MBJS is set in place. However, the variability in the MBJS designs often causes difficulties in detailing the blockout where the MBJS will be installed.

TABLE 2.2 MBJS degrees of freedom and observed movement ranges

Degree of Freedom	Maximum Observed Movement Range
Longitudinal Translation	+50 mm over design value (+2 in.)
Transverse Translation	38 mm (1.5 in.)
Vertical Translation	25 mm (1.0 in.)
Rotation about Longitudinal Axis (Twisting)	1 degree
Rotation about Transverse Axis (Abutment or Pier Rotation)	0.9 degree
Rotation about Vertical Axis (Racking)	0.5 degree

NOTE: Total movement ranges presented in the table are twice the plus or minus movement

In some blockouts where MBJS are installed, there is only 25 mm (1 in.) of space between the bottom of the support box and the surface of the blockout. It is not realistic to expect concrete to flow into such a small space. If support is not provided at one support-box location, the centerbeam span is essentially doubled, leading to increased stress and deflection of the components and associated premature failure. Therefore, at least 75 mm (3 in.) of clear distance between the top of the blockout concrete and the bottom of the support box is recommended. If adequate clearance cannot be provided, the solution may be to place a different material, such as grout, under the support boxes before the concrete is placed. A manufacturer has stated that 50-mm clear distance below the support boxes has been sufficient in the past and that 75 mm may lead to the necessity of using grout pads. Nevertheless, because of the severity and frequency of this problem, 75 mm is recommended. If 75-mm (3-in.) space is not possible, then 50 mm (2 in.) will probably be adequate (especially if aggregate size is limited) and can be used, rather than using a grout pad (grout pads are not encouraged).

It may be necessary to notch the ends of steel girders to allow the MBJS to be placed. This is because the MBJS is often deeper than the deck as illustrated in Figure 2.2. These notches create stress concentrations that should be analyzed for fatigue by the bridge designer early in the design phase and taking into account blockout requirements of all candidate MBJS. The alternative to this would be to design the MBJS so that none of the support boxes coincide with any girders. Of course, this is impossible in box girders. In concrete box girders, the end of the girder can be deepened as shown in Figure 2.3. For steel box girders, supports can be added to support the MBJS and blockout.

Reflective cracking in the concrete deck directly above support boxes and anchorages is extremely common (*14, 15*). There are three possible causes of this cracking. The first is the discontinuity in the slab thickness caused by the support box. The next is the relative flexibility of the thin plates used to construct the top of the support boxes. (Although the discontinuity caused by the support box cannot be changed, the thickness of the top plates of the support boxes should be at least 9 mm [3/8 in.].)

The third possible cause of reflective cracking is the lack of adequate concrete cover over the support boxes and anchorages. At least 75 mm (3 in.) of cover should be provided above the support boxes. It is also recommended that 75 mm (3 in.) of concrete cover (measured from the centerline of the anchor to the top of the concrete) be provided above the anchorages. It is recognized that there are many circumstances where this cover cannot be achieved. If the recommended cover is not provided, using a #3 transverse reinforcing bar over the anchorage details can minimize cracks.

Adequate access under the MBJS must be detailed into all bridge designs. There must be room for a person to inspect the bottom of the MBJS, and it must be possible to inspect inside the support boxes and replace the springs and bearings if necessary. Access should also be provided through the shear diaphragms of box girders. This can be accomplished with a small access hole, as shown in Figure 2.3.

MBJS are usually placed above a pier or abutment where there are bearings. The MBJS should be located as close as possible to directly above the centerline of the bearings to minimize the amount of rotation and vertical movement of the MBJS. Special attention should be paid to MBJS in curved bridges. Because of the superstructure geometry, the

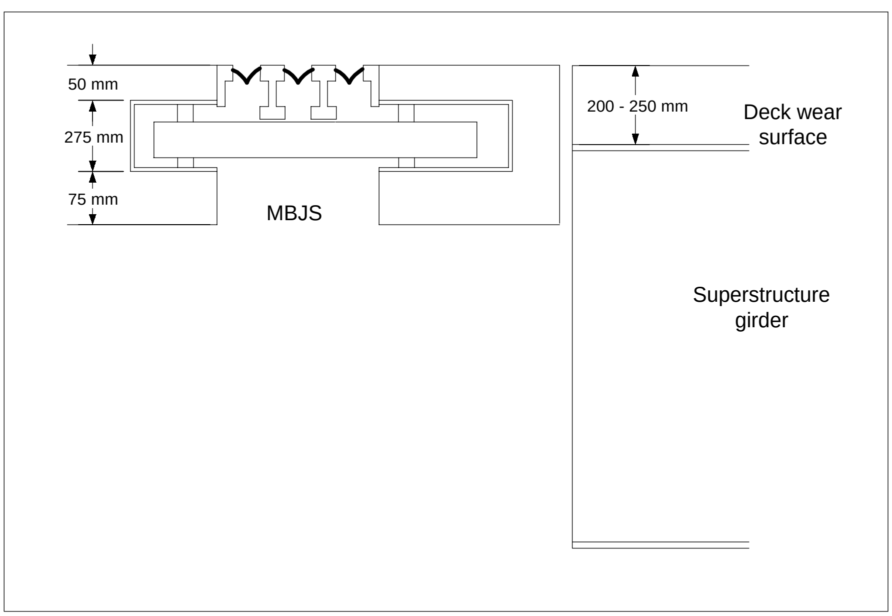

Figure 2.2. MBJS and superstructure interaction problems.

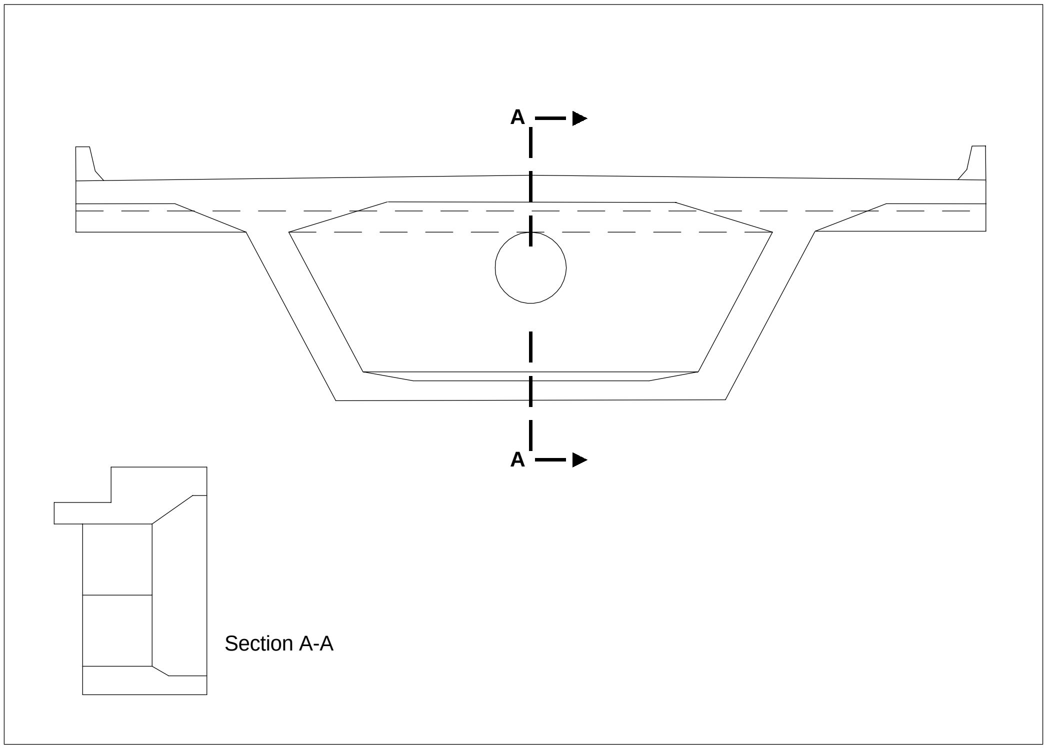

Figure 2.3. Concrete box girder notched for MBJS with diaphragm access hole.

expansion and contraction is more complex and dependent on the location, type, and placement of bridge bearings. Because the bearings are also factors in the bridge superstructure movement, they should be examined when designing the MBJS. If the MBJS is in a bridge with curved sections, then the anticipated direction of movement is usually not normal to the centerline of the joint. An MBJS with special transverse movement capabilities may be required.

MBJS must be considered in the overall drainage plan. Drainage should not be allowed to accumulate on the joint. The drainage plan should allow the drainage to guide debris away from the MBJS. MBJS are often specified to have curbs or upturns as shown in Figure 2.4. The overall drainage plan for the bridge should be considered when detailing these elements.

Debris accumulation at upturns at parapets or curbs is often excessive and can lead to seal push-out and leaking. The best solution to this problem is to have maintenance crews clean out the debris once per year. However, such cleaning is usually not done in the United States.

A possible solution to the problem of debris accumulation at the upturns is to allow the MBJS to extend through an opening in the parapet without an upturn, as shown in Figure 2.5. This detail would allow debris to run off the end of the MBJS. Scuppers may be provided at the ends to funnel the runoff and debris away from the bridge superstructure. If scuppers are not provided, the end of the MBJS should be extended far enough past the fascia girder to prevent runoff from touching the structure. In some locations, environmental regulations may preclude discharging drainage over the side of the bridge.

Allowing the MBJS to extend through an opening in the parapet without an upturn has been used successfully in a few states. However, there is little experience with this detail and it is quite controversial. Some engineers believe that this will eventually become a serious maintenance problem. Special attention must be paid so that debris and water do not come into contact with the bridge elements.

2.1.4 Installation

The performance of the MBJS depends heavily on quality installation. A large proportion of MBJS failures can be directly attributed to poor installation. Many bridge owners now require a manufacturer's representative to be on site to provide technical assistance and quality control. However, the contractor often uses the joint installation as fill-in work and decides on very short notice to do the installation, making it difficult to arrange for the manufacturer's representative to be on site. Communication between all parties involved with the MBJS is necessary to get the manufacturer's representative at the site for installation and for other reasons. For example, some problems have occurred because contractors are unfamiliar with these mechanical devices and their particular requirements.

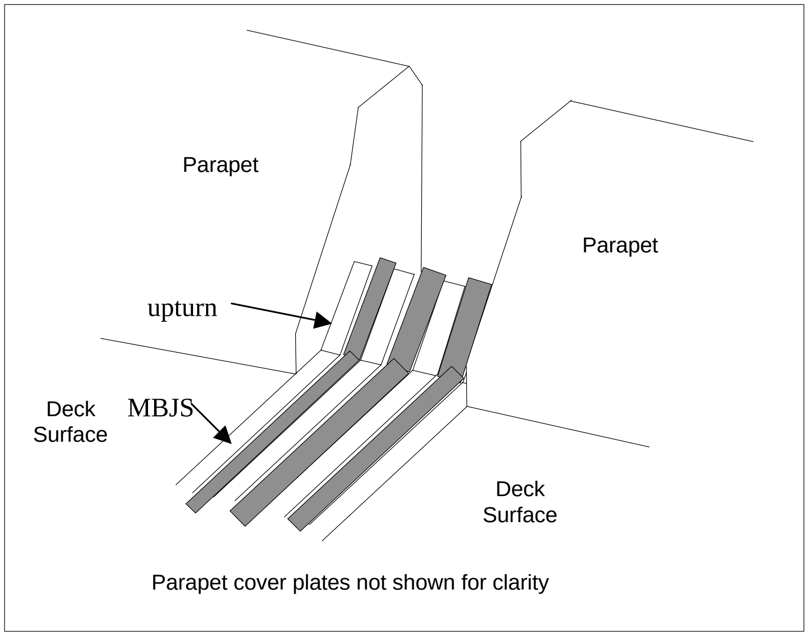

Figure 2.4. MBJS with upturn.

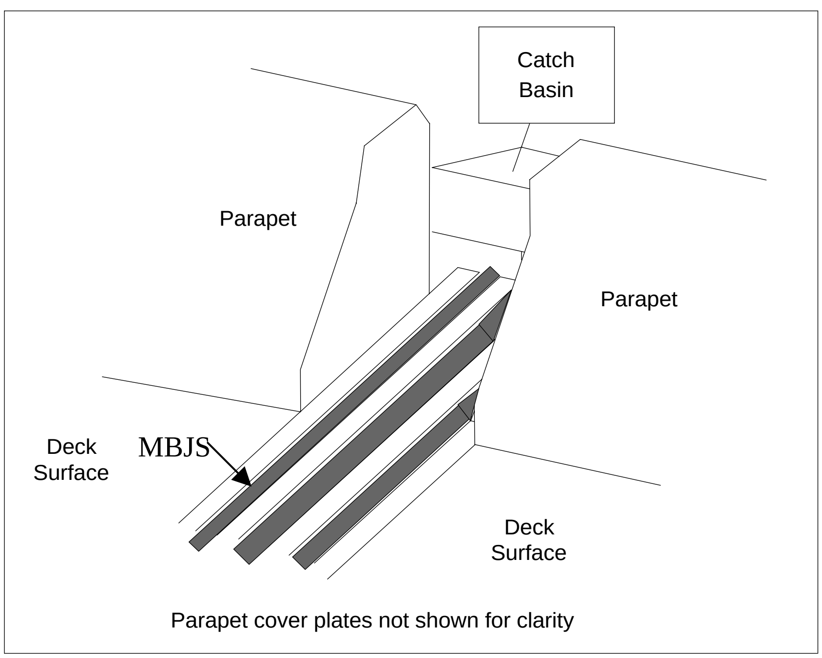

Figure 2.5. MBJS without upturn and catch basin for debris.

The most common installation problems follow:

- Inadequate concrete consolidation around MBJS, including at edgebeams and under support boxes;
- Use of poor-quality or poor-strength concrete in the blockout, especially when a high-slump concrete is used for better workability;
- Concrete placed inside support boxes;
- Improper setting of gap width for temperature at time of installation;
- Improper installation of seals;
- Improper or inadequate splicing of MBJS during staged construction;
- Cutting of deck reinforcement at blockouts;
- Mismatch between road grade profile and MBJS profile;
- Inadequate bridging of MBJS after installation to protect from construction vehicles; and
- Restraint of MBJS movement during concrete curing.

Most of these problems can be substantially reduced or eliminated through implementation of and adherence to the installation guidelines in Appendix B and education of construction personnel about these installation guidelines.

One of the most common defects is improper concrete consolidation (*16*). Poor consolidation of concrete next to the edgebeam may create air voids around the anchorage, leading to eccentric loading and bending of the anchor and possibly fatigue failure. Special measures are also required to achieve adequate concrete consolidation under the support box. At least 75 mm (3 in.) of clear distance between the top of the blockout concrete and the bottom of the support box is recommended, as discussed in the previous section. Careful vibration and monitoring of the work is still required to achieve good consolidation of the concrete.

Poor-quality or poor-strength concrete in the blockout can cause numerous problems, including spalling and excessive cracking. Concrete accidentally placed inside the support boxes may inhibit the movement of the support bars.

Early construction loads on the MBJS may cause movement of the edgebeams in the plastic concrete. These movements may cause gaps between the anchorage/edgebeams and the concrete. These gaps may eventually lead to anchorage failure. Seals can also be damaged during construction. The best solution is to not have any loads cross the MBJS for 72 hours. If it is necessary to cross over the MBJS in this time, suitable ramps or thick steel plates over the joint should be used.

The following subsections discuss installation problems that deserve greater attention and detail.

2.1.4.1 Temperature Gap Setting

The initial gap opening of the MBJS depends on the bridge superstructure temperature (not the air temperature) at the time of installation. The MBJS must be able to open when the superstructure cools/contracts and close when the superstructure warms/expands. If installed with incorrect gap settings, the MBJS may fail in one of two ways. During warm weather it may completely close. This may harm the seals, cause concrete crushing, or cause unanticipated stress on the bridge superstructure itself. The other scenario is that, during cold weather, the MBJS may be overextended and the seals may be pulled out of the retainers. The bearings, springs, and control springs may be damaged and/or dislodged. The anchorage, if improperly designed, may also fail. However, over-sizing of the MBJS relative to the actual anticipated movement range usually allows some latitude in the temperature gap setting.

ASHTO LRFD Bridge Design Specifications, in the Section on "Adjustment," states

> *In the absence of more accurate information, the installation temperature shall be taken as the mean shade air temperature under the structure for the 48 hours prior to joint installation in concrete structures and for the 24 hours prior to joint installation for structures where the main members are made of steel (3).*

This requires that measurements be taken prior to MBJS installation. However, installation of the MBJS is often performed as a fill in and is often not decided until the day of installation. The commentary for this section allows the use of concrete thermometers for concrete structures.

Most manufacturers provide temporary adjustment devices that allow for the MBJS gap settings to be adjusted and then locked off, depending on the site installation requirements. These devices should be removed before the concrete is placed. If they are left on after the concrete is placed, they may prevent the MBJS from moving with the concrete, thereby causing gaps between the MBJS and the concrete.

2.1.4.2 Deck Reinforcement

Often the deck or abutment reinforcement is placed and the concrete, excluding the blockout, is placed well in advance of installing the MBJS. The reinforcement that protrudes into the blockout often does not allow enough space for MBJS installation and must be removed as demonstrated in Figure 2.6. Once the reinforcement is removed, the MBJS can be inserted into the blockout. Additional reinforcement can then be added. If the reinforcing steel is not replaced, the structural integrity of the blockout may be compromised.

When placing reinforcing steel, strict adherence to minimum spacing requirements must be followed. If the reinforcement is too close to the edgebeams it may interfere with the flow of the concrete around the edges of the MBJS. The appropriate solution to this problem is to require the contractor to modify or to complete the reinforcing details after selection of the manufactured MBJS.

Figure 2.6 shows several other items worth noting:

- The movement capacity of this MBJS is about 380 mm (15 in.), much of which was from anticipated shrinkage

Figure 2.6. Reinforcement steel cut to allow MBJS placement, St. Paul, MN.

and creep of the post-tensioned segmental concrete box superstructure.

- Although the photograph was taken in the summer, a very small gap is opening between the abutment and the superstructure.
- Access to this MBJS from underneath will be very difficult, even in the winter; this is a common problem for concrete boxes.
- The blockout depth, not much greater than the support box depth, is insufficient.
- Finally, the reinforcement had to be burned off.

The reinforcement problem suggests the need for the structural designer to coordinate blockout reinforcement steel with the MBJS manufacturer's support box spacing. If this is not done, a change order and additional compensation will be needed during construction.

2.1.4.3 Splicing

Field splices are a common source of problems for MBJS. In new construction, field splices should be avoided, if at all possible, and the entire joint shipped and installed as one unit. The AASHTO LRFD specification requires details for transverse field splices for staged construction and for joints longer than 18 m (60 ft) and recommends that the splices be located away from potential wheel paths. It is preferred that splices be located under the median traffic barrier.

The manufacturer normally installs seals in the shop. However, when a field splice is required in the MBJS, AASHTO requires that the seals be installed in one piece after joint installation and splicing of the metallic components has been completed (*3*). Placing the seals after joint installation necessitates that the contractor install the seals. The contractor must receive instruction from the manufacturer on proper installation techniques and requirements.

If field splices cannot be avoided, the preferred splice detail consists of side plates bolted into recesses machined out of the centerbeam profiles. The nuts are tack welded to the unstressed stickout end of the bolt to prevent the nuts from backing off. This design of this splice detail is described in detail in *NCHRP Report 402* (*4*). The bolted splice behaves like a hinge and does not resist bending moments. Because the fatigue design dictates that the span of a spliced centerbeam must be smaller than the unspliced centerbeam, generally it is best to make the spliced centerbeam span as small as possible.

A full penetration field weld can sometimes be made from the deck when there is only one centerbeam and it can be lifted out enough to access the bottom of the centerbeam. Care must be taken to avoid weld metal getting into the seal retainer grooves, which can lead to seal pullout and leaking.

Full-penetration cannot be achieved when there is more than one centerbeam and, therefore, a welded splice cannot be used. A fillet weld or partial penetration weld should never be used because they will crack in a short time.

Numerous failed splice welds have been observed during field visits. For example, Figure 2.7 shows a crack in a hybrid splice with a bolted splice collar at the bottom of the centerbeam and a partial-joint-penetration butt weld. (This MBJS is located on Interstate 82 Columbia River Bridge near Umatilla, Oregon.) Figures 2.8 and 2.9 show why it is impossible to achieve good penetration when there are multiple centerbeams.

If it can be ensured that a splice will remain under a median barrier, it might be possible to just butt the ends of the two segments of joint together but not have them spliced. Leaking can occur at this location, unless it can be ensured that water cannot get to the location.

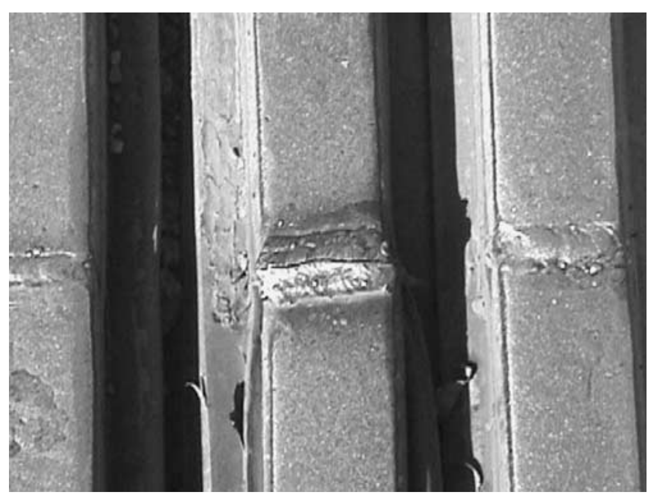

Figure 2.7. Cracked butt weld splice in Umatilla, OR.

Figure 2.8. Partial field splice of centerbeams.

2.1.4.4 Matching Road Grade Profile

MBJS with cast-in-place anchorages require precise alignment of the edgebeams with respect to the road grade profile. The MBJS should not be suspended from a crane during installation because the crane provides inadequate restraint. Other methods of supporting the MBJS during installation can be used, including the following:

- Tack welding to reinforcement,
- Attaching to bridge superstructure girders, and
- Bridging blockout gap.

Of these, the last method is the preferred method, but all will be discussed.

If the MBJS is tack welded to the reinforcement, the weight of the MBJS may cause the reinforcement to sag. This settlement must be calculated and compensated for or the MBJS will be installed too low. These calculations, when performed, are often imprecise and usually fail to predict the amount of sag adequately.

Figure 2.9. Complete field splice of centerbeams and mismatch of edgebeam.

When the support boxes are attached directly to the bridge superstructure, the connectors contain leveling bolts that allow for the precise vertical setting of the MBJS. It is important that the leveling bolts be strong enough to support the entire weight of the MBJS. If the MBJS is attached directly to the bridge girder, traffic loading may pass through these connectors directly to the superstructure elements. The superstructure elements must be designed for strength and fatigue to handle this traffic loading.

The third option is to bridge the blockout gap and suspend the MBJS from the bridging. This allows for a more precise leveling of the MBJS in relation to the road grade profile. There are also no permanent connections to the bridge girders.

If the MBJS is placed too high or too low, the contractor may attempt to correct this by varying the concrete height in the blockout. This should not be allowed because the resulting local change in roadway profile may induce unusually large dynamic impact forces on the MBJS, especially if the two sides of the MBJS do not follow the same profile.

The MBJS should be placed slightly lower, 3 to 6 mm ($\frac{1}{8}$ to $\frac{1}{2}$ in.), than the deck surface. If placed too high, there may be more severe loading from normal traffic and extreme loading from snowplow edges catching the edgebeams. If placed too low, the MBJS may experience dynamic loading as traffic “drops” onto the joint. Also, when installed too low, the MBJS may also collect excessive amounts of debris that could interfere with the proper functioning of the MBJS.

2.1.5 Metallic Components

The metallic component performance factors are discussed in the Materials, Fabrication, and Construction Guidelines, Performance Test Specifications, and *NCHRP Report 402.* All metallic components should be designed for fatigue in accordance with *NCHRP Report 402,* because fatigue, rather than strength, considerations typically govern the design. The most critical detail, after splices, is the centerbeam-to-support bar connection.

All metallic components should also have proper corrosion resistance. Thin stainless-steel slider plates are usually welded on the support bars to reduce the coefficient of friction between support bars and the elastomeric bearing assembly that supports them. Intermittent welds are inferior to continuous welds for fatigue and corrosion resistance and, therefore, should not be used. Some manufacturers have proposed epoxy bonding this plate to the support bar. However, the experience with bonded slider plates was not good.

2.1.6 Elastomeric Components

Problems with the elastomeric components are addressed in the Materials, Fabrication, and Construction Guidelines as well as the Performance Test Specifications. Elastomeric components of the MBJS consists of the springs and bearings that

hold the support bars, the seals that allow for the superstructure movement and, usually, the control springs that keep the centerbeams at equal spacing.

2.1.6.1 Springs and Bearings

Springs and bearings are installed above and below the support bars, respectively (refer to Figures 1.4 through 1.6). The springs and bearings hold the support bars in place and provide surfaces on which the support bars can slide to accommodate the movement of the bridge superstructure. The low stiffness and high damping properties of the springs and bearings serve to reduce the impact force from traffic loading and prevent noise caused by metallic contact.

During MBJS fabrication, the springs are precompressed to fit into the support box. The springs and bearings are secured in the support box by (1) a raised boss or protrusion on the spring and bearing that fits into holes in the support box or (2) by metal pins that fit into holes in the spring and bearing as well as holes in the support box. Once in place, the spring presses against the support bar, preventing the bearing connection of the support bar to the spring and bearing from going slack, even with some of the creep in the spring and bearing that typically occurs.

Problems with the springs and bearing include the following:

- Deterioration of the material through environmental exposure,
- Excessive creep or cracking/tearing under service load,
- Loss of sliding ability through excessive wearing of PTFE (Teflon) surface, and
- The bearing being dislodged or displaced.

The common polyurethane spring and bearing consists of three layers. The bottom layer is the low-friction PTFE sliding surface. The top layer is polyurethane rubber with a middle layer of a preformed fabric pad that bonds the PTFE (Teflon) to the polyurethane. This type of spring and bearing is held in place by a small protrusion on the top. There are numerous reports of these protrusions shearing off and allowing the springs and bearing to become dislodged.

The other type of spring and bearing is made from neoprene bonded to a PTFE sliding surface. This type of spring and bearing is typically held in place with a metal pin and has not had the shearing-off problem associated with the polyurethane spring and bearing. Neoprene springs and bearings had performed poorly because of excessive wear and creep (*4*). However, it seems that the formulation of this neoprene has improved in the past decade and these neoprene springs and bearings now perform, as well as polyurethane springs and bearings. The improved performance of the neoprene springs and bearings is evident from field visits and the testing described later in Section 2.2.3.

The formulation of the springs and bearings is proprietary. Slight changes in the formulation, or even a change in the producer of the spring and bearing (these are often outsourced) ostensibly using the same formulation, can lead to extremely poor performance. Therefore, there must be documentation that the spring and bearing used in an MBJS installation is produced by the same company and using the same formulation as was used in the performance tests described in Section 2.2.3.

Notwithstanding the sensitivity to slight changes in the formulation, the formulations used today have improved substantially. The improvement is such that deterioration of the material through environmental exposure and excessive creep or cracking/tearing are no longer significant problems with recently produced springs and bearings; at least not with those used by the established North American and European MBJS producers.

Loss of sliding ability can lead to shearing off of the protrusions that hold the typical polyurethane spring and bearing in place, leading to the spring or bearing becoming dislodged. Other factors may also cause the springs or bearings to become dislodged. Having the bearings being dislodged or displaced is a significant problem that essentially doubles the unsupported span of the MBJS. This can cause a rapid chain of future failures not only in other bearings, but also in the centerbeam/support bar connection.

These problems are often not discovered until the whole bearing or spring is missing. If the problem is found quickly and remedied, the life of the MBJS can be significantly extended. However, many MBJS are difficult or impossible to access for inspection and replacement.

Typically, a thin stainless-steel cover plate is fillet welded to the support bar to further reduce the friction. Thin support bars pressing against springs or bearings that are larger than the support bars can wear a groove in the spring or bearing, thereby leading to premature failure. Therefore, the support bars and stainless-steel sliding plate should be wider than the springs or bearings.

2.1.6.2 Seals

Elastomeric seals are designed to accommodate the MBJS movement by folding at a preformed hinge, as shown in Figure 2.10. Typically, they are made of neoprene, although natural rubber or polyurethane may be specified if extremely low temperatures are expected. The seals mechanically lock into grooves or attachments on the centerbeams and edgebeams.

One of the main functions of the MBJS is to protect the underlying superstructure and substructure from roadway drainage. This is accomplished through the watertightness of the seals. If the seals leak, then the MBJS fails to provide adequate protection. Several causes of seal failure are as follows:

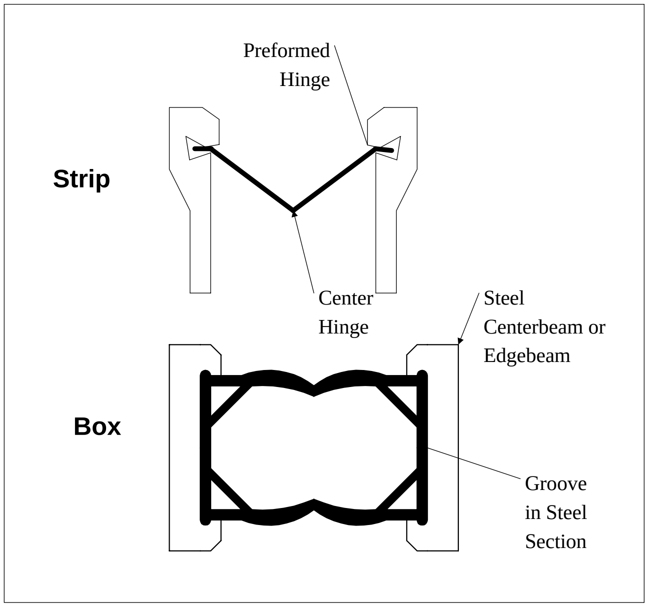

Figure 2.10. Strip- and box-type seals.

- Becoming detached from the centerbeam or the edgebeam,
- Failure of shop or field splices of seals,
- Buckling of the seal element,
- Cracking or tearing of the seal as a result of abrasion from debris and traffic,
- Degradation because of environmental exposure, and
- Snowplow damage.

There are strip and box seals as shown in Figure 2.10. Each type of seal is perceived to have advantages and disadvantages. It is thought that the double layer of material provided by the box seal design offers redundancy in case the top layer is punctured. However, it is also believed that if the top seal is punctured, the box will fill with water, which can lead to seal pullout as a result of the weight of the water-filled seal. It is also believed that, in winter, the water may freeze and inhibit movement. Some agencies believe that strip seals accumulate more debris. Finally, many agencies reported that their box seals are not sufficiently resistant to pullout. There is evidence supporting this last perception. A box seal has to be compressed approximately 12 mm (0.5 in.) to initiate pullout from the retainer, which is an average compression strain of 12 percent. A strip seal must be compressed 3 to 6 mm (0.13 to 0.25 in.) to initiate pullout from the retainer, which is an average compression strain of between 25 to 50 percent. The survey done by the research team for this project (NCHRP Project 10-52) showed that approximately 75 percent of the reported seal pullouts were box seals and occurred, on average, 5 years after installation.

The Seal Push Out (SPO) Test, which is described in Section 2.2, was specifically designed to test the resistance of the seals to separating from the centerbeams and edgebeams. The results of this test showed that box seals performed as well as strip seals. In fact, there was greater variability in the results among manufacturers with one particular type of seal than there was between the types of seals. Therefore, the type of seal is believed to be of secondary importance, and no clear preference can be established.

MBJS manufacturers claim that each seal can accommodate up to 38 mm (1.5 in.) of transverse movement, but some reports indicate that repeated shear buckling and associated premature wear, tear, and possible seal pullout result from transverse movement. Box seals seem to be more sensitive to buckling than strip seals, probably because of the high torsional and transverse stiffness of the box seal.

Adhesives may improve the pullout strength of the seals. These adhesives also serve as a lubricant to help the installation of the seals into the retainers. However, such adhesives also make the removal and replacement of the seals more difficult. The benefit of improved pullout strength is greater than the detriment of the difficulty in replacing the seals, and the use of a lubricant adhesive is recommended. However, the lubricant should not be the epoxy type or other adhesive that is so strong that it makes replacement of the seals too difficult.

The most common problem with MBJS is the accumulation of debris on the seals; such accumulation is believed to lead eventually to seal detachment. However, it is not clear if debris accumulation in itself is really a cause of detachment. Almost every MBJS has significant debris accumulation, and only a few have problems with detachment of the seals. Eventually, the debris accumulation could also inhibit the full closing of the MBJS. The best solution to this problem is to clean the debris from the seal once a year. However, most owners do not perform such maintenance.

The seals are supposed to be self-cleaning when they are fully open. Any debris in the seal is supposed to be pushed out by normal traffic. However, most agencies specify 25 mm (1 in.) of "extra" movement as a margin of safety against imprecise expansion calculations, construction tolerances, concrete shrinkage, and skew movements. Also the MBJS is designed to fully open only during the maximum coldest day. During most of the year, and even its life, the MBJS is not open to its full capacity. If the seals are not allowed to open fully, then self-cleaning will not occur as planned. Information gathered about the seals confirms that they have not fulfilled the promise of being self-cleaning. During field visits, it was observed that the self-cleaning action worked only in the traffic wheel path.

Manufacturers of seals have been improving the quality of their product and, with the ASTM specifications required for seals, it is believed that the seals can achieve a service life of 25 years.

2.1.6.3 Equidistant Devices

In common MBJS, the equidistant devices are elastomeric control springs used to keep the gap opening between center-

beams and edgebeams relatively equal. Keeping the gap opening equal will ensure even loading on the MBJS. If these elastomeric control springs fail, the gaps will be unequal and individual elements of the MBJS may receive excess traffic loading. Seals may also be pulled out of their retainers because of the unequal opening. Uneven loading could cause progressive failures in other MBJS elements, including bearings, springs, and centerbeam/support bar connections.

Control springs have undergone significant changes since the introduction of the MBJS. At first, the control springs were metallic automotive springs, but now they are typically urethane foam. As discussed in the introduction, one MBJS in Albany, New York, has scissor mechanisms for the equidistant device; these scissor mechanisms, also double as the support bars. One specimen in the testing program had scissor mechanisms with elastomeric foam control springs inside the mechanisms.

Based on the design, the control springs can work to either push the joint open or closed. Typically, if the control springs are attached to the adjacent centerbeams they will push the joint open. If the control springs are attached to the support bars, they will push the joint closed. Figure 2.11 illustrates how the control springs function when they are attached to the support bars. The most common control springs have a plate on each side with a nylon dowel that runs through the center of the spring to keep it in place.

The problems associated with modern control springs are as follows:

- Excessive creep,
- Cracking or tearing,
- Deterioration because of environmental exposure,
- Inadequate attachment to the MBJS, and
- Device becoming dislodged or displaced.

The first four may eventually lead to the device becoming dislodged, which is the really significant part of the problem in terms of the impact on joint function. Figure 2.12 shows a deteriorated elastomeric control spring found at the I-82 Columbia River Bridge near Umatilla, Oregon.

2.1.7 Anchorage System

The anchorage system ties the MBJS to the bridge deck and/or abutment. Experience has shown that most anchorage failures result from the following:

- Snowplow contact with the edgebeam,
- Lack of proper consolidation of concrete around the edgebeam and anchorage,
- Movement of the edgebeam while the blockout concrete is still plastic,
- Poor-quality concrete, and
- Deteriorated concrete.

The strength of the anchorage with regard to normal traffic loads is not listed. The problems with anchorage are addressed by the materials, fabrication and construction guidelines recommended in Appendix B. Sample calculations to verify an anchorage design are presented in Appendix C.

In the past, bolts and anchor connectors have been used to connect the MBJS to steel or concrete. However, these connectors are not recommended because of problems with nut loosening. Experience has demonstrated that cast-in-place anchorages are the most durable and cost-effective. A wide variety of cast-in-place anchorage details are specified by different agencies, including straight studs, bent studs, loops of reinforcing bar, sinusoidal bent reinforcing bar, and perforated plates.

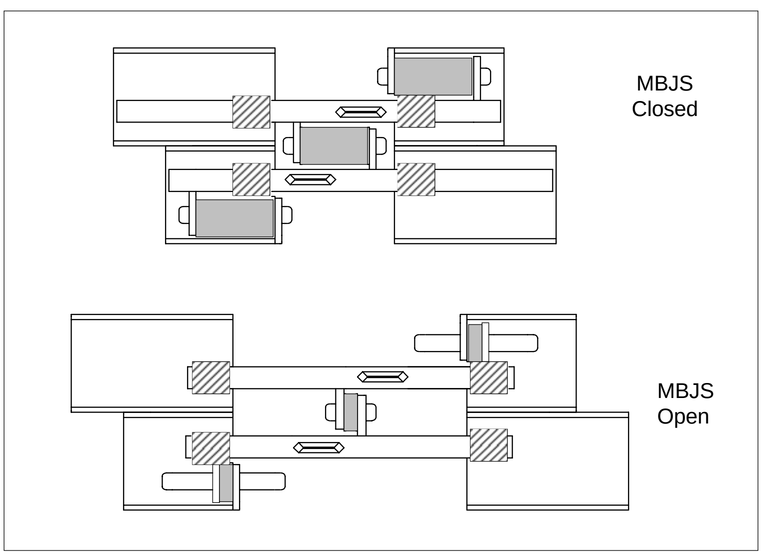

Figure 2.11. Typical control spring functioning.

Figure 2.12. Broken elastomeric control spring in Umatilla, OR.

Studs are the most commonly specified and most efficient anchorage devices. Studs are easily welded onto the edgebeams and are typically 13 or 19 mm (0.5 or 0.75 in.) in diameter and spaced at 150, 225, or 300 mm (6, 9, or 12 in.). A standardized design for edgebeam anchorage with studs is presented in Appendix C.

Loops of reinforcing bar, although more expensive to manufacture and install, provide a way to engage the reinforcement. Many bridge owners specify the looped anchorage because of perceived problems with the welded headed stud anchorage system. The looped anchorage is shown in Figure 2.13.

In Ohio, problems with end-welded reinforcing bars becoming detached when the edgebeam is struck by snowplows have led to the use of perforated plates because of the greater weld area. However, reinforcing bars are not weldable unless the low-alloy ASTM A706 reinforcing bars are specified, so it is not clear that the weld area has been the only issue. Although the perforated plates are a conservative solution, it is not clear whether the additional expense for such plates is warranted.

Edgebeams with a horizontal flange at the deck surface are often specified because the flange is envisioned to armor the corner of the deck or abutment and keep it from spalling. However, when concrete is placed around these edgebeams, it is difficult to achieve complete consolidation under the flange as shown in Figure 2.14. This cavity can lead to bending and premature failure of the stud (*16*). Figure 2.15 displays a preferred edgebeam profile that does not have a top flange. Use of this

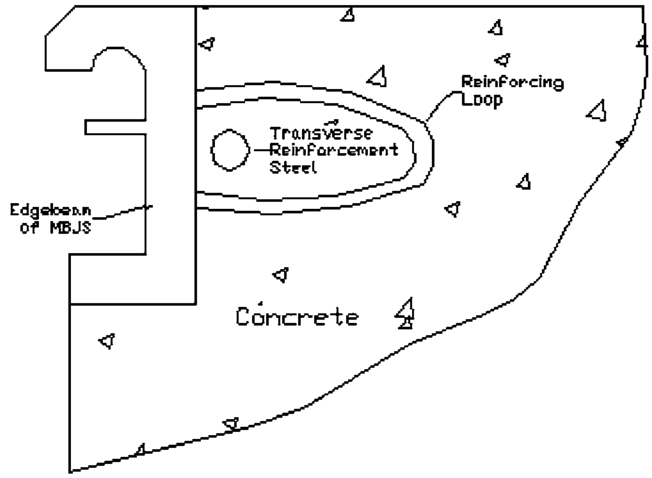

Figure 2.13. Loop anchorage for edgebeams.

profile eliminates the cavity and problems with stud failure (*16*). The strengths of both types of edgebeam profiles were tested and the results were comparable and well above strength demands from normal traffic (*16*).

There have been reports of concrete spalling near the edgebeam, but spalling has not been the cause of any known failures in MBJS. The spalling probably results from the lack of cover over the anchorage. The one significant problem that could be associated with concrete spalling is that it may allow snowplow blades to fall down and strike the back edge of the edgebeam. This is a possible scenario and the anchorage and edgebeam should be designed accordingly.

If the flanged edgebeam is used, AASHTO LRFD in Section 14.5.3.5, Armor, recommends that 19-mm (0.75-in.)-diameter holes be drilled in the horizontal armor flange every 466 mm (18 in.) (*3*). These holes facilitate concrete consolidation under the flange and allow easy verification of the con-

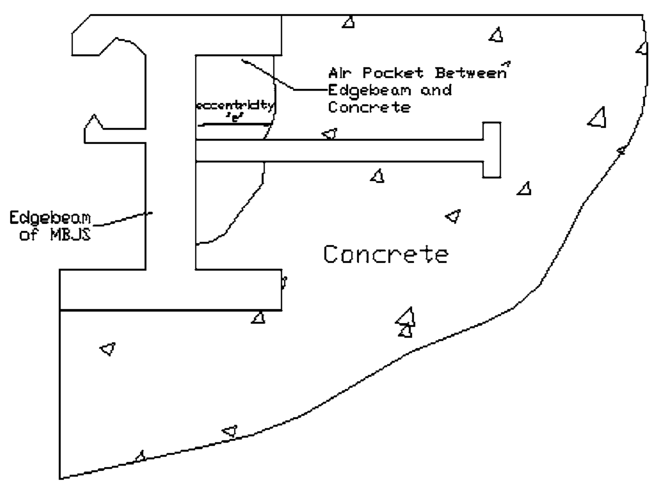

Figure 2.14. Nonconsolidation associated with edgebeam horizontal armor flange.

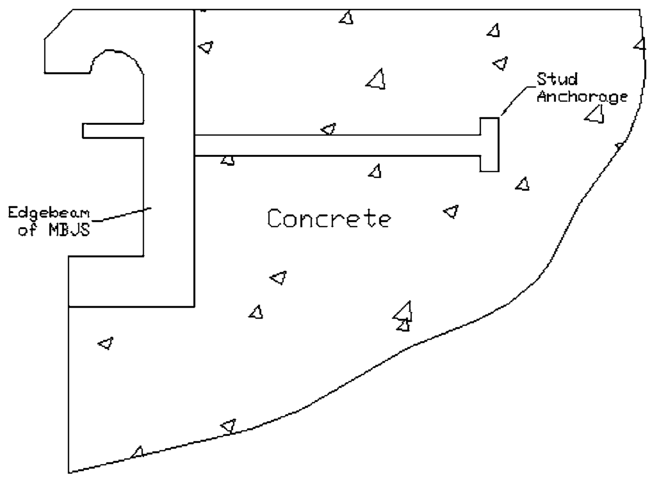

Figure 2.15. No edgebeam horizontal armor flange.

solidation as shown in Figure 2.16. This is considered a minimum requirement.

The major problems with anchorages are typically not related to the strength of the anchorage, but to the concrete in which they are placed and their proper installation. Few reported problems are associated with anchorage failure in properly consolidated concrete. There is also no correlation between anchorage type (other than bolted) and failure rate. This suggests that all of the anchorage designs are performing adequately and that there is no significant advantage of one system relative to another. There is no advantage to bending the studs, for example.

It would decrease the cost of MBJS slightly if some standardization of anchorage details could be achieved. Straight

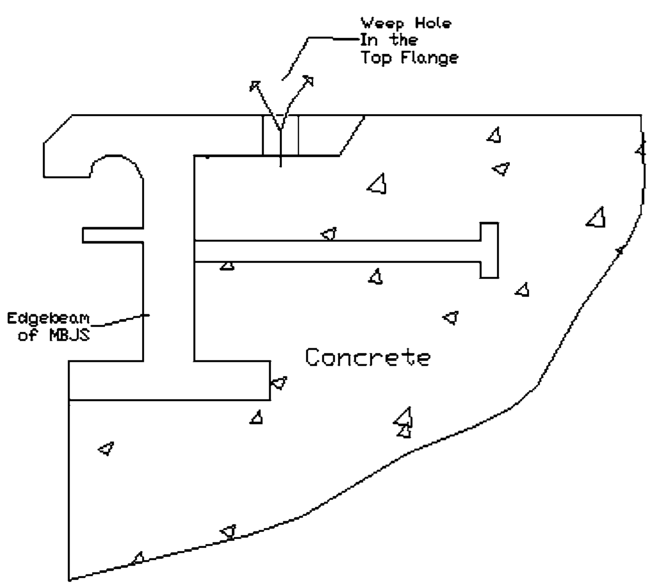

Figure 2.16. Weephole for edgebeam horizontal armor flange.

studs are the least-cost solution. AASHTO recommends a minimum anchorage of "12 mm (½ in.) diameter end-welded studs not less than 100 mm (4.0 in.) long spaced at not more than 305 mm (12.0 in.)" (*3*). The calculations in Appendix C demonstrate that this is slightly unconservative. For standard loading conditions with a 40-mm (1.6-in.)-wide edgebeam, it is recommended that the minimum anchorage be changed to 12-mm (0.5-in.)-diameter end-welded studs not less than 150-mm (6-in.) long spaced at not more than 305 mm (12 in.). The anchorages must also have 75 mm (3 in.) of cover (measured from the centerline of the anchor to the top of concrete) and be Grade 50. In some circumstances, in new construction, for example if studs are located on the edgebeam over the support boxes, it may not be possible to allow 75 mm (3 in.) of cover above the stud. In these cases, a minimum of 50 mm (2 in.) is recommended. In redecking of an existing bridge when the depth of the blockout is limited, even 50 mm (2 in.) may not be possible. In cases where 75 mm (3 in.) cover cannot be provided, the prescriptive solution presented above may not be adequate and the strength of the anchorage must be explicitly calculated as in Appendix C.

2.1.8 Traffic and Snowplow Damage

The materials, fabrication, and construction guidelines in Appendix B address the traffic and snowplow performance factors. It has been observed that most of the damage to MBJS has occurred in the traffic wheel paths, and most of this damage was greater in the lane carrying the higher volume of heavy axles. The first two resonant frequencies of MBJS are in the range from 30 to 200 Hz. Tests have shown that unless properly pretensioned, nuts and bolts will unscrew if vibrated or impacted at frequencies above 100 Hz. Vehicle wheel traffic has a loading frequency of 50–150 Hz (*4*). Hence, significant potential exists for resonant vibration of the MBJS and associated problems with loosening of nuts and bolts. Therefore, proper installation procedures for high-strength bolts must be invoked.

Traffic can also cause rutting of the blockout material. This is especially a concern if the material is composed of a lower strength material, such as asphalt or elastomeric concrete. These lower strength materials are also not compatible with the required 75-year bridge deck design life, unless allowances are made for significant, regular maintenance work. If there is significant rutting, the edgebeam may protrude above the roadway surface. This will cause an increase in the severity of traffic loading through dynamic effects. If the edgebeam profile is above the roadway surface, chances that snowplow blades will hit the profile increase, damaging the edgebeam profile, anchorage, and snowplow itself. Repair and maintenance of the rutting of the deck or approach surface have been shown to increase the performance of MBJS (*15*).

Many agencies have reported an increasing frequency of problems with skewed joints. They report that skewed MBJS exhibit more movement and have greater potential to be torn

by snowplows. The typical snowplow blade angle is 30 deg. If the MBJS skew angle coincides with the snowplow blade angle, the probability that the snowplow blade will fall into the seal gap and severely damage the seal, edgebeam, and/or centerbeam increases. Having a skew angle of less than 20 deg can minimize this problem.

2.1.9 Maintenance and Serviceability

Maintenance and serviceability are discussed in Appendix B. Ideally, MBJS should not require service, inspection, or maintenance during their expected service life. However, these systems are too complex to believe that they can be totally maintenance-free. It is recommended that they be inspected at least every 2 years or when the bridge has its regular inspection. The inspection crew must have adequate access to all of the parts of the MBJS. Unfortunately, many bridges are often detailed without adequate consideration of access to the MBJS. MBJS and the surrounding bridge superstructure elements need to be designed so that all MBJS components can be inspected regularly and replaced at the end of their service lives. The three major factors inhibiting good inspection and maintenance practice are as follows:

- High expense,
- Access limitations, and
- Lack of technical understanding of MBJS among engineers and maintenance personnel.

During inspection and maintenance, the condition of the entire MBJS and its components must be documented. Such documentation will allow the owner to determine if the MBJS is performing well or if corrective maintenance is required. It is recommended that the MBJS be analyzed with the rating system contained in *Transportation Research Record 1118* and in the checklist section of Appendix B (*17, 18*). Using this rating system will also allow a specific MBJS to be evaluated on the basis of the performance of other MBJS and standardized MBJS rating.

If a problem with the MBJS is discovered during regular maintenance inspection, the problem must be corrected as soon as possible. Because of the inter-related nature of the MBJS, a minor failure of one component can precipitate a much more serious chain reaction of other failures.

Another problem facing MBJS is the possibility that the bridge deck may be replaced or receive an overlay at some time during its service life. If the bridge deck is replaced, then the MBJS may be replaced along with this work. However, the MBJS may not need to be replaced and can be kept in place. Care should be taken during reconstruction work so that the MBJS is not damaged. A deck overlay will change the elevation of the wearing surface above the surface of MBJS. Some work will have to be done to the MBJS to accommodate the new deck surface.

One possible solution is to taper the overlay depth from zero at the edgebeams to the standard depth over a sufficiently long distance such that the smoothness is maintained (at an angle of about 1:80). Another solution is to raise the surface of the MBJS to the new deck level. This is accomplished by welding steel attachments to the tops of the centerbeams and edgebeams as shown in Figure 2.17 (*7*). This solution has been used in New York State. These attachments are similar to the tops

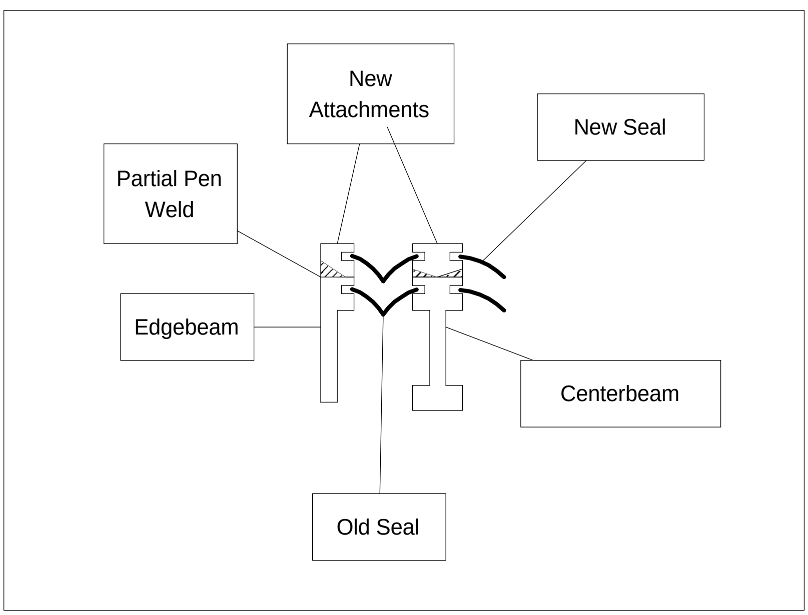

Figure 2.17. Method of rehabilitating MBJS to allow for bridge deck overlay.

of the respective steel parts in that they also contain retainer clips for new seals. It is advisable that these new attachments be welded continuously with fillet or partial penetration groove welds to the existing centerbeams and edgebeams. If this method of rehabilitation is used, the welds should be regularly inspected for cracking. The service life of this solution is unknown, but appears to be the most favorable.

The MBJS will need some maintenance during its service life. There is no evidence to support the expectation that the seals last 75 years. However, seals have been observed in good condition after 25 years. However, the seals may need to be replaced twice during the 75-year life of the MBJS. Fortunately, the seal replacement can be done entirely from the top of the joint. Currently, the life of the other elastomeric components in service is not known and depends heavily on the individual installation and traffic. It is reasonable to expect that such elastomeric components may also need replacement.

2.2 LABORATORY TESTS

This section describes the development of the performance tests, the design of the test apparatus, the test procedures, and results. A detailed test specification is provided in Appendix A. The proposed test specification was written so that owners or engineers can incorporate it into their standards to ensure that the MBJS has been properly tested. The test specification is sufficiently detailed so that laboratories can conduct these tests.

Performance-based tests have been used for various products that are proprietary in nature, most notably in the automotive industry. NCHRP has had previous success with performance testing of various products, for example, truck-mounted crash attenuators (*19*).

Performance testing of bridge joints is not new. Since their introduction, there has been a desire to validate these systems before they are used. The premature failures of MBJS have only increased the need for testing. Various sources have proposed tests that would measure the durability of bridge joints (*4, 20, 21, 22, 23*). These references were reviewed

- To determine if these tests could be adapted for the needs of this project,
- To examine the advantages and disadvantages of these tests, and
- To determine the most important performance factors to test.

Performance testing does not focus on the materials included in the MBJS but rather on the end results (*23*). The Materials, Fabrication, and Construction Guidelines were developed and are included in Appendix B to ensure that the MBJS contains quality materials and is manufactured properly.

The MBJS must be tested as one whole system, rather than as separate tests on individual components—the system performance depends on the interaction of all components. It is the goal of this testing to ensure that MBJS will have sufficient durability. If all MBJS are subjected to the same testing requirements, then the manufacturers would be competing to produce equal minimum performance levels. However, these tests should not restrict competition or inhibit innovation within the industry. MBJS are proprietary and unique. The tests must be applicable to all types of MBJS.

The laboratory performance tests had several other requirements, including the following:

- Behavior under test should be representative of service behavior,
- Reasonably easy to perform by typically equipped laboratories,
- Reproducible,
- Economical.

The objectives of the research to develop the laboratory tests were as follows:

- Design a testing protocol that would simulate actual in-service movements and durability demands,
- Verify that the testing protocol would produce failure modes found in actual MBJS as documented in the field visits
- Rate the durability of typical MBJS, and
- Address as many significant performance factors as possible.

After reviewing the existing tests, it was decided that no one test addressed all the performance factors not addressed through the Materials, Fabrication, and Construction Guidelines. One test was adapted for this project—a seal push out test that has been performed by Minnesota DOT, by the D. S. Brown Company, and probably by other agencies. The Seal Push Out (SPO) test was adapted, and a new test, the Opening Movement Vibration (OMV) test, was developed to measure the performance and durability of full-size representative systems. These tests were developed to assess the performance and durability of the elastomeric MBJS components in particular, including the seals, springs and bearings, and equidistant mechanisms.

2.2.1 Relationship Between Performance Factors and Laboratory Tests

MBJS performance problems and factors affecting the durability of the MBJS were identified through literature reviews, questionnaire results, field visits, and evaluation of failures observed or previously documented. These problems and factors were then rated for significance and importance.

It was determined which of the performance problems and factors were most efficiently addressed through the Materials, Fabrication, and Construction Guidelines. Problems and factors that cannot be addressed through the proposed guidelines must then be addressed in a test or tests that can be performed in a typical structural laboratory.

It was essential that any laboratory test produce a failure mode similar to those found in the field. The tests were developed especially to meet this specific requirement. The proposed performance tests should be used to prequalify MBJS much as AASHTO and ASTM specifications are used to prequalify materials, or as the fatigue testing proposed in *NCHRP Report 402* has been required by many states to prequalify the fatigue strength of certain MBJS.

The performance tests were developed and refined by

- Trial-and-error improvements to the test apparatus as problems occurred under the highly demanding conditions,
- Investigating the response of MBJS elastomeric components to simulated service-life demands,
- Developing relationships between field observations and laboratory response, and
- Developing realistic and practical performance-testing procedures and acceptance requirements.

Not all aspects of the performance factors can be tested in the laboratory. Most notably, the performance factors related to installation were not evaluated in these tests. Verification of proper installation cannot be prequalified. Implementation of and adherence to the “Materials, Fabrication, and Construction Guidelines for Modular Bridge Joint Systems and Strip Seal Bridge Joint Systems” found in Appendix B should substantially reduce the problems associated with installation.

Similarly, the anchorage of the MBJS into the blockout material was not tested in these performance tests. It was concluded from the field observations, literature review, and surveys that anchorage problems mostly result from improper installation, most notably improper consolidation of the concrete in the vicinity of the anchorage (*16*, *24*). If the installation is performed properly, there should be few problems with anchorage systems that are commonly used today (*16*, *24*). A standard anchorage design is recommended in Appendix B (the commentary for Materials, Fabrication, and Construction Guidelines) and in Section 2.1.7. Calculations showing the adequacy of this standard design for most applications are shown in Appendix C. It is hoped that most states will adapt this standard anchorage design, which should reduce the unnecessary expense of fabricating numerous unnecessary variations on anchorage details.

2.2.2 Test Specimens

Six MBJS specimens were tested to failure, as listed in Table 2.3. These specimens represented four manufacturers (three from the United States and a German manufacturer) and various MBJS types, seal types, skew angles, numbers of centerbeams, and numbers of centerbeam spans. The specimens featured typical splices and other details specific to those manufacturers.

The specimens that were tested were the most current models provided by the manufacturers at that time (1999). Much of the information in the literature and the information gained from inspecting MBJS in service is relevant to MBJS models that have been modified substantially or are no longer being manufactured. MBJS have undergone significant modifications in recent decades. There have even been significant modifications of some manufacturer’s MBJS designs since *NCHRP Report 402* was published in 1997.

MBJS with both box and strip seals were tested to investigate individual performance. A skew of 45 deg was specified for most of the specimens. This is viewed as the largest typical skew. It was hoped that this large skew would cause shear problems in the seals to manifest. Several specimens with no skew were also included for comparison. Centerbeams with two and three spans were tested to investigate the effect of length on the accuracy of the OMV test.

Most of the specimens also contained a centerbeam field splice. This splice was designed and installed by the manufacturer before the specimen was brought to the testing facility.

TABLE 2.3 MBJS test specimen details

Specimen	Type	Seal	# of CB	Skew	Spans	Splice
1	WMSB	Box	5	0	2	No
2	WMSB	Strip	4	0	2	No
3	SSB	Strip	2	45	3	Yes
4	SSB	Strip	2	45	3	Yes
5	WMSB	Strip	2	45	3	Yes
6	WMSB	Box	2	45	3	Yes

The results of *NCHRP Report 402* testing showed that bolted splices performed better than welded splices. All manufacturers have now adopted bolted splices that are all relatively similar. Therefore, it was decided to include the bolted splices as part of this testing to determine their durability, in terms of bolt loosening and falling out, loss of functionality, and effect on the overall performance of the MBJS system.

2.2.3 Opening Movement Vibration (OMV) Test

The opening movement vibration (OMV) test was designed to test the ability of the MBJS to withstand the repeated movement demands of the bridge superstructure while being subjected to a simulated traffic load. The OMV test simulates the most common movement of MBJS, the movement due to the daily thermal expansion and contraction of the superstructure by opening and closing the expansion joint with an actuator with a period of about 10 seconds. Traffic loads are simulated by attaching a powerful pneumatic vibrator to one of the centerbeams.

The OMV test is an accelerated test in relation to the opening and closing movement and the application of simulated traffic loading. The best simulation of the complex loading and time-dependent response of an MBJS was obtained by driving a heavy-axle load over the MBJS either outdoors or in a laboratory at realistic loading rates (i.e., at about every 3 seconds). However, it would take thousands of hours before the joint experiences the millions of load cycles associated with the service life. Accelerated tests must be carefully designed and calibrated against actual service performance because of the inherent problems with the time-dependent behavior of the materials, especially the elastomeric parts that exhibit viscoelastic material behavior (i.e., strain-rate dependent elastic properties).

The specimen is also subjected to simulated truck traffic through the use of a pneumatic vibrator. The frequency of the vibration, about 100 Hz, is similar to the resonant frequency of the MBJS for bending in the vertical plane and is similar to the frequency associated with the impulse of the dynamic wheel load of a truck traveling approximately 100 kph (60 mph).

The vibrator applies a load to one centerbeam that is approximately constant but rotates its direction at about 100 Hz. Therefore, the vertical and horizontal components of the load vary sinusoidally. One difference between the wheel loads and the vibrator load is that the wheel loads do not continue sinusoidally, they occur in groups of two to five or more corresponding to the vehicle configuration. There is a time delay between application of these axle loads corresponding to the separation between both the axles and between trucks.

A time history of realistic loading of an instrumented centerbeam by a dump truck with a tandem rear axle is shown in Figure 2.18 (from *NCHRP Report 402*). The vertical frequency of this MBJS was 120 Hz, the horizontal frequency was 60 Hz, the vertical damping was 7 percent, and the horizontal damping is 10 percent. Other MBJS tested as part of *NCHRP Report 402* displayed similar frequencies and damping characteristics.

One potential disadvantage of the vibrator test is that heat can build up in the elastomeric parts if there is not that period between loading to cool off the bearing. Heat buildup was observed when limited high-frequency fatigue tests were performed on bearings in previous research (*4*). However, the heat buildup was not that significant in the present tests.

Tests performed for *NCHRP Report 402* also indicated that the elastomeric springs and bearings exhibit a dynamic stiffness versus frequency power law relationship. The dynamic stiffness increases as the loading frequency increases. *NCHRP Report 402* also states that at a loading frequency of 100 Hz, the dynamic stiffness for neoprene springs is approximately 5.25 kN/mm (30 kips/in.). Some of the springs and bearings tested for this project were neoprene, but most of the springs and bearings were urethane based. No information was provided in *NCHRP Report 402* on urethane behavior.

Although not a completely accurate representation of actual in-service demands, the test was deemed successful at reproducing actual in-service failure modes and rating the MBJS for durability.

2.2.3.1 Description of Test

Figures 2.19 through 2.23 show typical test setups. The specimen was supported on stands. An actuator supplied the simulated thermal longitudinal opening movement. It is envisioned that electric or mechanical devices other than hydraulic actuators could also provide this movement.

There was one set of stands per support box. The stands consisted of vertical W 12×53 sections with 25.4-mm (1-in.) base plates and 38.1-mm (1.5-in.) top plates. The height of the stands was sufficient that the interior of the support boxes and underside of the MBJS could be conveniently viewed periodically to check for damage to the elastomeric components, as well as damage to the centerbeam/support bar connection. The two individual columns were braced together by two 8×6.2 channel sections and were attached to the strong floor by long tensioned anchor rods. Between the stands and the strong floor, isolation pads were used to dissipate the vibration generated by the vibrator.

The tops of the stands were sloped 1:10 or 5.7 deg in the longitudinal direction. It was hoped that this would induce a net downward movement of the elastomeric springs and bearings during testing and possibly facilitate their displacement. A 5.7-deg slope was seen as large but not unusual bridge deck slope.

Linear bearings were attached to the front column of the stands on the actuator side. These would restrain the MBJS movement in all directions except longitudinal translation. The support boxes on the side opposite of the actuator and linear bearings were welded to the top plate of the stands.

The linear bearings were a two-part system consisting of a grooved rail bolted to the top plate of the stands and a carriage

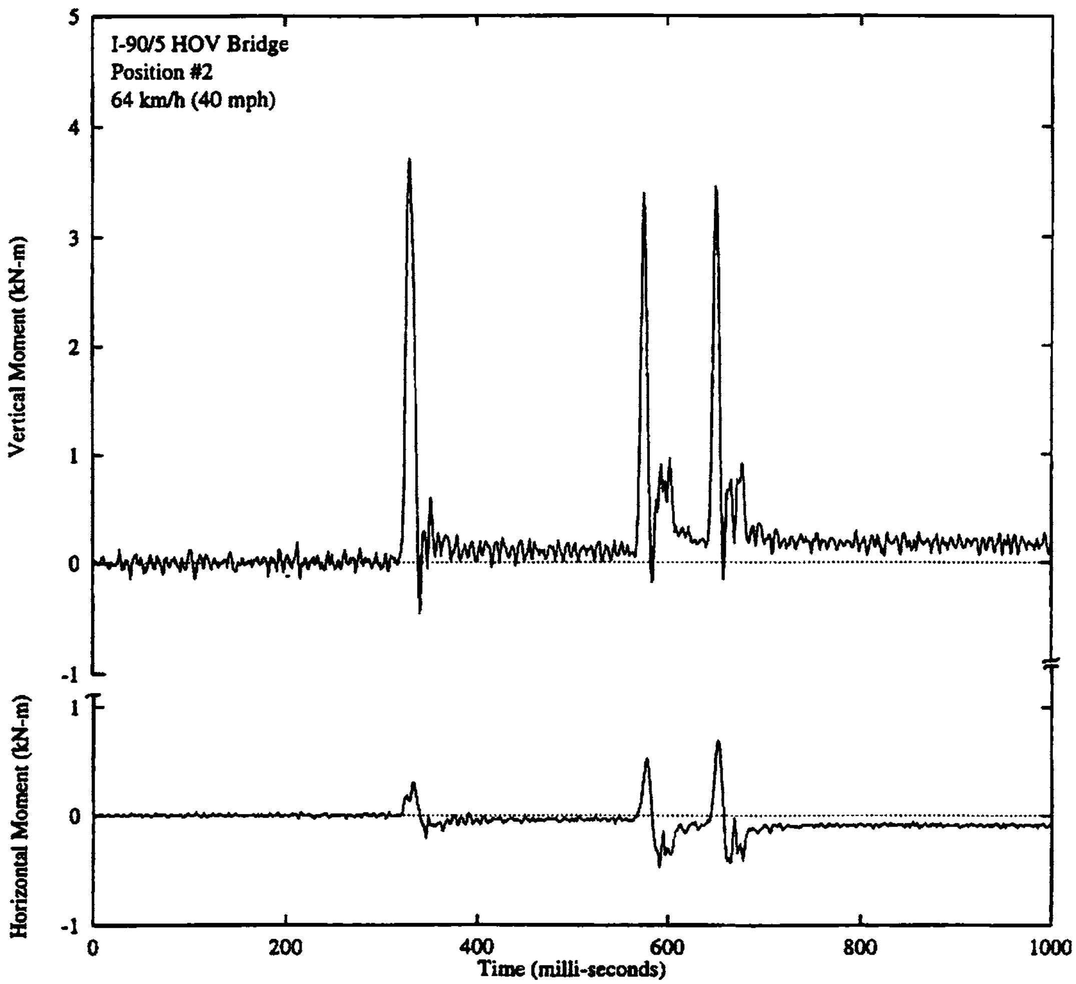

Figure 2.18. MBJS dynamic time history for double-axle truck.

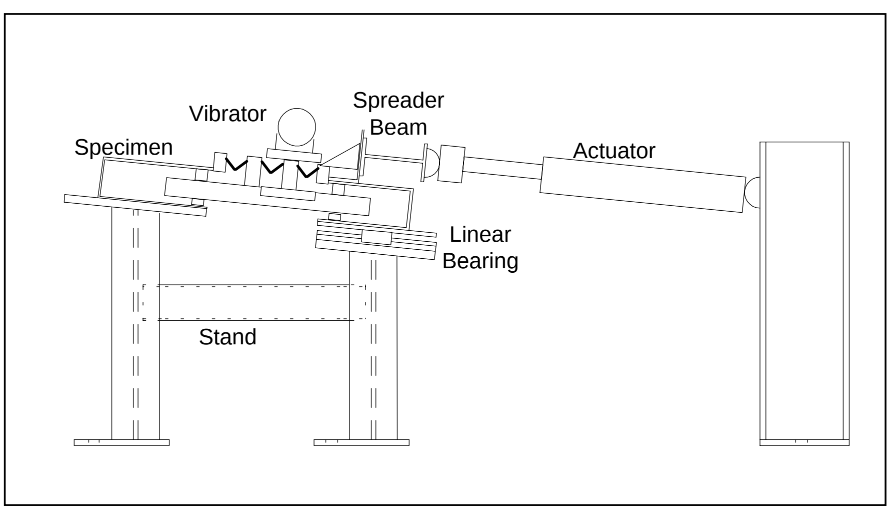

Figure 2.19. Side view OMV test set up.

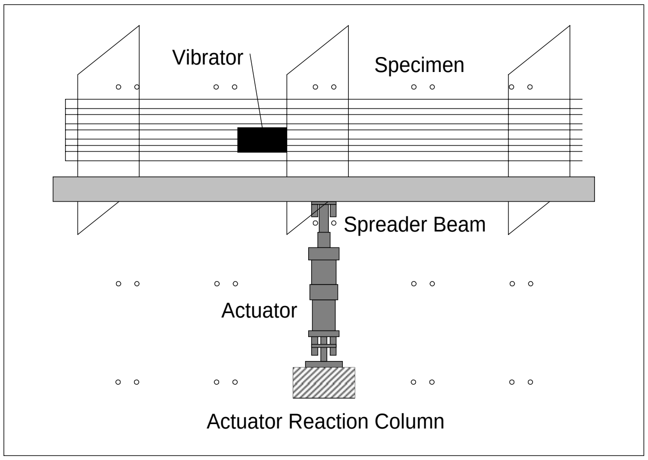

Figure 2.20. Plan view no skew OMV test set up.

that rode in the grooves of the rail. A 25.4-mm (1-in.) plate was bolted to the top of the carriage. The support box connected to the linear bearing was then fillet welded to this plate, allowing longitudinal movement. Figure 2.24 shows the linear bearing placement in relation to the stands and the specimen.

At first, it was attempted to place a linear bearing at each support box. Problems were encountered because of the difficulty in perfectly aligning three parallel systems. It was decided that only two linear bearings were required. This system worked well, even for the skewed specimens. Finally, testing was performed with only one linear bearing. The linear bearings are necessary to prevent the thrust of the actuator from lifting the MBJS off the stands and to keep the specimen aligned. In actual installations, the support boxes will be held in their aligned configuration by the concrete. Given that testing was successful with only one linear bearing, it was decided that, when the test specimen contains three support boxes, only one linear bearing is required. Two linear bearings are required

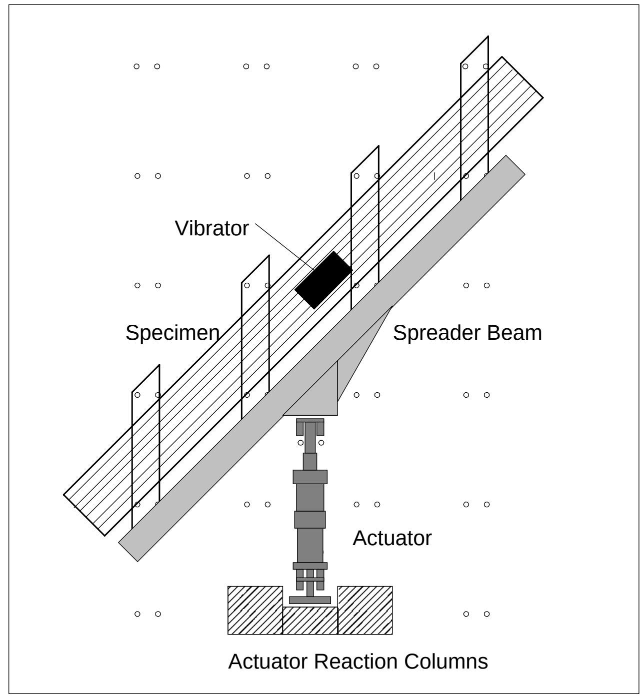

Figure 2.22. Plan view 45-deg skew OMV test set up.

if the test sample has four support boxes, in order to maintain symmetric restraints.

Longitudinal opening movement was applied to the test specimen by a displacement-controlled 155 kN (35 kip) actuator. The load to open and close the MBJS was measured by a load cell, although it is not believed that this will be absolutely necessary in future testing.

The specimens were cycled through 102 mm (4 in.) of movement at a frequency of 0.1 Hz. The forcing function was a sine wave, but the exact waveform is not considered impor-

Figure 2.21. No skew OMV test set up for Specimen 1.

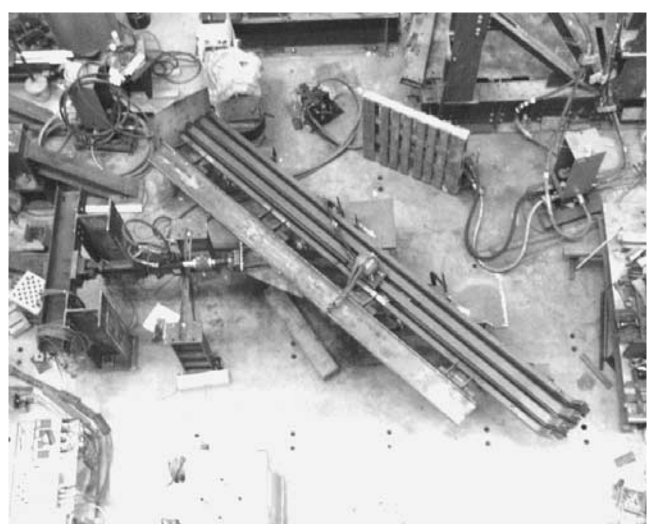

Figure 2.23. 45-deg skew OMV test set up for Specimen 4.

Figure 2.24. Linear bearing placement in relation to stand and Specimen 5.

tant. The cycling frequency was chosen to make the test economically feasible to conduct while still accurately simulating MBJS movement in service. For the MBJS with the greater number of centerbeams, the 102 mm (4 in.) of movement is similar to one daily cycle. However, for the skewed, smaller two-centerbeam MBJS, this movement is significantly larger than a daily cycle and is on the order of the longitudinal movement capacity. (The useful movement rating in the longitudinal direction of the smaller skewed MBJS was determined by multiplying the non-skew capacity of 230 mm (9 in.) by the cosine of 45 deg or 0.707. This resulted in a movement capacity of 162 mm (6.4 in.).)

It was decided to keep the cycling range at 101.6 mm (4 in.) to induce the same amount of wear in the smaller capacity MBJS as in the larger. The failure modes and times indicate that moving the smaller, skewed MBJS through this large displacement did not induce excessive or premature failure. For example, there were frequent bearing failures in both the specimens with the larger movement range and the specimens with the smaller movement range. The 102 mm (4 in.) of movement was sufficiently severe to make the test practical to perform in a short period while still providing reasonably similar failure modes to service failures.

Using current AASHTO design requirements, it was decided that the MBJS should be cycled for the equivalent of 75 years of 365 daily thermal cycles or 27394 cycles. At 0.1 Hz this equated to 76.1 hours of actuator cycling.

The correspondence between the test times and service in years is only used for reference. It is very difficult to defend the cycle as being equivalent to 1 day of service. However, the results of the various specimens in terms of their hours of endurance did spread out well and seem to be approximately close to the actual years in service before failure.

The actuator was horizontally centered on the MBJS and the load was applied to all of the support boxes through the use of a rigid spreader beam, a W10 $\times$ 30 rolled beam, as shown in Figure 2.24. The spreader beam was bolted to $8 \times 4 \times \frac{1}{2}$ angles that were welded to the top of the support boxes. This allowed the spreader beam to be reused for all of the specimens.

The center of the actuator was located 101 mm (4 in.) above the top of the support boxes as shown in Figure 2.25. This eccentricity created a torque on the edgebeam that reversed direction as the motion changed direction. This torque caused normal forces on the springs and bearings, as can occur in service.

A pneumatic high-frequency industrial vibrator was used to simulate vibration from traffic. The vibrator was selected on the basis of both cycling frequency and force deliverable. It was desirable to have a vibrator that could operate near the resonant frequency of the specimens. *NCHRP Report 402* lists the observed vertical frequencies for the centerbeams between 91 and 130 Hz with the observed horizontal frequencies between 30 and 60 Hz. Using this information, it was decided to choose a vibrator that could operate in the range of vertical frequencies.

The vibrator selected was a Vibco model number SVRLS 8000. A 5.24 cubic meter per minute (185 cubic feet per minute {cfm}) air compressor supplied the pneumatic power. It was found that the vibrator matched the frequencies of the MBJS best when the air supply was set at 2.2 cubic meters per minute (75 cfm). At this setting, strain gage data showed that the frequency of vibration varied between 70 and 100 Hz. The published specifications for the Vibco model number SVRLS 8000 are shown in Table 2.4. Force amplitude information is not given for the lower frequencies of about 100 Hz used in these tests. Table 2.4 shows that force amplitudes of 42 kN (9.5 kips) or ranges of 85 kN (19 kips) would be expected at around 158 Hz.

Strain gage measurements, discussed below, showed that the force range was approximately 45 kN (10 kips) at the lower

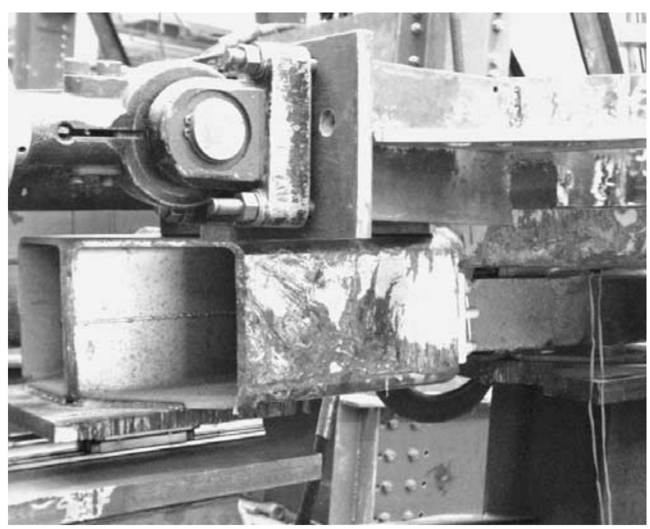

Figure 2.25. Actuator eccentricity to support boxes for Specimen 5.

TABLE 2.4 Vibco SVRLS 8000 specifications

Air Pressure		Frequency	Force Amplitude	
(kPa)	(psi)	(Hz)	(N)	(lbs)
551.6	80	141.7	33900	7625
620.6	90	145	35600	8000
689.5	100	158	42500	9550

frequency. The vibrator force range is close to the fatigue wheel load of 47 kN (10.5 kips) recommended in *NCHRP Report 402.* This fatigue load is based on the HS20 axle load, split in two to represent an actual pair of tandem axles, appropriately factored for impact, fatigue, and for distribution to one centerbeam.

The vibrator had its own fixture that was then welded to a 38-mm (1.5-in.)-thick plate. The vibrator plate was bolted to the top of a single centerbeam as shown in Figure 2.26 and Figure 2.27. Another 38-mm (1.5-in.) plate was used on the bottom of the same centerbeam. The vibrator was mounted as closely as possible to a centerbeam/support bar connection to attempt to induce failure in that connection or the elastomeric components at that location.

2.2.3.2 Measurements of Opening and Closing Load and Effect of the Vibrator

Measurements of the opening load and strains in the centerbeams and support bars were made on several of the specimens to investigate the realism of the test and to determine the effectiveness of the vibrator. Specimen 1 was a welded multiple-support-bar system with five centerbeams and 460 mm (18 in.) of movement range. This specimen was used to shake down

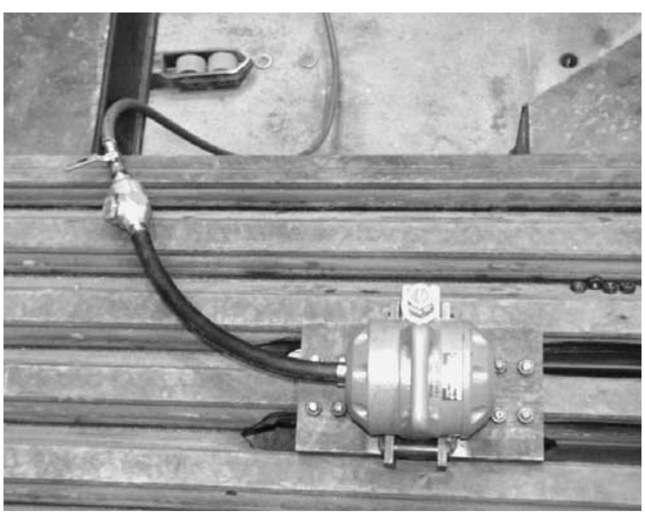

Figure 2.26. Vibrator attached to Specimen 1.

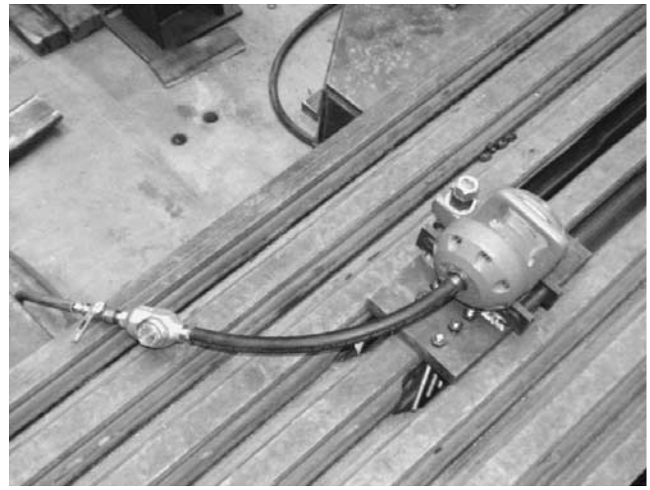

Figure 2.27. Vibrator attached to Specimen 1 showing bolts alongside centerbeam.

the apparatus and investigate the opening and closing load requirements. The specimen was also one of the few with more than two centerbeams. Comparison of the results shows whether the results from specimens with two centerbeams were applicable to MBJS with larger numbers of centerbeams.

Load versus stroke graphs for both 101 mm (4 in.) and 254 mm (10 in.) movement ranges are shown in Figure 2.28. Positive stroke corresponds to closing the MBJS. When the specimen was closed to approximately 75 mm (3 in.), the load began to spike toward a maximum of –66.7 kN (–15 kips) at 127 mm (5 in.). This increase in force was primarily due to binding of the linear bearings and should not be interpreted as a property of the MBJS.

The 254-mm (10-in.) cycling done on Specimen 1 was not possible with the smaller capacity specimens. It was decided to standardize the remainder of the tests with a movement range of 101 mm (4 in.) because that could be performed on all of the test specimens. The few cycles performed at the 254-mm (10-in.) cycling range were not included in the failure time for Specimen 1.

Opening and closing load versus stroke graphs for Specimens 1 through 4 and 6 are shown in Figure 2.29. Specimen 5 failed before data were taken. All of the data were taken while the vibrator was running. The collection rate for each specimen is shown in the legend. There is some difference in the loads and the shape of the individual graphs, but all values are relatively similar.

Figures 2.30 and 2.31 show the measured strains on the centerbeam and support bar. In each graph, the measured strains due to the actuator alone are shown near the bottom centered at about zero. The strain history plots with the vibrator running have been shifted by 100 microstrain to allow plotting on the same graph. Figure 2.30 shows strain gage data for the centerbeam to which the vibrator was mounted but one span away from the vibrator location. It was positioned 152 mm (6 in.)

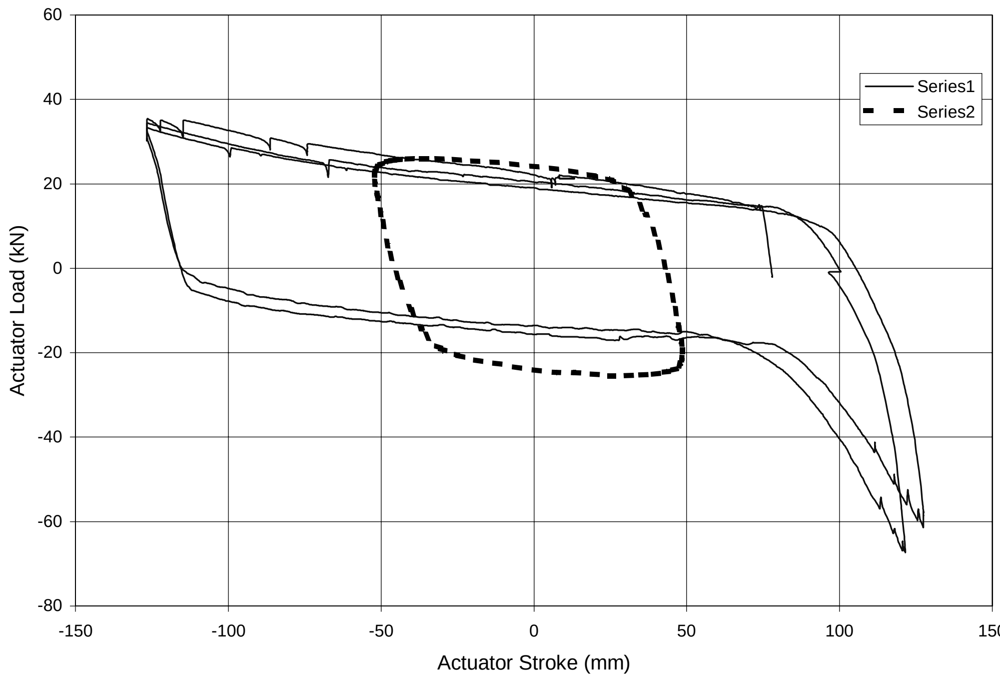

Figure 2.28. Specimen 1 graph investigating stroke range.

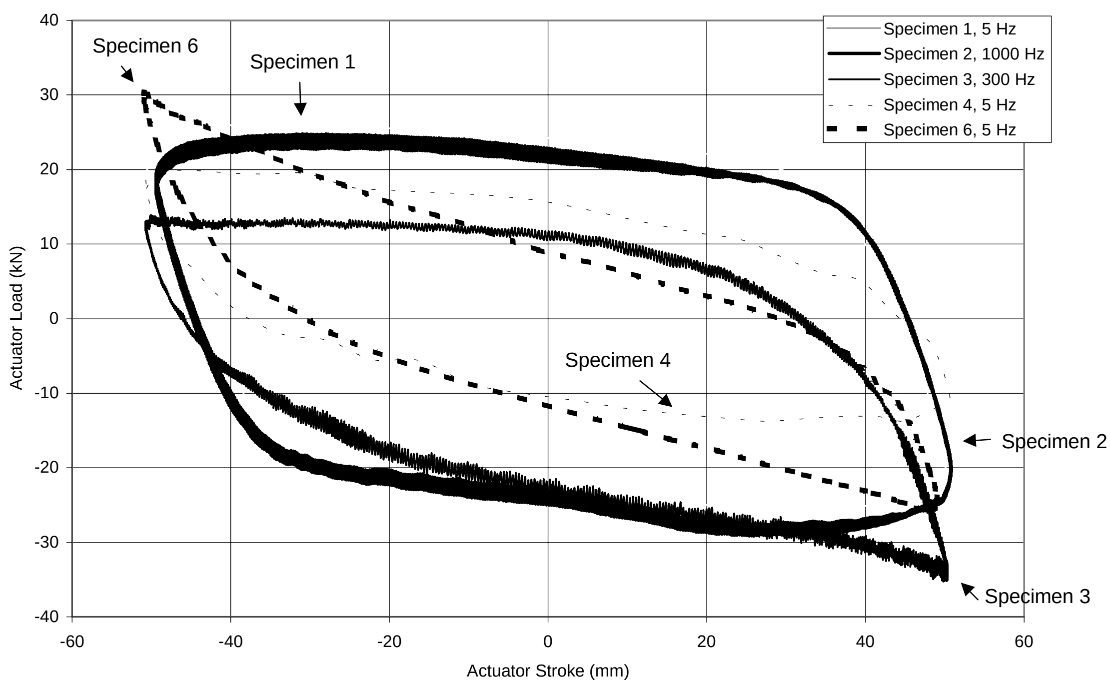

Figure 2.29. Load vs. stroke graphs comparing specimens.

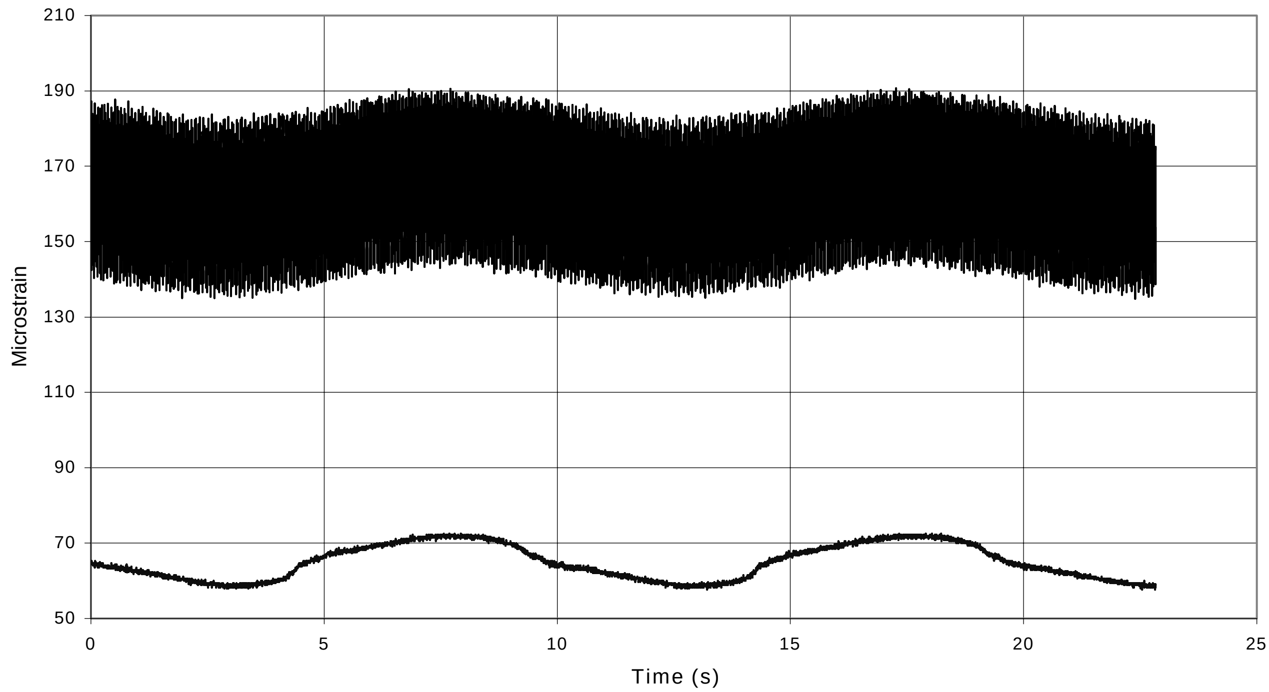

Figure 2.30. Specimen 1 centerbeam strain gage data showing vibrator influence.

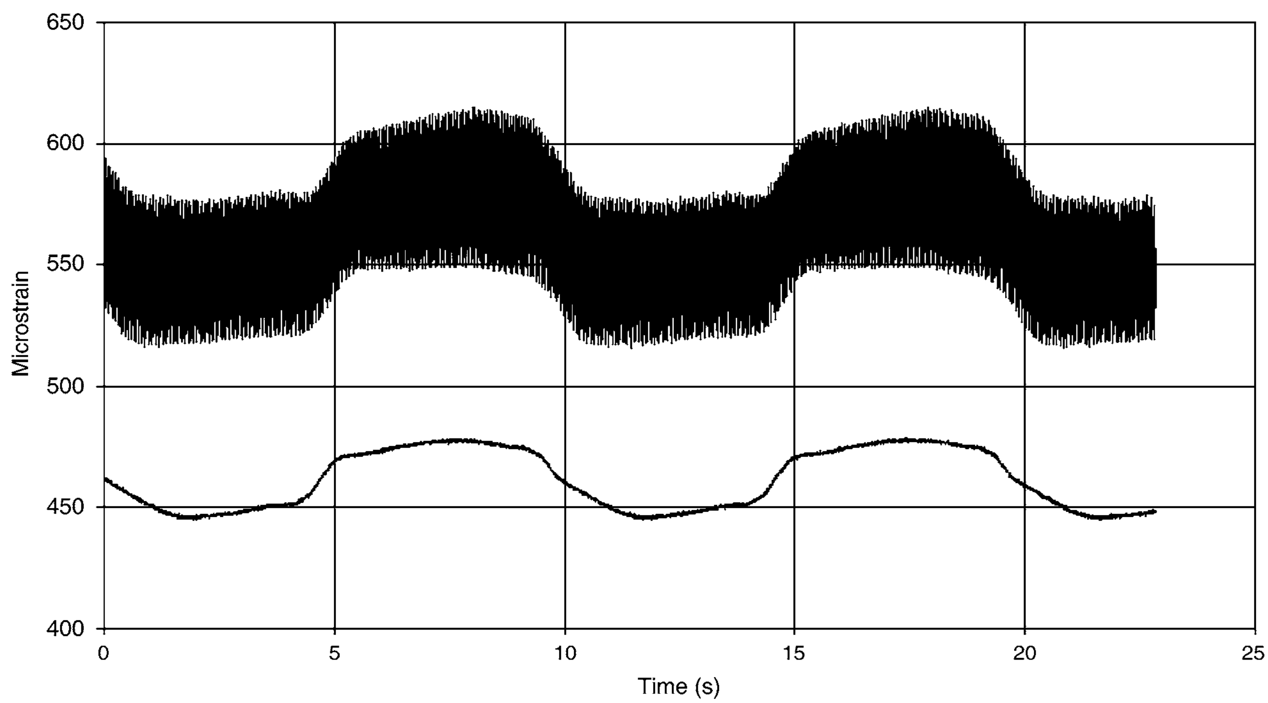

Figure 2.31. Specimen 1 support bar strain gage data showing vibrator influence.

away from a support bar. The figure shows that the opening and closing loads from the actuator cause strain ranges of 15 microstrain or 3.0 MPa (0.435 ksi). The vibrator acts to superpose high-frequency strain ranges of 45 microstrain or 9.0 MPa (1.3 ksi).

Figure 2.31 shows strain gage data for a support bar connected to the centerbeam to which the vibrator was mounted. Even though there is no direct contact to the vibrator, it still produces a strain range of 60 microstrain or 12.0 MPa (1.74 ksi). The actuator alone produces a strain range of 25 microstrain or 5.0 MPa (0.73 ksi). As mentioned previously, the measured strain ranges were consistent with an equivalent static applied force range of 45 kN (10 kips), which is close to the fatigue wheel load of 47 kN (10.5 kips) recommended in *NCHRP Report 402.*

Strain gages were attached to Specimen 2 to investigate the behavior of this MBJS. In this case, strain gages were placed at midspan of the centerbeam to which the vibrator was attached. Gages were also placed on the support bar directly under its connection to the centerbeam that the vibrator was attached to. Figure 2.32 shows the vibration frequency on a smaller time scale. The strain gage data were taken at midspan of the centerbeam with the vibrator attached to it. The frequency of vibration is 100 Hz. As can be seen in Table 2.5, there were some small strain ranges in the centerbeams when the MBJS was being cycled without the vibrator. There was no measurable strain in the support bar. When the vibrator was turned on, there was a measurable amount of strain at all locations. The influence of only the vibrator was determined by subtracting the actuator influence out of the total response. As can be seen in the table, the major stress is found in the vertical direction of the centerbeam. There is little stress in the horizontal direction.

Strain gages were also placed on Specimen 3 and the results from measurements can be seen in Table 2.6. The strain gages were placed at midspan for the centerbeam to which the vibrator was attached. Again measurements were taken both with and without the vibrator running. In this specimen, there was significant strain in the horizontal direction without the vibrator running. The vibrator increased the strain in the vertical direction but actually served to reduce the strain in the horizontal direction.

The actuator cycling that simulates the longitudinal opening and closing movement does not cause enough strain to be a problem for the limited number of cycles for which it runs. However, the stress ranges from the vibrator may be large enough to cause fatigue of poor connection details, as explained in the next section. Given that most details did not experience fatigue, it is reasoned that the strain ranges caused by the vibrator are reasonably close to those measured in traffic.

Figure 2.33 shows load versus stroke graphs for Specimen 4 for a 101-mm (4-in.) movement range. Specimen 4 was a

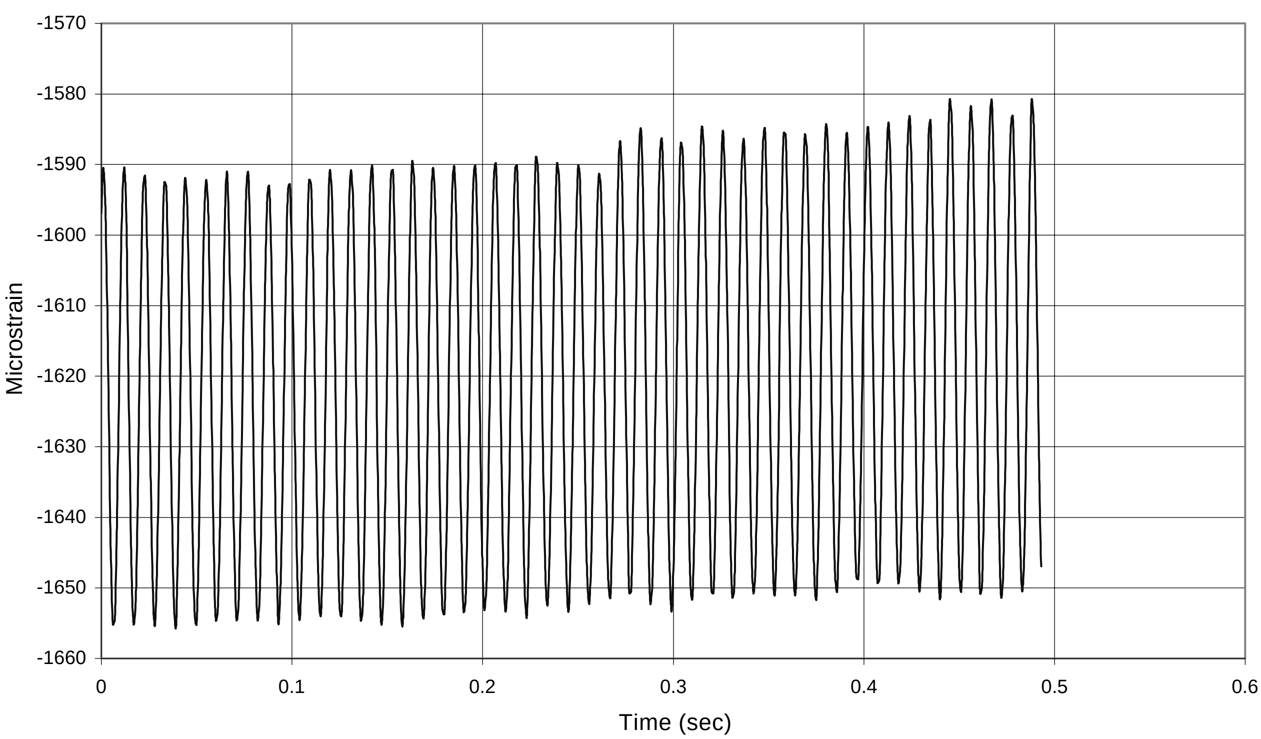

Figure 2.32. Specimen 2 centerbeam strain gage data showing vibrator cycles.

TABLE 2.5 Strain gage information for Specimen 2

		CB horiz.	CB vert.	SB vert.
Without vib.	Strain (*10^-6)	12.5	15.0	----
	Stress (MPa)	2.50	3.00	----
	Stress (ksi)	0.363	0.435	----
With vib.	Strain	20.8	98.9	45.4
	Stress (MPa)	4.16	19.8	9.08
	Stress (ksi)	0.603	2.87	1.32
Vib. Influence	Strain	8.3	83.9	45.4
	Stress (MPa)	1.66	16.8	9.08
	Stress (ksi)	0.241	2.43	1.32

TABLE 2.6 Strain gage information for Specimen 3

		CB vert.	CB horiz.
Without vib.	Strain (*10^-6)	14.2	108.1
	Stress (MPa)	2.84	21.62
	Stress (ksi)	0.412	3.135
With vib.	Strain	54.4	92.8
	Stress (MPa)	10.9	18.6
	Stress (ksi)	1.58	2.69
Vib. Influence	Strain	40.2	-15.3
	Stress (MPa)	8.04	-3.06
	Stress (ksi)	1.17	-0.444

single-support-bar model with four support boxes and two centerbeams. This figure shows several opening and closing cycles. Cycles are shown both with and without the vibrator running.

The minimum, most negative, opening load of 18 kN (4.0 kips) without the vibrator and 13 kN (2.9 kips) with the vibrator is significantly lower than the maximum closing load of 26 kN (5.8 kips) without the vibrator and 20 kN (4.5 kips) with the vibrator. This difference is due to the control springs, which are arranged to push the specimen open. This was the only specimen detailed that way. The other specimen's equidistant devices were designed to close the MBJS.

Table 2.7 shows the opening and closing loads for most of the specimens with the vibrator running. It also breaks down the load into load per support box and then into load per support bar. Specimens 1, 2, and 6 are welded multiple-support-bar systems. In these types of MBJS, the equidistant devices (control springs in these specimens) are designed to push the MBJS closed. However, there is no clear trend in the difference between the opening load and the closing load in these specimens, and the differences are very small. In terms of the load per support bar, the opening/closing load in these specimens ranged from 1.7 to 3.8 kN (0.38 to 0.85 kips) per bar. If there is a trend among the opening/closing loads for these specimens, it is that the joints with the greater numbers of bars require less force per bar. Considering that the same company manufactured specimens 1 and 6, it is more likely that the opening/closing load is just highly variable within this range for this type of MBJS.

Specimens 3 and 4 are single-support-bar systems. In Specimen 4, the control springs are designed to push the MBJS open. The greater closing load, 5.0 kN (1.1 kips) per bar, is consistent with this design. Specimen 3 has a more complex equidistant device, and the opening load was greater, in this case 8.8 kN (2.0 kips) per bar.

Figure 2.34 shows the measured actuator peak opening and closing load for Specimen 4 at various times during the test. The actuator load both with and without the vibrator was measured at various times. The vibrator decreased the actuator force needed to both open and close the MBJS. The amount of load reduction varied between 2.2 and 6.7 kN (0.5 and 1.5 kips).

That the vibrator decreases the load to both open and close the MBJS indicates that the movement is probably a "stick-

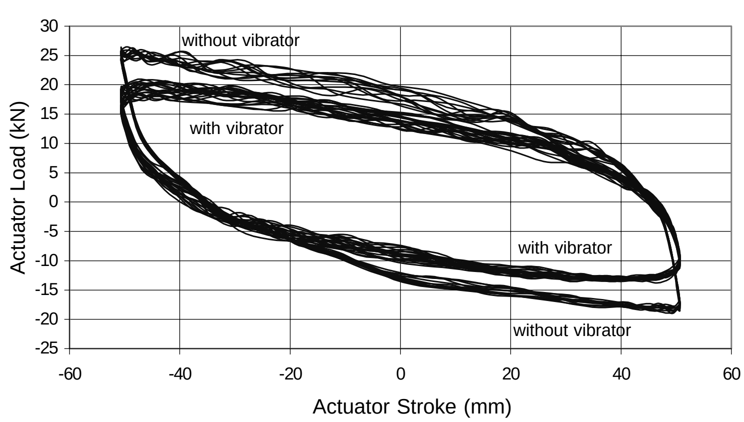

Figure 2.33. Effect of vibrator on Specimen 4.

TABLE 2.7 Opening and closing loads per box and bar with vibrator

Specimens→	1	2	3	4	6
Closing Load (kN)	25	25	12	20	30
C. Load / box (kN)	8.3	8.3	3.0	5.0	7.5
C. Load / bar (kN)	1.7	2.1	3.0	5.0	3.8
Opening Load (kN)	25	28	35	13	25
O. Load / box (kN)	8.3	9.3	8.8	3.3	6.3
O. Load / bar (kN)	1.7	2.3	8.8	3.3	3.2

slip" type of movement. The traffic load or the vibrator puts an alternating normal force on the bearings that momentarily reduces the friction force. The opening and closing load varied during each specimen's test, but generally did not give any indication of impending failure.

2.2.3.3 Results of the Opening Movement Vibration Test

The failure modes for each specimen tested will be discussed in detail in this section. It is important to understand the failure modes in order to determine if they are similar to service failures. It will also help in future tests as it can be seen that some failures are common and will probably continue to be problems. A table describing failure times (and equivalent service lives) is provided for each specimen.

Tables 2.8 through 2.13 display times until failures for each specimen. The tables also include information on actuator and vibrator cycles. Vibrator cycles were determined by assuming a loading frequency of 100 Hz.

Specimen 1. Specimen 1 was used in the research for *NCHRP Report 402*. The previous tests performed on this specimen were static and did not damage the specimen. Figure 2.21 shows Specimen 1 in the test fixtures. Specimen 1 failed because a fatigue crack formed in the centerbeam/support bar connection. The weld failure can be seen in Figure 2.35. The connection was a fillet weld; this connection detail is known to be inferior to the full-penetration weld as was shown in *NCHRP Report 402* (*4*). Figures 2.36 and 2.37 show the S-N (stress range versus number of cycles) fatigue data plots for full penetration welds and fillet welds, respectively. These graphs were originally provided in *NCHRP Report 402.* Most of the test data for the full penetration welds is above Category C, while all of the fillet weld data fall below Category E. The weld failure demonstrated that the vibrator provided enough force to cause a failure. Moreover, it caused a failure that has also been observed in the field.

This specimen also exhibited significant amounts of wear on the PTFE wearing surface on the support bar elastomeric bearings and springs. Excessive wear can cause bearing and spring failure. However, the test was stopped before the wear could become a problem and cause a failure. The test was stopped after the occurrence of the fatigue crack, which resulted in an inability to transfer load from the vibrator to the

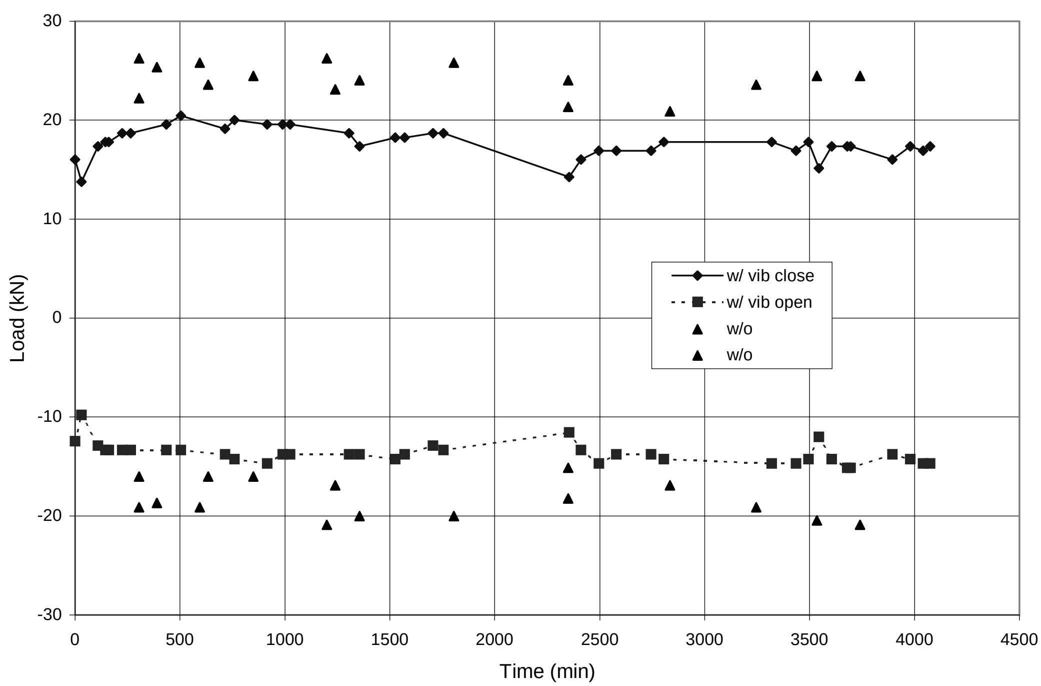

Figure 2.34. Vibrator influence on required actuator load over time for Specimen 4.

TABLE 2.8 Test results for Specimen 1

Failure	Actuator time	Actuator cycles	Relative bridge life	Vibrator time	Vibrator cycles
Till 1st	4 hrs 35 min	1650	4 yrs 189 days	6:35	2,370,000
Final	9 hrs 10 min	3300	9 yrs 13 days	7:55	2,850,000

TABLE 2.9 Test results for Specimen 2

Failure	Actuator time	Actuator cycles	Relative bridge life	Vibrator time	Vibrator cycles
Till 1st	26 hrs 35 min	9,570	26 yrs 74 days	9 hrs 50 min	3,640,000
Till 2nd	30 hrs 25 min	10,950	29 yrs 358 days	10 hrs 49 min	3,894,000
Till 3rd	33 hrs 47 min	12,162	33 yrs 18 days	14 hrs 11 min	5,106,000
Till 4th	40 hrs 25 min	14,550	39 yrs 305 days	19 hrs 21 min	6,966,000
Final	76 hrs 30 min	27,540	75 yrs 146 days	23 hrs 3 min	8,298,000

TABLE 2.10 Test results for Specimen 3

Failure	Actuator time	Actuator cycles	Relative bridge life	Vibrator time	Vibrator cycles
Till 1st	33 hrs 40 min	12,120	33 yrs 67 days	15 hrs 15 min	5,490,000
Till 2nd	37 hrs 10 min	13,380	36 yrs 231 days	18 hrs 10 min	6,540,000
Till 3rd	39 hrs 35 min	14,250	39 yrs 5 days	19 hrs 20 min	6,960,000

TABLE 2.11 Test results for Specimen 4

Failure	Actuator time	Actuator cycles	Relative bridge life	Vibrator time	Vibrator cycles
Till 1st	21 hrs 35 min	7,770	21 yrs 100 days	17 hrs 5 min	6,150,000
Till 2nd	59 hrs 55 min	21,570	59 yrs 20 days	38 hrs 40 min	13,920,000
Final	70 hrs 25 min	25,350	69 yrs 148 days	46 hrs 50 min	16,860,000

TABLE 2.12 Test results for Specimen 5

Failure	Actuator time	Actuator cycles	Relative bridge life	Vibrator time	Vibrator cycles
Till 1st	50 min	300	180 days	35 min	210,000
Till 1st	30 min	180	180 days	25 min	150,000
Till 1st	1 hr 30 min	540	1 yr 175 days	1 hr 30 min	540,000

TABLE 2.13 Test results for Specimen 6

Failure	Actuator time	Actuator cycles	Relative bridge life	Vibrator time	Vibrator cycles
None	76 hrs 6 min	27,394	75 years	76 hrs 6 min	27,396,000

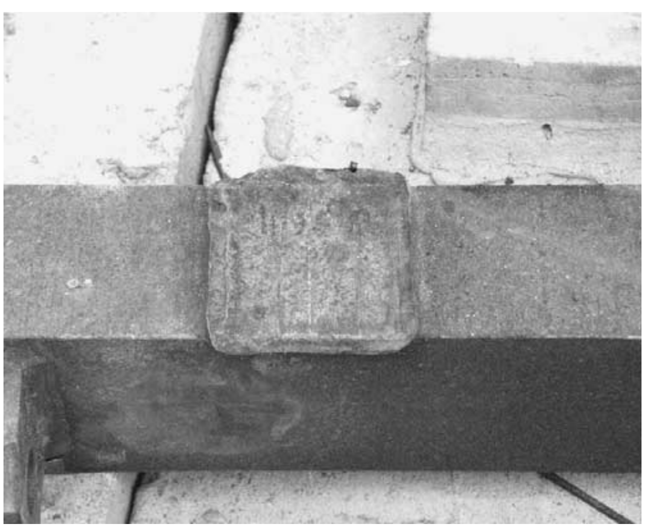

Figure 2.35. Fatigue weld failure of centerbeam/support bar connection.

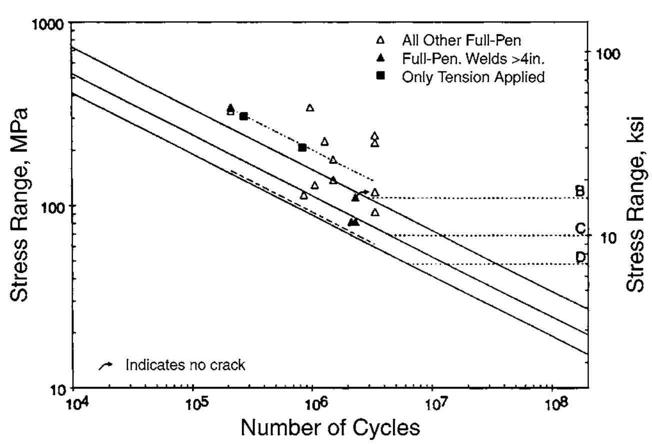

Figure 2.36. S-N plot of full penetration centerbeam/ support bar connection.

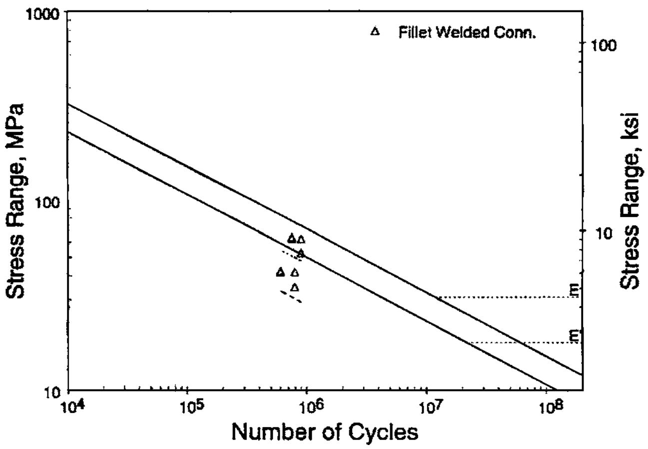

Figure 2.37. S-N plot of fillet welded centerbeam/support bar connection.

bearings and springs. This MBJS was not designed according to the fatigue design requirements of *NCHRP Report 402.*

A centerbeam/support bar fatigue crack (as discussed in Specimen 1) results in the bar failing the test. This type of failure quickly leads to loss of function of the MBJS. The failure of the centerbeam/support bar doubles the span length of the centerbeam and causes further centerbeam/support bar connection failures. Under traffic loading, the lack of positive connection at the joint causes excessive noise.

The results from this test reinforce the importance of designing MBJS according to the fatigue requirements of *NCHRP Report 402.* Specimens undergoing performance testing must already have passed the fatigue testing requirements found in *NCHRP Report 402* and be designed according to the requirements in the same document.

Specimen 2. Specimen 2 was removed from the Hudson Bridge that carries I-94 over the St. Croix River between Minnesota and Wisconsin. At the initial installation, the MBJS was installed at an incorrect width for the installation temperature. During the first winter, the MBJS was extended beyond its movement capacity and was significantly damaged. In an attempt to save the MBJS until it could be replaced, one of the seals was fixed in a completely open position by welding plates between an edgebeam and one centerbeam. The elastomeric components were also replaced. After 3 years, the MBJS was removed and replaced with a completely new MBJS. The removal and replacement was observed and a section of the old MBJS was saved for testing. The MBJS survived the removal process with little damage.

Specimen 2 had several failures during the test. (In all tests, testing was continued after initial failures to investigate the effect of one failure on the overall performance of the specimen as well as the frequency of subsequent failures.) The first failure was in the support bar bearings and springs. Both the spring and bearing that failed were holding the support bar that was welded to the centerbeam with the vibrator attached.

The bearings and springs for this specimen were made of three layers. The wear surface was a low-friction PTFE layer bonded to a preformed fabric that was then bonded to a urethane layer. The test caused the three layers of the bearing to separate (delaminate) (as shown in Figure 2.38) and the PTFE layer to separate (as shown in Figure 2.39).

The second failure was in the control spring equidistant device. The elastomeric control springs were held in place by keeper plates. These plates were welded to the support bar and bolted to the support box. At the failure location, the keeper plate bolted to the support box was fabricated so that it was too close to the support bar. When the support bar moved, it rubbed against the keeper plate. This continuous rubbing caused bending in the keeper plate. The bending of the keeper plate induced stress in the two bolts that hold it in place until both bolts eventually fractured as shown in Figure 2.40. The keeper plate and control spring then fell out of place. The elastomeric control springs were not damaged.

The third and fourth failures were also in the elastomeric bearings. The third failure was similar to the first failure. There was a delamination of a bearing at a support bar connected to the centerbeam on which the vibrator was mounted. This bearing was not adjacent to the vibrator, however. Although the fourth failure was also a support bar elastomeric bearing failure, in this fourth failure, the PTFE layer was worn down through the opening and closing movement action until it was completely removed. The loss of the low-friction PTFE layer meant that the support bar was riding on the woven fabric layer. This increased the friction on the bearing and spring until the shear stress was large enough to separate the fabric layer from the urethane layer as shown in Figure 2.41. The fourth bearing failure was not on the centerbeam/support bar assembly on which the vibrator was mounted, nor was it adjacent to where the vibrator was mounted. The specimen exhibited no other failures and testing was stopped after the equivalent of a 75-year life was achieved.

It is believed that the first failure led to the third failure. This conclusion demonstrates that the MBJS behaves as a system

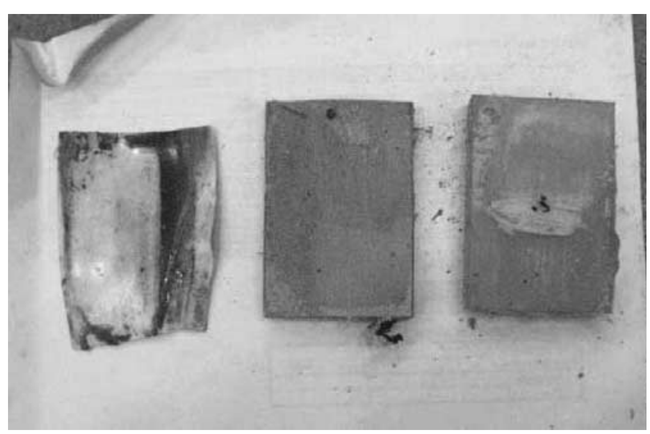

Figure 2.38. First failed support bar bearing.

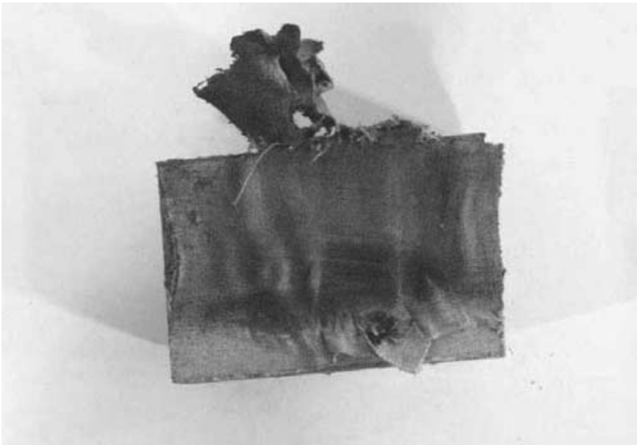

Figure 2.39. First failed support bar spring.

with the performance of each component affecting the others. The second failure was unrelated. It is not known if the first or third failure contributed to the fourth failure.

Specimen 3. Specimens 3, 4, 5, and 6 were purchased specifically for laboratory testing. Specimen 3 experienced several problems that would not have occurred in service because the support boxes are normally embedded in concrete. For example, the elastomeric bearings and springs were retained in the support boxes with a steel dowel or pin that could be removed. During the test, the vibration caused the pins for the springs to move vertically up and out of place. Normally these pins are kept in place by the concrete that is placed around the support boxes. The movement of the pins allowed the elastomeric springs to fall out of place. Because this was not a failure mode that would occur in service conditions, it was decided to replace the springs and pins. The springs and pins were replaced, clamps were placed on the support boxes

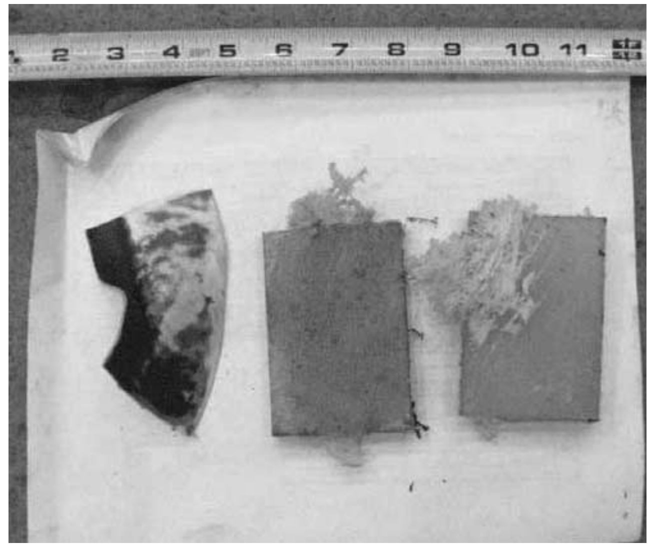

Figure 2.41. Second failed support bar bearing.

to block the pins from backing out of their holes, and testing was resumed. This illustrates the importance of securing these types of details when these tests are conducted in the future.

This specimen was a single-support-bar model with one centerbeam welded to the support bar and the other one held in place with bearings and yokes. This specimen eventually failed when the bearing on a yoke assembly became dislodged. The bearing for the yoke was held in place by a bolt that protruded through the yoke as shown in Figure 2.42. The failure occurred in a yoke bearing next to where the vibrator was mounted. The bearing moved out of place and moved over its keeper bolt. It soon fell out of place. The bolt that held it in place had a height of 6 mm ($\frac{1}{4}$ in.) above the yoke surface. Of that, 3 mm ($\frac{1}{8}$ in.) was tapered. It is believed that

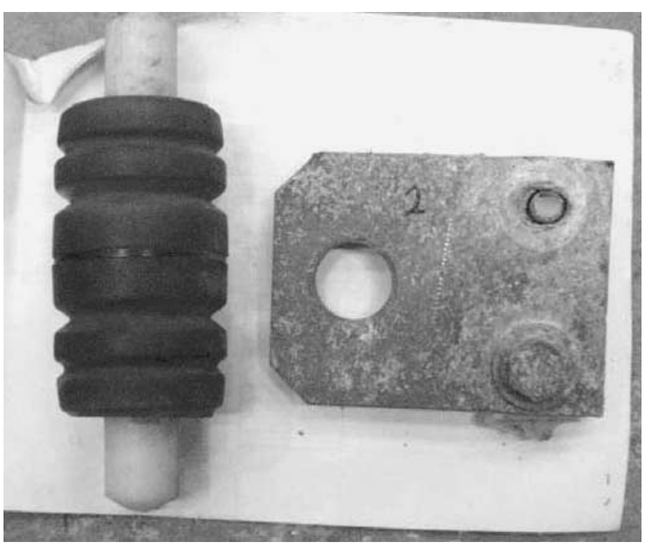

Figure 2.40. Failed equidistant control spring keeper plate.

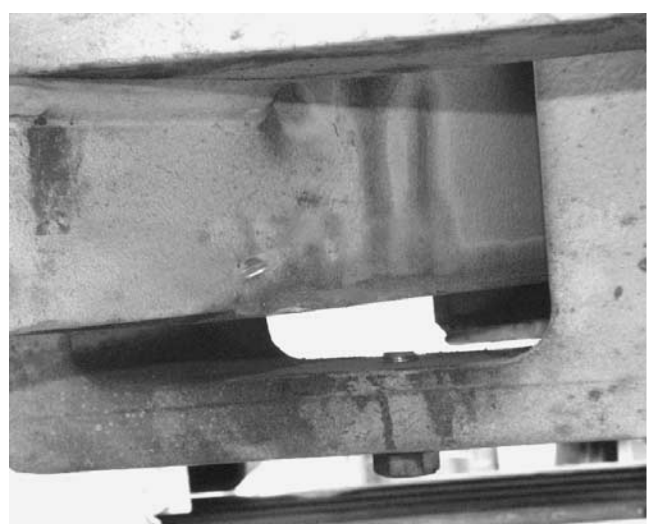

Figure 2.42. Missing yoke bearing.

a longer bolt would have prevented the bearing from moving out of place.

The MBJS specimen could still be opened and closed, so testing was continued. A second failure occurred when a pin holding a spring in place in a support box fell down and into the spring. This pin is the same type of pin that previously had migrated out of the box, but was later prevented from moving up and out of the box. The pins were not prevented from falling down and into the box. Once the pin moved down and out of place, the spring was no longer secured and it fell out of place. Notice the damage to the spring in Figure 2.43. This spring was also adjacent to where the vibrator was mounted, but was not one of the springs that had previously fallen out of place and had to be replaced.

Finally, this specimen developed a crack in the centerbeam weld splice as shown in Figure 2.44. This occurred after 39 hours and 35 minutes of testing. The centerbeam splice for this specimen consisted of a bolted splice in the web of the centerbeam profile with the top part of the cross section being welded as shown in Figure 2.45. The top part of the splice that was welded cracked. There was no damage to the bolted part of the splice. It is not known how this weld crack would affect the performance of the splice, but it is doubtful that it would significantly decrease the durability because the bolted part of the splice was strong enough to withstand the loading. These welds would crack in the field. It is recommended that an improved splice be designed. Testing for this specimen was stopped before an equivalent life of 75 years was reached.

Figure 2.46 shows a graph of the actuator load versus stroke requirements for Specimen 3 before any failures and after the first failure. As can be seen, the graphs are similar in their shapes. There is a small difference in the load versus stroke curves at the upper left end of the graph. It is believed that the loss of the bearing in the first failure and the beginning of the influence of the second failure can be seen in an increase in the load requirements.

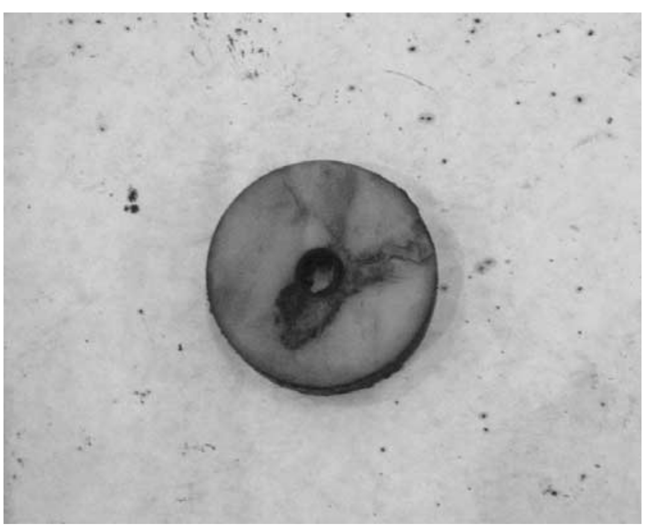

Figure 2.43. Failed support bar bearing.

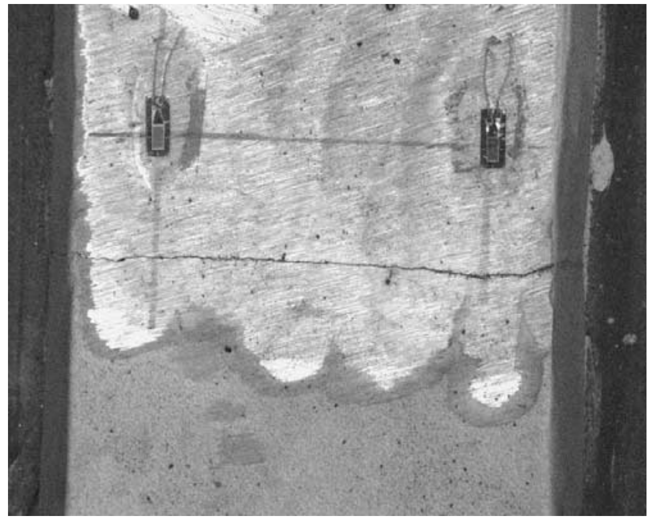

Figure 2.44. Centerbeam splice weld failure.

Specimen 4. The fourth specimen, a single-support-bar MBJS, had the first failure to occur in the control spring equidistant device. The equidistant device consisted of elastomeric control springs mounted between steel plates attached to the edgebeams and centerbeams. The control springs were held in place with either steel rods or nylon dowels, depend-

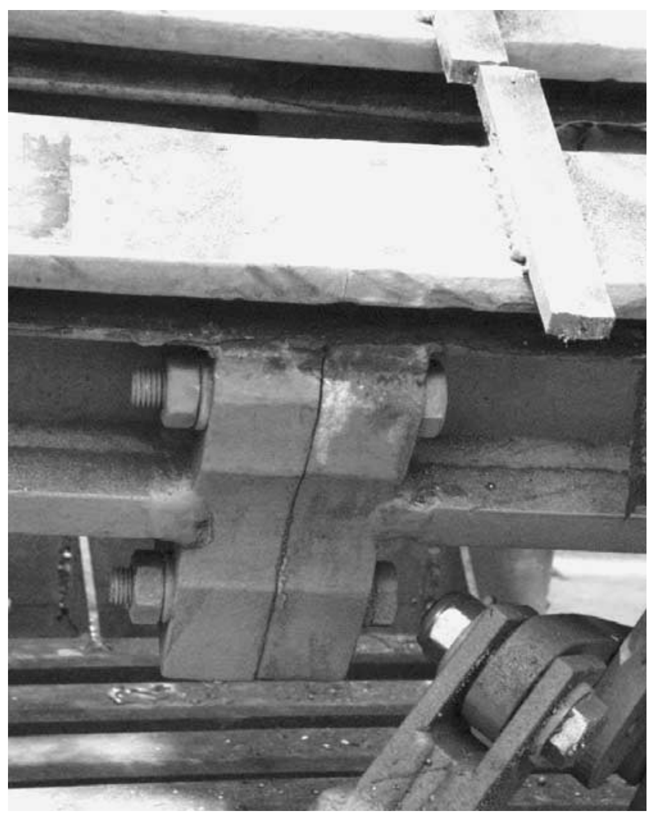

Figure 2.45. Bolted centerbeam splice for Specimen 3.

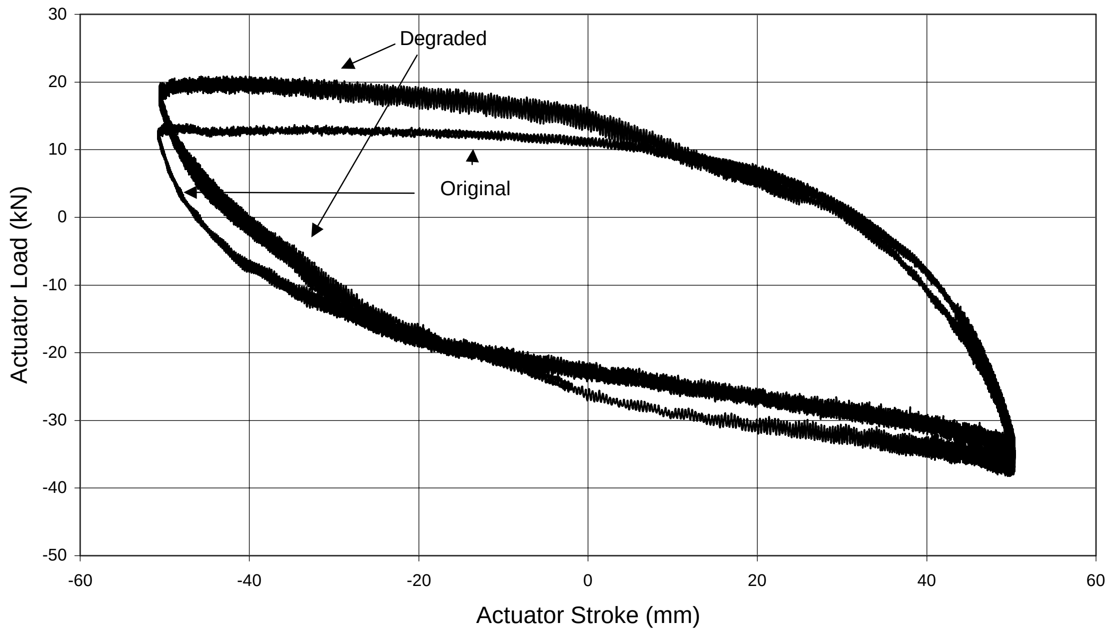

Figure 2.46. Graph showing degradation of Specimen 3.

ing on where the control spring was mounted on the MBJS. Specimen 4 had a steel rod if it was attached to an edgebeam, but a nylon rod if it was mounted to centerbeams on both sides. The steel rod was welded to the steel plate with what appeared to be a "plug" weld. The opening movement of the test caused the steel rod to rub against the steel plate that held the control spring in place as shown in Figure 2.47. This rubbing induced stress in the rod that eventually caused the plug weld holding the dowel in place to fail as shown in Figure 2.48 and Figure 2.49.

The second failure was similar. At the same time as the second control spring failure, a crack in the field splice was discovered. This crack was in the weld that connected the two edgebeams as shown in Figure 2.50. The crack continued to grow during the remaining testing, but never became large enough to separate the joined edgebeam sections. An

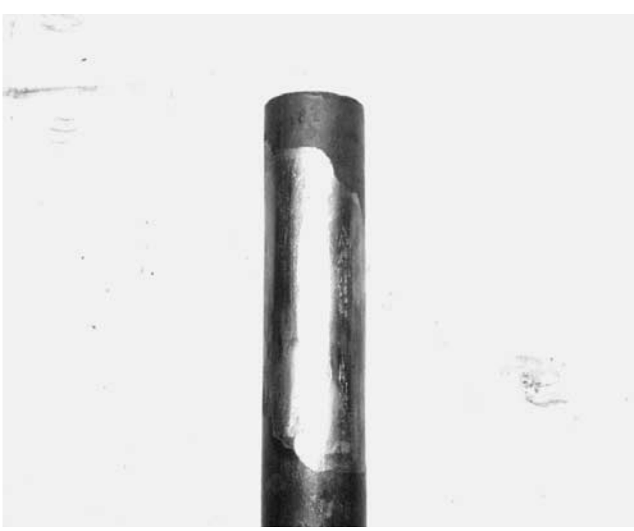

Figure 2.47. Wear on equidistant control spring keeper rod.

Figure 2.48. Weld failure of equidistant control spring keeper rod.

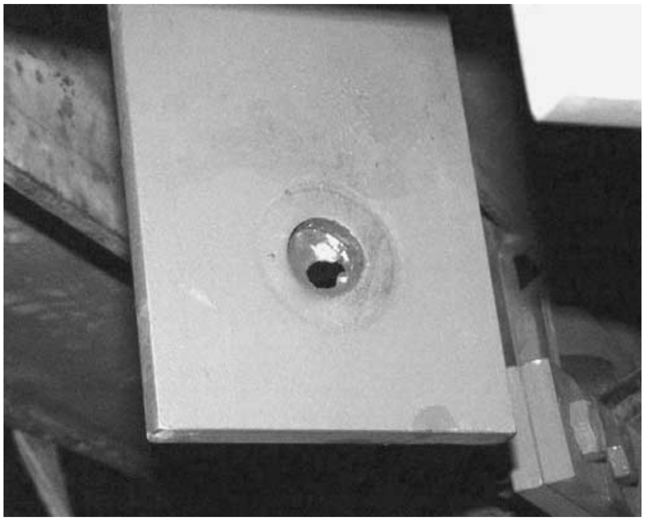

Figure 2.49. Weld failure of equidistant control spring keeper rod.

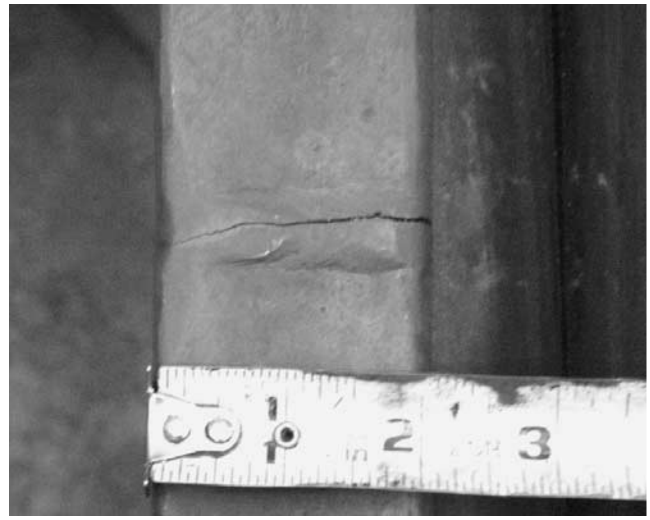

Figure 2.50. Edgebeam weld splice crack.

edgebeam failure is of little consequence in service, because the edgebeam is continuously anchored to the blockout concrete.

A graph of the actuator load versus stroke requirements is found in Figure 2.51. This figure shows the different requirements of the specimen as the testing progressed. There are two locations where the graphs differ significantly. The upper left location is where the influence of the first failure can be found. There was significant rubbing during the testing up to the time of the first failure. The first failure and loss of that rubbing can be seen in the lower load requirements. The lower right location shows the response of the specimen to a condition that was not severe enough to cause a failure. The support bar was kept in place laterally by two plates. However, the support bar moved during the testing until it was resting against one of these plates. It then caused wear both in the plate and the sup-

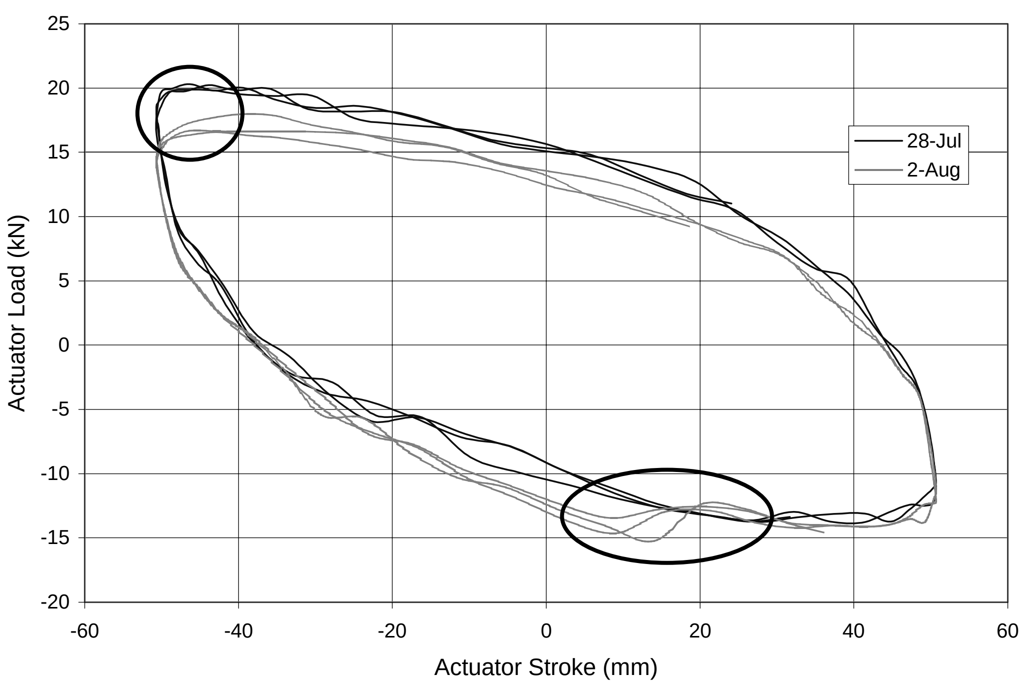

Figure 2.51. Specimen 4 Load vs. Stroke graph showing MBJS degradation.

port bar as shown in Figure 2.52. The effect of the wear can be seen in the load requirements. The wearing was not severe enough to cause a failure in the support bar or the plate.

Specimen 5. When Specimen 5 was inspected prior to testing, it was discovered that one of the bearings had moved out of place. The pin holding the bearing in place had been torn off. The bearing was replaced before testing started.

Testing then began, and a urethane bearing failed by delamination from the fabric pad after 50 minutes. This was a bearing supporting the centerbeam to which the vibrator was mounted and was adjacent to the vibrator. The failure was similar to those found in Specimen 2. That the failures were similar supports the test strategy that the specimens with only two centerbeams (such as Specimen 5) will be an adequate simulation of what happens in specimens with greater numbers of centerbeams (such as Specimen 2) subjected to the same movement range.

Because the bearing failed in such a short time relative to the other tests, it was decided to replace the bearing and continue the test. Discussions with the manufacturer suggested an inadequate bond between the fabric and urethane layers. The areas coated by the bonding agent are shown in Figure 2.53.

The replacement bearing also failed after another 30 minutes of testing. Further discussions with the manufacturer suggested that the problem might not be with the bearings, but rather in the manufacture of the MBJS. It was decided to replace all of the springs and bearings, including the one that failed, to test this hypothesis.

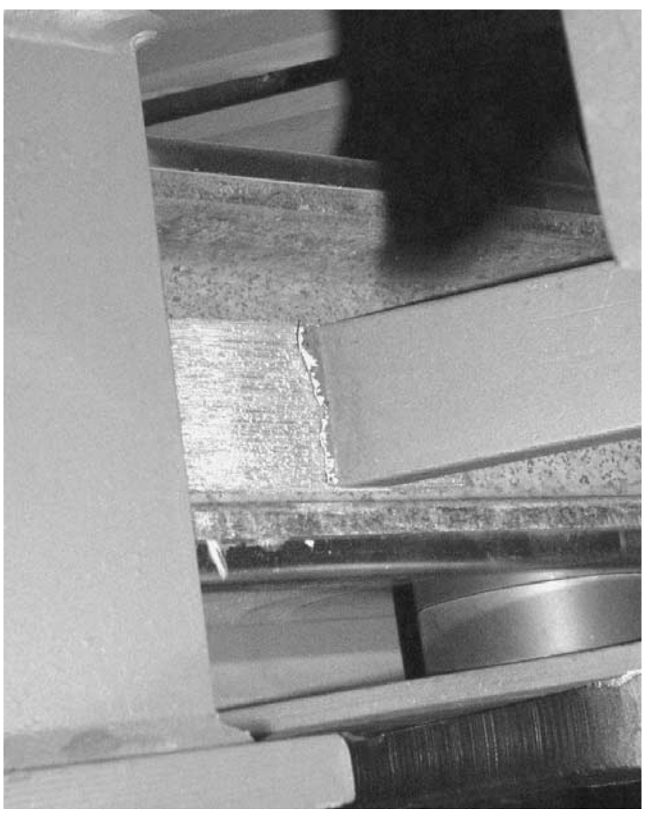

Figure 2.52. Wear caused by OMV test.

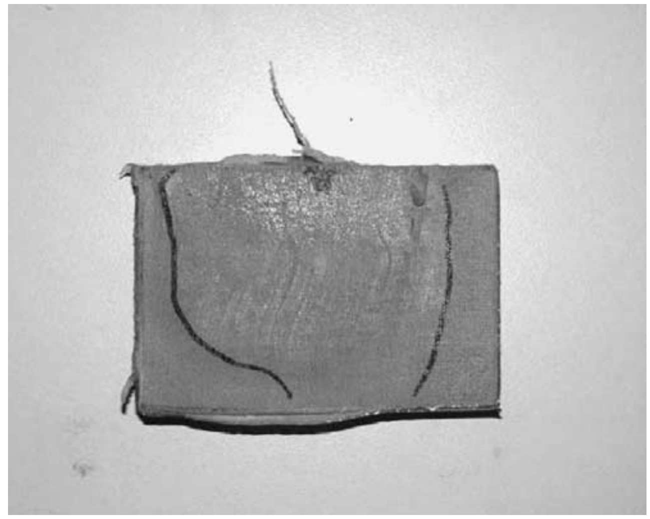

Figure 2.53. Support bar bearing failure with limits of bonding agent outlined.

During replacement of the springs and bearings, the support bar was measured. Measurements show that the support bar was welded to the centerbeam at an angle that caused significant downward force on the bearing that failed (see Figure 2.54). The test was restarted and the same bearing failed after 1.5 hours of testing. The testing was stopped at this point.

Specimen 6. Specimen 6 completed the testing requirements with no failures. There were two problems with this specimen that were not severe enough to be classified as failures. The first problem was that a nylon control spring keeper rod moved out of its designed position shortly after testing started. The nylon rod was restrained from completely falling out by the support box. The elastomeric control spring did not move out of position and was unharmed. The second problem was that at approximately 74 hours into the testing a bolt for a centerbeam splice fractured and fell out. This splice used a total of six bolts; three for each side of the splice. The loss of one of the bolts did not affect the performance of the splice.

2.2.3.4 Summary of the Opening Movement Vibration Test

By using the test results, the specimens can be rated based on durability. Table 2.14 rates the specimens based on the time it took to reach the first failure. There is a wide variation in the results, which is good because it indicates the results separate the good-performing MBJS from the inadequate MBJS by a distinguishable margin. The results demonstrate the ability of the test to produce the same type of failures observed in the

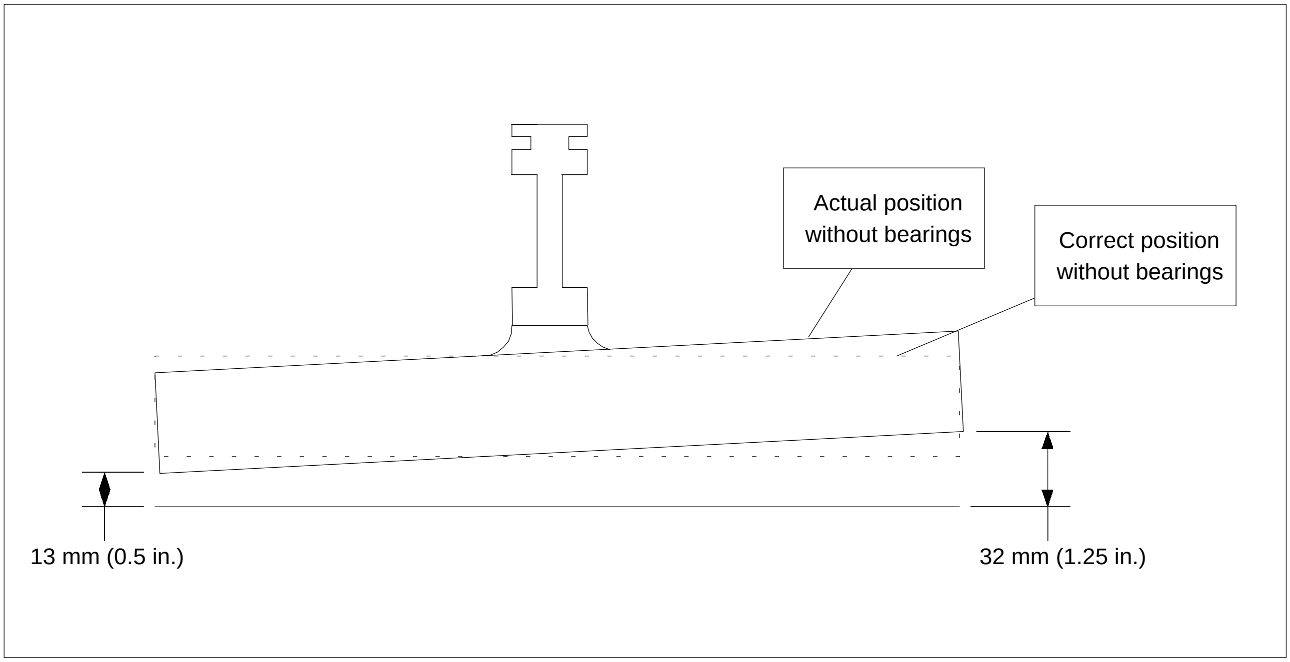

Figure 2.54. Misalignment of support bar contributed to failure of bearings in Specimen 5.

field. As previously discussed, Specimen 5 had a fabrication problem that caused a quick failure. Specimen 1 was not designed according to *NCHRP Report 402,* and the results demonstrated the lack of durability associated with MBJS not designed for fatigue. Specimen 6 was unique in that it survived the entire testing regiment with no failures. The results from the other three specimens compare well. For these three specimens, the time until first failure ranges between 21 and 33 hours, which corresponds to approximately 21 and 33 years, respectively. This is typical of actual in-service performance.

The test confirmed that there are significant problems with splices. It is believed that these problems would also be detected in the fatigue testing proposed in *NCHRP Report 402.* However, it is important that the field splice be installed as it was designed ad tested. Therefore, it is important that the manufacturer produce clear guidelines for the contractor on how to properly install the field splice.

In most specimens, the problems were confined to the elastomeric components. Although it is desirable to have the 75-year life as a goal, it may not be reliably achieved in all cases. To ensure continued serviceability over the 75-year design life, it is essential to allow for the replacement of the elastomeric components. It is possible to design and build am MBJS capable of surviving the testing process, as demonstrated by Specimen 6.

TABLE 2.14 Durability of test specimens

Specimen	Time 1st Fail	Durability Rank
6	76 hrs 6 min	1
3	33 hrs 40 min	2
2	26 hrs 35 min	3
4	21 hrs 35 min	4
1	4 hrs 35 min	5
5	50 min	6

Both two- and three-span specimens were tested. There was no trend with the failure modes or times. Therefore, a minimum of two spans is required for the test specimens.

Specimens were tested that had between two and five centerbeams. There was no correlation between the failure mode or time and the number of centerbeams. Also, no correlation was noticed in the service performance of MBJS and the number of centerbeams. Therefore it is believed that a two-centerbeam specimen may be tested and the results can be considered representative of similarly designed MBJS with up to six centerbeams. This covers movement ranges up to 533 mm (21 in.), which includes most installations. Although it is believed that these tests would also be applicable to even larger movement range joints with more centerbeams, these larger specimens were not tested and the results are less certain. Therefore, the research team recommends that additional OMV tests be conducted on these larger specimens in order to prequalify joints with more than six centerbeams.

2.2.4 Seal Push Out Test

The Seal Push Out (SPO) Test was developed specifically to investigate the resistance of the seals to detachment, from the edgebeam and centerbeam, as a result of vertical load on compacted debris. This is the most common problem associated with MBJS.

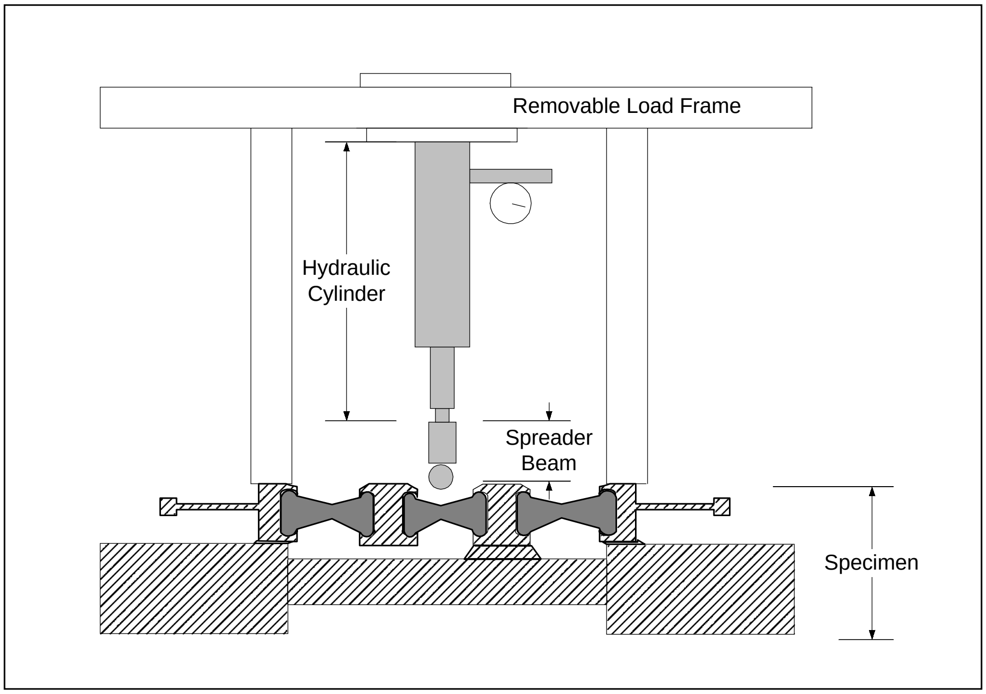

Figure 2.55. Graphical representation of Seal Push Out Test set up.

2.2.4.1 Description of Test

This test is performed after the OMV test. The test does not simulate actual service conditions, such as debris in the seals, which could significantly alter the results but would be extremely difficult to quantify and replicate. However, the test can be used to rate the effectiveness of the seals to resist a vertical load. A self-reacting load frame was constructed that can be connected to the specimen. The frame consisted of two columns and a beam that connected to the top of each column as shown in Figure 2.55.

The columns were attached, either through clamping or welding depending on the profile, to the edgebeams as shown in Figure 2.56. A 44 kN (10 kip) capacity single-acting, solid plunger hydraulic cylinder was used to provide the load necessary to cause the seals to detach. The load was applied to the seals through a spreader bar. The spreader bar was a 25.4-mm (1-in.)-diameter round bar stock 533.4 mm (21 in.) in length, which is the width of a double truck tire. A $25 \times 50 \times 483$ mm ($1 \times 2 \times 19$ in.) stiffener bar was welded to the round bar stock to ensure that the spreader beam did not undergo significant bending. The ends of the round bar were beveled to 45 deg for 13 mm (½ in.) to reduce the possibility of tearing the seal.

The hydraulic cylinder was mounted to a base plate that was in turn bolted to the self-reacting test frame. A pressure gauge was used to monitor the load for each test. A portable electric hydraulic pump powered the hydraulic cylinder. The portability of the test equipment for this test allowed it to be performed almost anywhere, including at the MBJS fabricator's shop.

The test was considered completed when one of three conditions was met: the seal tore, the seal became separated from its retainer, or the maximum capacity of the cylinder was reached.

2.2.4.2 Seal Push Out Test Results

The full results of tests on all of the specimens are given in Table 2.15. The seal opening, pressure required to push out

Figure 2.56. Seal Push Out Test set up.

TABLE 2.15 Seal Push Out Test results

Specimen	Opening		Pressure	Force		Engage Length		Fail mode	EB
	(mm)	(in)	(psi)	(N)	(lbs)	(mm)	(in)		
1	66.675	2.625	3300	11528.4	2591.8	711.2	28	pullout	y
	69.85	2.75	2600	9083.0	2042.0	635.0	25	pullout	n
	73.025	2.875	2200	7685.6	1727.9	609.6	24	pullout	n
	63.5	2.5	3000	10480.4	2356.2	609.6	24	pullout	y
	60.325	2.375	2400	8384.3	1885.0	584.2	23	pullout	y
	66.675	2.625	1800	6288.2	1413.7	609.6	24	pullout	n
	69.85	2.75	2100	7336.2	1649.3	not measured		pullout	n
	66.675	2.625	3200	11179.0	2513.3	not measured		pullout	y
2	76.2	3	3500	12227.1	2748.9	736.6	29	pullout	n
	57.15	2.25	1800	6288.2	1413.7	482.6	19	tear	y
	50.8	2	5000	17467.3	3927.0	787.4	31	pullout	n
	57.15	2.25	5000	17467.3	3927.0	787.4	31	tear	y
	53.975	2.125	4400	15371.2	3455.8	736.6	29	pullout	n
3	76.2	3	1500	5240.2	1178.1	736.6	29	pullout	y
	53.975	2.125	1400	4890.8	1099.6	711.2	28	pullout	n
	73.025	2.875	1200	4192.1	942.5	660.4	26	pullout	y
	57.15	2.25	1300	4541.5	1021.0	685.8	27	pullout	n
	73.025	2.875	1200	4192.1	942.5	660.4	26	pullout	y
	69.85	2.75	1200	4192.1	942.5	635.0	25	pullout	y
	57.15	2.25	1400	4890.8	1099.6	660.4	26	pullout	n
4	85.725	3.375	1700	5938.9	1335.2	812.8	32	pullout	y
	69.85	2.75	1500	5240.2	1178.1	736.6	29	pullout	n
	88.9	3.5	1800	6288.2	1413.7	889.0	35	pullout	y
	66.675	2.625	1700	5938.9	1335.2	736.6	29	pullout	n
5	73.025	2.875	>5000	17467.0	>3927				y
	85.725	3.375	>5000	17467.0	>3927				n
	82.55	3.25	4900	17117.9	3848.5	812.8	32	pullout	y
	70.739	2.785	>5000	17467.0	>3927				n
	82.55	3.25	>5000	17467.0	>3927				y
	79.375	3.125	4600	16069.9	3612.8	736.6	29	pullout	n
6	69.85	2.75	2700	9432.3	2120.6	609.6	24	pullout	y
	60.325	2.375	1600	5589.5	1256.6	609.6	24	pullout	n
	60.325	2.375	1600	5589.5	1256.6	533.4	21	pullout	y
	69.85	2.75	2600	9083.0	2042.0	533.4	21	pullout	y
	60.325	2.375	2100	7336.2	1649.3	508.0	20	pullout	n
	57.15	2.25	2700	9432.3	2120.6	431.8	17	pullout	y

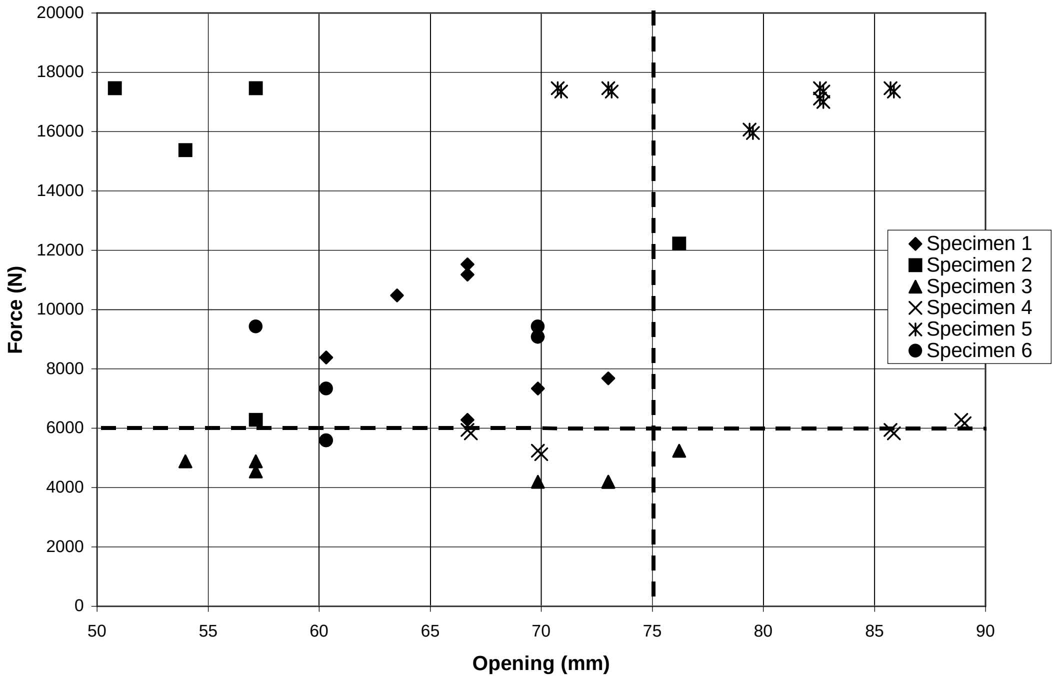

Figure 2.57. Seal Push Out Test graphical results.

the seal, the length of seal engaged in the failure, and whether the seal was attached to an edgebeam were all recorded. The force was calculated from the pressure by multiplying by the cross sectional area of the hydraulic cylinder.

The results are represented in Figure 2.57. The opening of the seals was varied to investigate the effect of seal opening on push-out strength. No opening was less than 50 mm (2 in.) and only a few tests were done with an opening greater than 75 mm (3 in.). The tests indicate that, within this range, the gap opening has little effect on push-out strength. The opening for the seals in the test specification is set at 75 mm (3 in.) to standardize the tests and also because that is the maximum permissible opening for a modular seal.

A minimum performance level is proposed based on such factor as observations of the seal tests and an analysis of the data. The proposed minimum force required to push out the seal is 6000 N (1350 lbs).

Specimen 3 did not reach this performance level. Specimens 4 and 6 had some tests exceed this performance level and some that did not. The other specimens all passed the required minimum, although some were close to not meeting the performance level. There is a large variance in the results. Some values for Specimens 2 and 5 were almost three times as large as the required minimum value. However, the values from individual specimens plot relatively closely to one another. This consistency in each specimen verifies that the test was accurately measuring the force requirements to push out the seals.

No splices in the seals were allowed in the specimens. If splices were to be used in the application (which is not recommended), they should be included in the specimen for this test.

CHAPTER 3

INTERPRETATION, APPRAISAL, AND APPLICATIONS

The survey, literature review, field visits, and previous experience were used to identify typical service problems with MBJS and factors affecting their performance and durability. Some of these service problems can be mitigated through guidelines for the following:

- The design and detailing of the bridge and the MBJS,
- The materials for and fabrication of MBJS, and
- The installation of the MBJS.

The Materials, Fabrication, and Construction Guidelines, Appendix B, were developed to address these issues. Other service problems were not easily addressed through guidelines. Prequalification tests on full-scale MBJS specimens were developed to address these other performance problems.

3.1 MATERIALS, FABRICATION, AND CONSTRUCTION GUIDELINES

3.1.1 Development of the Proposed Guidelines

The proposed guidelines in Appendix B of this report were designed to be used by owners, design engineers, contractors, and manufacturers involved in designing, specifying, building, and installing MBJS. The guidelines were developed from the literature review, survey, field visits, laboratory testing, and previous experience. They were written to substantially reduce, if not eliminate, many of the problems that have been found in MBJS.

Theses guidelines should be used in conjunction with the requirements found in the proposed Performance Test Specifications for Modular Bridge Joint Systems, provided in Appendix A of this report, and the proposed fatigue testing and design requirements in Appendices A and B of *NCHRP Report 402.*

Many parts of these guidelines are also applicable to strip-seal bridge joint systems (SSBJS) as well as MBJS. Typically, the edgebeams and seals for SSBJS and MBJS are the same, and, therefore, the guidelines pertaining to the seals and the anchorage of edgebeams apply to both SSBJS and MBJS. Although it was not within the scope of this project to develop guidelines for SSBJS, it is thought that this is a useful byproduct of the research and could improve the durability of SSBJS. These guidelines are not applicable to plug seals, cushion seals, compression seals, or other similar types of joint systems.

The guidelines are intended to be as performance-based as possible (i.e., not to be prescriptive). Every effort has been made to avoid guidelines that will restrict further innovation. However, there are instances where it was unavoidable that the guidelines be relatively prescriptive. For example, there are explicit detailing requirements for the blockout. The guidelines do not provide information on how to design or improve on existing BJS. It is the bridge designer's and BJS manufacturer's responsibility to determine how best to meet these guidelines.

The guidelines begin with a discussion of detailing requirements for contract drawing development. This section gives prescriptive tolerances for the blockouts, for the level of the tops of the centerbeams relative to the top of the pavement, and other dimensional requirements. It should remind the detailer and designer of the bridge to consider how the bridge details affect the MBJS performance.

A discussion of the various performance factors is then given. This discussion should make clear what levels of performance are expected of MBJS. However, there is no guidance on how to meet these performance goals.

The next section of Appendix B has guidelines for materials. Previously ASTM material tests have been specified for some MBJS components. The review of these ASTM specifications showed that appropriate specifications exist for the seals. ASTM D5973 *"Strip type expansion seals"* provides specifications for strip seals and AASHTO M297, ASTM D3542, *"Multiple-web expansion seals"* provides specifications for box seals. It is thought that seals provided under these specifications have performed adequately, with the exception of susceptibility to detachment from the edgebeams and centerbeams. ASTM standards can ensure the quality of the material, but cannot predict the interaction of these components with the edgebeams and centerbeams. The OMV test specifically evaluates seal performance, although a seal failure in this test must be considered. The SPO test explicitly evaluates seal detachment susceptibility under vertical load.

Many agencies required additional testing or certification of the seals beyond these ASTM specifications. There is no evidence that environmental exposure, exposure to sunlight, deicing chemicals, or oil affected the performance of MBJS. Therefore, it was concluded that no additional testing or

requirements for the seal components were required to ensure seal performance and durability.

The springs and bearings are made by proprietary formulations of urethane or neoprene and are bonded to PTFE layers or surfaces. The ASTM specifications that have often been cited in state specifications for the springs and bearings were found to be ineffective. These specifications mostly referred to test methods of the basic materials rather than the springs and bearings themselves. It would be difficult to write a specification for these components.

The manufacturers have developed specific proprietary formulations, manufacturing methods, and sources for these components. There is anecdotal information that the performance of these springs and bearings is very sensitive to the precise formulations, manufacturing methods, and source. It was concluded that the best way to detect and avoid potential problems with these components was to require that the manufacturers continue to use only the same formulation, manufacturing process, and supplier of these components as they used in the MBJS that passed the OMV test. If the components perform well in the relatively severe conditions of the OMV test, it is envisioned that they will also perform well in service.

After these materials guidelines, fabrication guidelines are presented. Detailing guidelines are presented for steel sections, support boxes, and so forth. Reference is made to applicable AWS, ASTM, ACI, and AASHTO specifications. Installation of the seals is discussed. Finally, shop plans and other submittal requirements are discussed.

A significant part of the guidelines is the installation requirements. Shipping and handling of the MBJS is discussed, followed by pre-installation inspection that refers to the tolerances cited in the section on Drawing Information. Topics covered in detail include

- Protection of the MBJS from damage prior to installation,
- Setting gap opening,
- Formwork,
- Finished BJS tolerances,
- Supporting BJS during placing of concrete,
- Placing the concrete,
- Bridging BJS after installation,
- Removal of forms and debris,
- Watertightness test,
- Acceptance, and
- Post installation inspection.

The guidelines have extensive commentary with extensive explanations. Checklists of performance factors, service problems, inspection items, and installation requirements are also provided.

3.1.2 Impact of the Proposed Guidelines

Currently, there is little guidance on the material, fabrication, construction, and installation of MBJS. Manufacturers have provided limited installation guidance, and some state specifications have a list of ASTM specifications to which MBJS components must conform. Other states have developed some design specifications. However, there are no comprehensive, uniform, national specifications or guidelines. This lack of guidance and general information has caused significant problems. Implementation of the guidelines presented in Appendix B should substantially reduce or eliminate these problems.

3.2 PREQUALIFICATION AND PERFORMANCE TESTS

Proposed specifications for the fixtures, procedures, and results of a pair of performance tests, the Opening Movement Vibration test and the Seal Push Out test, are provided in Appendix A. These proposed specifications should enable any laboratory to conduct the tests and obtain similar results. Photographs, drawings, and commentary are included in the test specifications.

It is the ultimate goal of these performance tests to ensure that MBJS being installed into bridges have adequate service-life with few problems and little required maintenance. The proposed testing specification will allow the MBJS owner to specify a product that has demonstrated durability.

3.2.1 Development of the Proposed Tests

The proposed test specification is intended for use by the bridge designer and owner to ensure that the MBJS being specified or purchased will have sufficient durability while providing an effective seal against debris and deck drainage from reaching the other bridge elements.

All previous laboratory and field testing was reviewed that could possibly be used or adapted for the proposed performance tests (*4, 20, 23, 24, 25*). The proposed performance tests were tried on a few full-scale MBJS specimens that were going to be scrapped. The test methods were modified and refined and the refined procedures were performed and verified on various specimens specially purchased for this research. The results of these tests were compared with actual service performance of similar MBJS to validate the proposed performance test requirements.

The target life for MBJS was set at 75 years to be consistent with current AASHTO LRFD requirements for bridge decks. At the beginning of the testing, it was decided to simulate the daily thermal movement typically experienced by MBJS. To ensure that the same damage was induced in small movement range MBJS as in large movement range MBJS, it was decided to retain the same movement of 101 mm (4 in.). This causes smaller MBJS to be cycled through a test movement that is significantly larger than the daily thermal cycle in service and may be closer to a yearly thermal cycle. This decision is justified because the smaller MBJS specimens did not fail faster

than the larger specimens. This also standardizes the movement requirements instead of specifying the movement based on the capacity of the MBJS, which will vary with the specimen tested.

It was decided that the OMV test on the two-centerbeam (three-seal) specimens should prequalify a joint for up to six centerbeams, seven seals. MBJS with up to six centerbeams are the most commonly used. MBJS with more than six centerbeams would have to be prequalified separately through another OMV test, possibly with a greater required movement range. However, an additional SPO test need not be performed for these larger MBJS unless the seals or the method of attachment is different. The behavior of all MBJS with up to six centerbeams can be determined by a test on a representative specimen with only two centerbeams.

The choice of vibrator was based on delivering a force range close to the dynamic wheel load range recommended *in NCHRP Report 402* and frequency close to the resonant frequency of the MBJS for bending in the vertical plane. The force range and frequency of the vibrator were verified through strain gage measurements. The effectiveness of the vibrator is shown by the ability of this test to cause fatigue cracking and other failure modes similar to those observed in service.

A manufacturer should submit one two-span two-centerbeam specimen for each of the manufacturer's basic types of MBJS for performance testing. (This design should already meet the fatigue testing and design requirements of *NCHRP Report 402*.) Once this basic type and manufacturer of MBJS has demonstrated an adequate level of performance in these tests, that MBJS design, manufacturer, and components are pre-qualified. If a basic type of MBJS is prequalified, limited variations on that basic type are also considered prequalified, including

- MBJS with any number of support boxes;
- MBJS with from one to $n + 4$ centerbeams (where n is the number of centerbeams in the configuration that was tested) and the associated varying support bar spans;
- MBJS with any centerbeam span less than 1.25 times the span that was tested;
- MBJS with smaller skew;
- MBJS with a lower angle of upturn or no upturn;
- MBJS with a flatter vertical crown or less of a horizontal kink; and
- MBJS with centerbeams or edgebeams with cross-sectional area that is from 75 percent to 125 percent of the cross-sectional area that was tested.

If the MBJS parameters are outside these limits, then the OMV test will need to be performed on the new configuration to verify that the changes do not decrease the durability of the MBJS.

The manufacturers must document the size, shape, formulation, and method of manufacture, or the supplier of the springs and bearings that were used in the OMV specimen. Then, in order to market that model of MBJS as prequalified by these performance tests, the manufacturers must certify that the size, shape, formulation, and method of manufacture, or the supplier of the springs and bearings used in the MBJS are the same as those used in the OMV test. If any of these factors change, the OMV test must be repeated to demonstrate that the components are still working properly.

The OMV test produced many failures in the elastomeric springs and bearings. The type of failures and the rate of occurrence of these failures were consistent with the information gained from the literature and the field studies in this project. Refinement of these components may need to be undertaken by some manufacturers in order to meet the proposed test requirements.

In addition, the tests must be repeated if

- The composition of any of the other components changes, other than the steel plates used to make the support boxes or the studs;
- The dimensions of the elastomeric components varies;
- A different type of seal, seal splice, or centerbeam splice is to be used; or
- The fabricator changes.

The specimens described in Section 2.2 were instrumented to determine the strain in the centerbeam and support bar and to determine the load versus stroke curves. Although it was believed that this information was useful, it was not thought essential for ensuring that the MBJS meet the performance levels. All that is required to ensure that the MBJS is meeting the performance levels is measurement of the opening movement range, recording of the number of opening cycles, and observations about the failure modes, if any. Therefore, no instrumentation will be required in the proposed test specification. This should increase the number of laboratories that can perform the test and make the tests more economical.

The SPO test should be performed on the same specimen as the OMV test, after the OMV test has been performed. If the SPO test is not successful, but the OMV test was successful, then future SPO tests can be performed on a specimen consisting of two 1-m (3-ft)-long pieces of centerbeams and two edgebeams with seals in between. If the SPO test is successful and the OMV test was not, then the SPO test need not be repeated unless the seals or the attachment detail are different.

It is conceivable that a manufacturer can resubmit a similar test article until a favorable result is obtained. However, it is hoped that the manufacturers learn how to better design their products from this experience. For example, it was observed that tolerances on the positions of the support bars were found to be extremely important in the performance of these specimens, and it is expected that the manufacturers will experience variations in these tolerances.

It was considered whether some measures should be taken to avoid such retests or to increase the burden of testing once a specimen had failed. However, given the severity of the test

conditions, it is not expected that repeated testing of the same MBJS design would enable a manufacturer to obtain acceptable results. Furthermore, the expense of the test and the specimens should be a deterrent to such repeated testing. Therefore, it was decided that no special provisions should be required if a MBJS fails one or more tests before finally passing. Ultimately, if changes are made to pass the test, the manufacturers must use the improvements in general production and not revert to a non-passing design. There is little that can be done to guarantee that this is accomplished and the owner or engineer should verify that the appropriate MBJS components and fabrication procedures are being furnished.

3.2.2 Impact of the Proposed Requirements

The proposed guidelines and performance test specifications should give the bridge owner greater confidence in using MBJS. The performance tests have effectively rated MBJS specimens based on durability. If used by the bridge owner, these tests will require MBJS manufacturers to demonstrate that their products perform to a preset and definable level of durability. Combined with the Material, Fabrication and Construction Guidelines, these test specifications will substantially reduce, although not eliminate, durability problems.

Although subject to the discretion of the bridge owner, the suggested level of MBJS durability is set for 75 years, with a reduced expected seal life of 25 years. Test requirements were derived that are supposed to be roughly equivalent to a 75-year service life. Present testing has demonstrated that few MBJS models (only one specimen that was tested) can survive these equivalent 75-year test requirements without failure, which is consistent with the present level of reliability of MBJS in service. The equivalent service life of the other specimens was less than 33 years.

Improvements by most of the manufacturers will be necessary in order to produce products capable of 75-year lives. Based on preliminary analysis of the test failures, most MBJS manufacturers will probably be able to pass the requirements with simple changes.

Only after 50 or more years will it be known if the proposed correlation between hours of performance testing and years of service is reasonably accurate. Only then will it be known for sure if the improvements that the manufacturers make in their designs to meet the proposed guidelines and performance-testing requirements actually result in significantly improved performance and durability under real service conditions. Nevertheless, it is believed that the proposed guidelines and performance-testing requirements are an important and significant step forward and will benefit the bridge owners, designers, contractors, and MBJS manufacturers. It is expected that these proposed guidelines and performance test specifications, if implemented, will be continually updated and calibrated as long-term service experience is accumulated with MBJS designed to meet them.

The refinement and redesign of MBJS and their various components has previously been conducted on a trial and error basis based on the service experience of MBJS. In these cases, the expense of inspecting, maintaining, and replacing these systems, many with marginal performance, was the responsibility of the bridge owner. The implementation of the proposed Materials, Fabrication, and Construction Guidelines as well as the performance test specifications should be far less costly than current spending for MBJS maintenance and should significantly reduce the spending necessary for MBJS maintenance.

Any structural testing laboratory should be able to perform these prequalification tests for less than $30,000 per specimen. This cost will be paid by the MBJS manufacturer but probably will be passed on to the bridge owner through higher prices. However, the cost of completing these tests is minimal when compared with the price of even a small fully installed MBJS.

CHAPTER **4**

CONCLUSIONS AND SUGGESTED RESEARCH

4.1 CONCLUSIONS

The significant problems and performance factors for MBJS were established through a survey of transportation agencies, a literature search, and inspection of MBJS in the field. Many of these problems can best be addressed by promulgation of the guidelines for material, fabrication, and construction that were developed as part of this research. Performance tests were developed to address those performance problems not addressed by these guidelines or previously developed fatigue testing and design specifications. The following conclusions were reached:

1. In order to be considered prequalified, an MBJS design must pass two performance tests: the Opening Movement Vibration test and the Seal Push Out test. The first test simulates the cyclic bridge superstructure thermal movements while vibrating the MBJS to simulate traffic loading. The second test measures the seal resistance to a vertical push-out force.
2. Failures that occurred in these tests were similar to failures observed in the field, including
   - Problems attributable to poor fabrication.
   - Inadequate durability of typical three-part composite elastomeric bearings. and
   - Welded field splices.
3. The relative ranking of the MBJS in the performance test was similar to that observed in the field, indicating the test is a good surrogate for actual service demands.
4. MBJS should be required to (1) pass these proposed performance test requirements; (2) be tested and designed for fatigue in accordance with *NCHRP Report 402;* and, (3) be specified and installed in accordance with the proposed materials, fabrication, and constructions guidelines. If these three requirements are met, the occurrence of durability problems with MBJS in service should be significantly reduced.

4.2 SUGGESTED RESEARCH

Additional research should be performed on springs and bearings to clarify the differences between urethane and neoprene, the stress-strain-strain rate relationships, the variability among manufacturers, the lot-to-lot variability, and the need for fatigue testing as described in *NCHRP Report 402.* In addition, an instructional videotape or training course that can be used to instruct contractors, maintenance personnel, and inspectors on detailing, installation, inspection, and maintenance of MBJS should be prepared.

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APPENDIX A

RECOMMENDED PERFORMANCE TEST SPECIFICATIONS FOR MODULAR BRIDGE JOINT SYSTEMS

1. GENERAL

1.1 Scope

This specification describes two test procedures for modular bridge joint systems (MBJS): (1) Opening Movement Vibration (OMV) Test for determining overall durability and (2) Seal Push Out (SPO) Test for determining the resistance to seal detachment from centerbeams and edgebeams. Minimum performance levels for these tests are recommended. If a particular model of MBJS is tested under this specification and meets the specified performance levels, it is considered prequalified and can be used with variations allowed in Section 2.1 without further testing.

These test methods are applicable to all types of MBJS, including (but not limited to) welded or bolted single-support bar and multiple-support-bar systems. The testing procedures described here are not applicable for other expansion joint systems (e.g., strip seal joints and finger joints) used in bridge superstructures.

2. SPECIMEN

2.1 General Requirements

Specimens shall be full-scale MBJS representative of those to be used in field applications. The specimen shall include at least two centerbeams. Specimens shall be designed for fatigue in accordance with the appendix, "Special Requirements for Modular Joints" in *NCHRP Report 402.* Each specimen shall contain at least three support boxes. Anchorage devices need not be attached to the specimen. Provisions shall be made so that the condition of the components inside the support boxes can be viewed from the outside of the MBJS. If any of the following are to be used in this type of MBJS, they must be included in the test specimen: skew, shop splices, field splices, vertical upturns for curbs or parapets, vertical crowns, or horizontal kinks.

Prior to testing, specimens shall be visually inspected for any flaws, loose fasteners, etc. that could possibly affect the performance of the specimen. Any observed problem shall also be reported with the data.

A manufacturer shall submit for testing one sample of each basic type of MBJS. Successful test performance pre-qualifies a specific configuration MBJS with specific components and the following limited variations of that configuration:

- MBJS with any number of support boxes;
- MBJS with from one to $n + 4$ centerbeams (where n is the number of centerbeams in the configuration that was tested) and the associated varying support bar spans;
- MBJS with any centerbeam span less than 1.25 times the span that was tested;
- MBJS with smaller skew;
- MBJS with a lower angle of upturn or no upturn;
- MBJS with a flatter vertical crown or less of a horizontal kink; and
- MBJS with centerbeams or edgebeams with cross-sectional area that is from 75 percent to 125 percent of the cross-sectional area that was tested.

However, if the MBJS parameters are outside of these limits, then the OMV test will need to be performed again. Additionally, any change to the following MBJS characteristics will necessitate retesting:

- Composition of the material or component supplier changes, other than the steel plates used to make the support boxes or the studs;
- Dimensions of the elastomeric components varies;
- Different type of splice is to be used; or
- Fabricator change.

To pre-qualify MBJS with more than six centerbeams, a specimen with a larger number of centerbeams must be tested and, if successful, this test shall pre-qualify similar MBJS with from seven to the number of centerbeams in the test specimen.

2.2 Instrumentation

Each specimen shall be instrumented to measure the frequency and magnitude of force applied by the testing apparatus in the OMV test and the force applied during the SPO test.

3. Opening Movement Vibration Test

3.1 Fixtures

3.1.1 Fixture Details

Fixtures capable of adequately supporting and securing the specimen during test shall be provided. All support boxes shall be supported throughout the test. The fixtures shall be designed so that the specimen is supported at a minimum height of 0.76 m (30 in.) to allow for the visual inspection of all com-

ponents of the specimen during testing. The fixtures shall provide a 1:10 slope (i.e., 5.7 degrees), to facilitate movement of the springs and bearings. One side of the specimen shall be securely attached (no movement) to the fixtures. The other side shall be free to move in the longitudinal direction (parallel to the support bars of the MBJS).

3.2 Test Procedure

3.2.1 Movement ranges and vibration

Simulated longitudinal opening and closing movement ranges shall be applied through hydraulic actuators or other similar loading devices. The specimen shall be cycled at a frequency not to exceed 0.1 Hz. The specimen shall be cycled with a displacement of +/– 50.8 mm (2.0 in.) about the mid-opening. The load requirements of the specimen shall be monitored continuously throughout the test as a function of the MBJS gap opening or actuator stroke. The displacement shall be applied at the horizontal center of the specimen. The displacement shall be applied to a spreader beam that is attached to the edgebeam and each support box on the freely moving side of the MBJS. The center of the simulated longitudinal opening movement displacement shall be at a height of 101 mm (4 in.) above the top of the support box. The spreader beam shall be capable of withstanding all displacements and loads applied to it and transferring those displacements and loads to the specimen.

Simulated traffic vibration loads shall be applied by a pneumatic high-frequency vibrator capable of at least 33 kN (7.5 kips) at a frequency between 125 and 150 Hz. The vibrator shall be one that was previously used (discussed in the commentary) or testing shall be performed to determine the force deliverable and frequency of vibration. The vibrator shall be placed as close as possible to the center centerbeam/support bar connection, not to exceed 0.3 m (12 in.) from the center of connection to the center of vibration. The vibrator shall be securely fixed to one centerbeam. It shall not be allowed to interrupt the opening and closing action of the MBJS in any way. It is permissible to cut the elastomeric seals in order to attach the vibrator to the centerbeam. The vibrator shall be run continuously while the specimen is undergoing simulated opening and closing movement cycles.

3.2.2 Definition of Failure

The inability of any component of the specimen to function that reduces the load capacity of the MBJS or inhibits the correct functioning of the MBJS shall be defined as failure. The following criteria have been observed in preliminary tests and, although not a complete list of possible failure modes, are typical.

3.2.2.1 Welded Connections. Occurrence of fatigue cracks or fractures in any weld shall be considered as failure.

3.2.2.2 Elastomeric Components. The movement out of designed placement of springs or bearings shall be considered as failure. The movement out of designed placement of the equidistant control springs shall be considered as failure. The equidistant device shall be considered failed if the largest gap between any two adjacent edgebeams or centerbeams is greater than twice the smallest gap. The loss of seal bond or integrity against passage of water through the seal (except at the locations where the seals have been cut for the vibrator clamping device) shall be considered a failure if it occurs before 9,130 simulated longitudinal movements (equivalent to a 25-year life).

3.2.2.3 Bolted Connections. The loosening, fracture, or movement out of place of bolts used in any connection shall be considered a failure.

3.2.3 Termination of Test

The test shall be continued through failures until:

- 27,400 simulated longitudinal cycling movements have been completed (equivalent to a 75-year life);
- The MBJS is not functioning properly;
- It is deemed unsafe to continue testing; or
- Failure mode has altered the test specimen so that no further failures will occur.

3.2.4 Results

3.2.4.1 Reporting of Data. Data shall be reported in a tabular format and shall contain the following information:

- Cumulative number of simulated longitudinal movement cycles until failure(s) or end of test,
- Relative in-field life—Each simulated cycle shall represent one daily movement cycle,
- Cumulative number of simulated vibration cycles until each failure or until end of test, and
- Failure mode(s).

The following additional information shall also be reported:

- MBJS type and manufacturer;
- Drawings showing shape, size, and dimensions of the specimen along with the connections of the actuator and vibrator and their positions;
- Section properties and detail dimensions of the centerbeam and support bars;
- Manufacturer(s), position and material properties, including ASTM or other testing agency specifications and values, of elastomeric components, including, but not limited to, springs, bearings, equidistant control springs and seals;
- Fatigue calculations in accordance with Special Requirements for Modular Joints contained in *NCHRP Report 402;* and

- Certification that the MBJS has passed previous testing in accordance with the Fatigue Test Specification for Modular Bridge Expansion Joints contained in *NCHRP Report 402.*

SEAL PUSH OUT TEST

3.3 Fixtures

3.3.1 Fixture Details

A self-reacting test frame capable of resisting the vertical push out force shall be provided. The test fame may be connected to the edgebeams of the specimen.

3.4 Test Procedures

3.4.1 General

Once a specimen has passed the OMV test, it shall be subjected to the Seal Push Out (SPO) Test. A minimum of five consecutive SPO tests shall be performed on each specimen.

3.4.2 Loads

Loads shall be applied to the seals by any device capable of delivering a minimum load of 22.24 kN (5 kips) in displacement control and measuring the applied load.

3.4.2.1 Application of Load. The seals shall be opened to 75 ± 10mm (3 ± 0.38 in.) while performing this test. The displacement shall be applied perpendicular to the plane of the centerbeams. Load shall be applied to the seals through a 25.4-mm (1-in.)-diameter cylindrical steel bar 533.4 mm (21 in.) in length. The ends of the cylindrical bar shall be tapered to prevent tearing of the seal. The load shall be applied in displacement control at a stroke rate of 10 mm/sec (0.4 in./sec).

3.4.3 Definition of Failure

If any of the tests for a particular specimen fail to reach a minimum force of 6,000 N (1,350 lbs), it shall be considered a failure. In the event that only one of the five consecutive tests fails to reach the minimum requirements, that one test may be discarded and replaced by three new consecutive tests using the original specimen.

3.4.4 Special Procedures for New Seal Designs for Previously Prequalified MBJS

In the event that the seal manufacturer or seal profile changes and there are no other changes in the overall MBJS, the SPO test may be conducted on a new specimen without repeating the OMV test to retain the prequalification previously attained through these two tests.

When an SPO test is to be done by itself without also performing an OMV test, the specimens shall consist of 1-m (3-ft)-long sections similar to the full size specimens used for the OMV tests. The specimens shall contain two edgebeams and two centerbeams, and the edgebeams shall be secured as shown in Figure A-2.

4. REPORTING OF DATA

Data shall be reported in tabular format and shall include the following information:

- Manufacturer of MBJS and supplier of seals (if different);
- Type of seal (box or strip);
- Lubricant adhesive use, manufacturer of lubricant adhesive, and chemical formulation and material properties of lubricant adhesive;
- Load at failure;
- Description of failure mode;
- Length of failure; and
- A drawing showing the loading rod, the centerbeam, edgebeam, and seal cross sections and connection method, as shown in Figure A-2 (see commentary).

COMMENTARY TO THE TEST SPECIFICATIONS FOR MODULAR BRIDGE JOINT SYSTEMS NCHRP PROJECT 10-52

Commentary on specific articles follows.

COMMENTARY TO ARTICLE 1.1 SCOPE

These test methods for modular bridge joint systems (MBJS) were developed as part of NCHRP Project 10-52. The desired serviceable life is 75 years for the entire MBJS and all its components, excluding the elastomeric seals, which, because they can be replaced, are expected to have a service life of at least 25 years. It is supposed that the OMV test described in Section 3 approximately simulates a 75-year service life with 27,400 opening and closing movement cycles, which is approximately the number of days in 75 years. At a frequency of about 0.1 Hz, this number of cycles is applied in approximately 76 hours of continuous testing. The experience in Project 10-52 was that only one out of six sample expansion joints could meet this criterion. The Engineer of Record or Owner may permit shorter service life for the entire MBJS or any component.

Once an MBJS has passed the requirements of these tests it shall be considered prequalified. However, if the MBJS changes outside the range of parameters discussed in Section 2, then it will need to be retested to verify that the changes have not caused a reduction in durability.

In addition, to these prequalification tests, several subassemblies of the load-carrying components must be tested according to “Fatigue Test Specification for Modular Bridge Expansion Joints,” which was included as Appendix B of *NCHRP Report 402.* These tests are used to establish fatigue resistance categories for the MBJS details. Fatigue design calculations must be provided for each unique configuration of MBJS (e.g., spans and number of seals) in accordance with the Special Requirements for Modular Joints proposed in *NCHRP Report 402.*

The functional design of MBJS is left to the discretion of the manufacturer. These specifications will only test the effectiveness of those designs.

COMMENTARY TO ARTICLE 2.1 GENERAL REQUIREMENTS

The size and dimensions of the MBJS have been determined to be the minimum so that the specimen is still representative of the behavior of in-service MBJS. The two or more centerbeam requirement allows for the longitudinal movement requirements. After an MBJS passes the testing specifications, configurations other than two centerbeams are considered prequalified, subject to the limitations outlined in Section 2.1.

A visual inspection is used before testing to identify any obvious problems with the specimen before testing begins. In an actual installation, the MBJS should also be visually inspected. If there is a problem with the MBJS, it should be reported along with the test data. Replacement of missing or out-of-place elastomeric components is permissible before testing begins, if the lack or misplacement of such components would be found in a normal pre-installation inspection. The idea behind the testing specification is to examine the durability of a representative typical specimen.

COMMENTARY TO ARTICLE 2.2 INSTRUMENTATION

For the OMV test, it is recommended that strain gages be placed on the centerbeams and support bars. These are used to monitor the force being delivered to the MBJS and metallic components. They can be used to ensure that the force is not severe enough to cause yielding in steel components, as this is not typical for in-service MBJS. Strain gages can also be used to analyze the degradation, if any, of the MBJS. For example, bearing degradation may cause higher stress in the support bar as a result of the loss of restraint.

The actuator used to deliver the simulated movement should be equipped with a load cell. The actuator displacement plotted against actuator force is also helpful in analyzing the behavior of the MBJS. Different MBJS have different load requirements.

For the SPO test, a pressure gauge was used to monitor the load requirements. The pressure was converted to force. In lieu of a pressure gauge, a load cell is also an acceptable method of measuring the load requirements of the seal.

COMMENTARY TO ARTICLE 3.2.1 MOVEMENT RANGES AND VIBRATION

The vibrator has its own fixture that should be welded to a plate. A clamping device should be made from the plate with the vibrator welded to it and another similarly sized plate with four threaded rods. This clamping device fits over one centerbeam. The seals were cut for the threaded rods to pass through.

The vibrator used in the original experiments was a Vibco SVRLS 8000 pneumatic high-frequency vibrator. A similar vibrator should be used if this model is no longer available. If an equivalent vibrator is used, it shall be tested in a controlled situation to determine the force deliverable and frequency of vibration, and the force shall exceed that of the Vibco SVRLS 8000 as shown in Table A-1.

Figure A-1 shows a cross section of the specimen and the general requirements of the fixture for the OMV test. It is recommended that linear bearings be attached to the testing fixtures. These devices will allow for movement only in the longitudinal direction. Verification testing has shown that only one linear bearing is required per specimen. More than two linear bearings is not recommended because of the possibility of non-parallel movement and binding of the bearings.

COMMENTARY TO ARTICLE 3.2.2 DEFINITION OF FAILURE

Seals are allowed to fail after 9,130 cycles because their life is set at 25 years and not 75 years. This number of simulated longitudinal movement cycles, 9,130, corresponds to a life of 25 years at 365 cycles per year. However, any seal that fails this part of the test will not have adequate strength to pass the SPO test. In the testing in Project 10-52, this was not a problem.

As discussed in the Commentary to Section 1.1, it is the responsibility of the Owner or Engineer of Record to specify the required life of all components for the MBJS. It is not recommended that the life of any component be set at less than 25 years.

The failure of certain components should be evaluated on the basis of the potential consequences of that failure. A failure of the centerbeam/support bar connection is a serious failure, as is failure of the elastomeric springs and bearings that hold the support bar. Failures in the edgebeam are not likely to cause the MBJS to fail. Failures related to the control spring mechanisms have only a slight effect on the performance of

TABLE A-1 Vibco SVRLS 8000 specifications

Air press		Vib per sec	Force	
(kPa)	(psi)		(N)	(lbs)
551.6	80	141.7	33900	7625
620.6	90	145	35600	8000
689.5	100	158	42500	9550

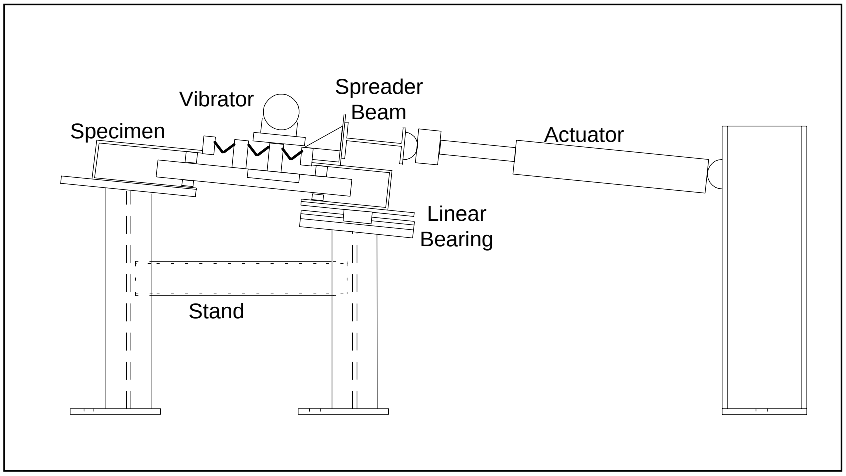

Figure A-1. OMV test set up.

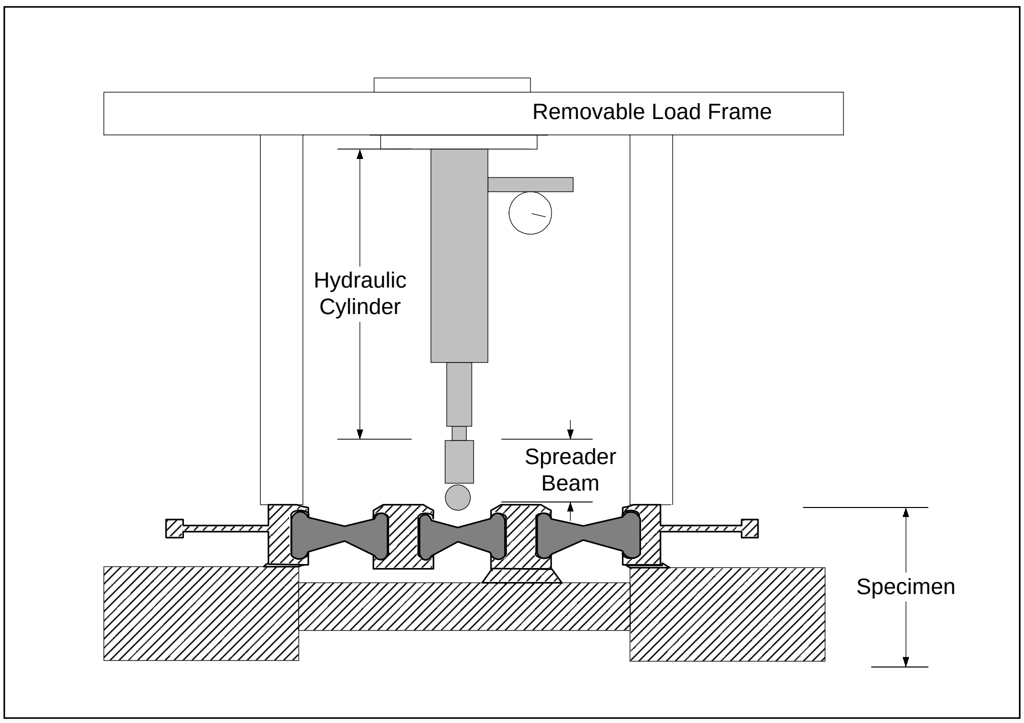

Figure A-2. SPO Equipment Set Up.

the MBJS. These elements control the relative spacing of the centerbeams. Although all failures are recorded, the type of failure and not just the occurrence may ultimately determine the durability of the MBJS.

COMMENTARY TO ARTICLE 3.2.3 TERMINATION OF TEST

A 75-year design life with 365 cycles per year is assumed to be equivalent to 27,400 simulated longitudinal cycling movements.

COMMENTARY TO ARTICLE 3.4.4 SPECIAL PROCEDURES FOR NEW SEAL DESIGNS FOR PREVIOUSLY PREQUALIFIED MBJS

This article was included to allow manufacturers to change and improve seal designs and requalify the MBJS by performing only additional SPO tests without the expense and time delay of performing the OMV test. The intent of this specification is to facilitate innovation in these sealing systems, while verifying that changes made will not degrade the durability.

Figure A-2 shows a cross section of the specimen and the general requirements of the fixture for the SPO test.

APPENDIX B

MATERIALS, FABRICATION, AND CONSTRUCTION GUIDELINES FOR MODULAR BRIDGE JOINT SYSTEMS AND STRIP SEAL BRIDGE JOINT SYSTEMS

1. GENERAL REQUIREMENTS

1.1 Definitions

Strip-seal bridge joint systems (SSBJS) and modular bridge joint systems (MBJS) are sealed expansion joints located in the bridge deck that work with the bridge bearings to permit movements between independent spans of bridge superstructures or between superstructures and abutments.

1.2 Scope

Materials, fabrication, installation, and inspection guidelines are provided for SSBJS and MBJS, which will be referred to collectively as bridge joint systems (BJS). This section does not provide design specifications for BJS. The design of BJS shall conform to the AASHTO Bridge Design Specification–LRFD. MBJS shall also conform to the proposed fatigue design specification in Appendix A of *NCHRP Report 402.*

These guidelines are not applicable to plug seals, cushion seals, compression seals, or other similar types of joint systems.

Typically, the edgebeams and seals for SSBJS and MBJS are the same, and therefore most of these guidelines apply to both SSBJS and MBJS. When the guidelines refer to bridge joint systems (BJS) in general or do not explicitly refer to SSBJS or MBJS, the guidelines apply to both SSBJS and MBJS.

1.3 Referenced Standards and Specifications

The following standards and specifications are referenced herein:

AASHTO LRFD Bridge Design Specification
AASHTO Standard Specifications for Highway Bridges
American Concrete Institute (ACI) 318 Building Code Requirements for Reinforced Concrete
AASHTO M111, Zinc Coatings on Products Fabricated from Rolled, Pressed, and Forged Steel Shapes, Plates, Bars and Strips
AASHTO M164 Type 1 or 2, High Strength Bolts
AASHTO M169 Welded Stud Shear Connectors (Headed Concrete Anchors)
AASHTO M232 or AASHTO M298 Grade 50
AASHTO M270 GR36, 50 or 50W
AASHTO M232 Standard Specification for Zinc Coating (Hot-Dip) on Iron and Steel Hardware
AASHTO M293 Hardened Washers
AASHTO M291 Nuts for High Strength Bolts
AASHTO M297 Multiple-Web Expansion Seals (ASTM D3542)
AASHTO M298 Class 50 Standard Specification for Coatings of Zinc Mechanically Deposited on Iron and Steel
ASTM A240 Type 304 Stainless Steel Plate and Sheet
ASTM D5973 Strip Type Expansion Seals
ASTM D4070 Adhesive
ASTM D3574 Urethane Foam

1.4 Drawing Information

The Engineer of Record shall address the following in the contract document development:

(1) A cross section of the deck at every unique BJS shall be shown. The BJS shall be shown near midrange of its movement capacity. The total gap dimension between a reference vertical plane near the inside surfaces of the edgebeams and the bridge temperature corresponding to this position shall be clearly noted.
(2) Unless the BJS is to be cast at the same time as the rest of the deck, a blockout shall be used. The dimensions of the blockout at abutments and deck slab haunches at the ends of deck segments shall be shown on the cross section. Blockouts must be designed to support the weight of the BJS and the wet concrete, particularly on deck overhangs. Blockouts shall be designed to integrate the deck reinforcement with the design of a specific BJS.
(3) The location of the BJS and the dimensions of the blockout shall be shown on the plan view of the bridge deck. The BJS axis is defined to be parallel to the axes of the edgebeams and seals of BJS (and the centerbeams of MBJS). Typically, the BJS axis should be oriented parallel to the centerline of superstructure bearings. The vertical grade sand superelevation of the bridge deck should be shown relative to the BJS axis.
(4) Maximum imposed movements shall be estimated due to extreme temperature changes, due to long-term shrinkage and creep of concrete, and due to live load. Calculation of thermal movement shall be in accordance with AASHTO Bridge Design Specification–

LRFD. The analysis of movements shall consider the effects of: (1) skew; (2) horizontal curve; (3) vertical grade; and (4) the placement of the BJS in reference to bridge bearings. Movements perpendicular to the BJS axis will be referred to as longitudinal movements. Movements parallel to the BJS axis, along the centerline of bearings will be referred to as transverse movements. The total estimated longitudinal movement in each direction (about the midrange position shown in the cross section) shall be shown on the drawings. The total estimated transverse and vertical movement in each direction shall also be shown, as well as the rotation in each direction about the three principal axes. Vertical movement due to vertical grade (with horizontal bearings) and vertical movement due to girder end rotation shall be explicitly considered.

(5) Special consideration should be given to detailing of the bridge bearings, particularly if vertical grade exceeds 2.5 percent, to limit the vertical movement demands on BJS.

(6) There shall be adequate space between BJS and deck blockouts to allow easy placement of concrete and allow for adequate consolidation of concrete under and around all parts of the BJS, especially under any horizontal surfaces such as the bottom of support boxes. It has been suggested that 50 mm has been sufficient in the past (especially if aggregate size is limited); however 75 mm (3 in.) is recommended if possible. Grout pads are not encouraged.

(7) The top surface of the BJS shall be located between 3 and 6 mm ($\frac{1}{8}$ and $\frac{1}{4}$ in.) below the finished deck surface. If there are to be future deck overlays, provisions shall be made to retrofit or replace the BJS.

(8) In new construction, there shall be at least 75 mm (3 in.) of concrete cover above the top of support boxes (measured from the outside surface of the top of the support box to the surface of the concrete). When possible, there should be at least 75 mm (3 in.) of concrete cover above the anchorages (measured from the centerline of the anchor to the surface of the concrete). However, this cover may not be possible in some situations, e.g., where the edgebeam is over the support box. In these situations, the minimum cover shall be 50 mm (2 in). These requirements may be waived for rehabilitation work when there are space constraints on the BJS. In this case, the effect of the inadequate cover shall be taken into account in the anchorage design calculations.

(9) In cases where the preferred cover cannot be provided, transverse temperature and shrinkage reinforcement shall be provided above the support boxes to minimize reflective concrete cracking above support boxes.

(10) There shall be at least 152 mm (6 in.) of clear space between the ends of the edgebeam anchorages (and the support boxes or anchorages on the ends of support boxes for MBJS) and the periphery of the blockout to permit placing of concrete around the BJS.

(11) There shall be at least 610 mm (24 in.) of clear space in the longitudinal direction between end diaphragms or abutment wall under the BJS to allow for inspection and maintenance. There shall be provisions for access into box sections or between the girders of multiple girder systems and a flat surface large enough for at least one person to stand on no more than 2,440 mm (96 in.) below the deck surface to facilitate inspection and maintenance.

(12) If the skew exceeds 20 degrees and there is frequent snowplowing, the anchorage shall be designed for the impact of snowplow blades.

(13) The deck and the approach pavement for 10 m (30 ft) on either side of the BJS shall be designed to remain smooth and free of ruts to minimize additional dynamic forces on the BJS.

(14) Provisions shall be made for bridge drainage around the BJS to facilitate washing debris from the joint seals. The grading shall keep the drainage from accumulating on the BJS. Every reasonable effort shall be made to provide drainage paths designed to remain unclogged from debris.

(15) A detail showing how the BJS is to be configured at the curbs and/or parapets shall be included. Horizontal kinks are problematic and are generally discouraged. There must not be any horizontal kink coincident with the upturns or curb details. If the open parapet detail is used and the drainage is to run off the ends of the BJS without scuppers, the ends of the SSBJS or MBJS shall extend out past the facia girder far enough to allow the drainage to fall freely without splashing any part of the bridge, including the substructure. Provisions shall be made to prevent drainage from flowing back along the underside of the BJS.

1.5 Performance Requirements

The BJS shall not generate excessive noise or vibration during the passage of traffic. The BJS shall not cause inconvenience or danger to any class of road user (including cyclists and pedestrians). Additionally, MBJS shall have an acceptable level of skid resistance.

The BJS shall not impart undue stress to the structure due to structure expansion and contraction. The forces generated by the BJS in opening and closing shall be explicitly considered in seismic design.

1.5.1 Durability and Service life

The BJS shall be designed to meet the performance requirements in this section for 75 years. The seals of BJS must resist

extremes of weather, oily runoff from the road, and accumulation of debris, including sharp objects, without leaking for a period of 25 years. There shall be provisions for replacing the seals during the life of the BJS.

1.5.2 Sealing and Drainage

The BJS shall seal the deck surface, gutters, curbs, and walls as indicated on the bridge plans. If the drainage is to run off the ends of the BJS it shall not flow back along the bottom of the BJS or any part of the bridge.

1.5.3 Movement

BJS shall permit movements in all six degrees of freedom, i.e., translations in all three directions and rotations about all three axes. The entire BJS shall permit at least 25 mm (1 in.) but no more than 51 mm (2 in.) movement in the longitudinal direction in addition to the calculated movement, as shown in Table B-1. More than 25 mm (1 in.) should not be added if it causes an additional seal to be used. In the five degrees of freedom other than the longitudinal direction, BJS shall provide at least the minimum movement range capabilities shown in Table B-1. Half of the movement range shall be assumed to occur in each direction about the mean position. If the estimated movement in these five directions exceeds the minimum movements in Table B-1, the BJS shall provide for the estimated movements without any additional margin required.

1.5.4 Loads and Load Factors

Centerbeams, support bars, bearings, and other structural components shall be designed for the simultaneous application of vertical and horizontal wheel loads from a tandem axle. The tandem axle shall consist of a pair of axles spaced 1.2 m (4 ft) apart with vertical and horizontal loads specified in Articles 14.5.7.2.1 to 14.5.7.2.3 in the proposed fatigue design specification in Appendix A of *NCHRP Report 402.* The wheel loads can be assumed to be two strip loads 530 mm (21 in.) wide and 1830 mm (72 in.) center to center. The wheel loads shall be transversely positioned to maximize the force effect under consideration.

The number of load cycles accumulated during the life of the BJS shall be estimated by assuming 4.5 axle loads per truck. The MBJS shall be durable enough to resist repeated vertical load ranges equal to the largest axle load from the three-axle design truck specified in Article 3.6.1.2.2 of the AASHTO Bridge Design Specification–LRFD. For design of MBJS, this axle load shall be considered as the total load on a tandem, i.e., the total load shall be split into two axle loads spaced 1.2 m (4 ft) apart. Only one of these tandem axles must be considered in the design, unless the joint opening exceeds 1.2 m (4 ft). The load range shall be increased by the dynamic load allowance (Impact Factor) of 75% specified for Deck Joints in Table 3.6.2.1-1 of the AASHTO Bridge Design Specification–LRFD.

The vertical load for strength design shall be the design tandem axle specified in Article 3.6.1.2.3 of the AASHTO Bridge Design Specification–LRFD. This load shall be increased by the dynamic load allowance (Impact Factor) of 75% specified for Deck Joints in Table 3.6.2-1. The effect of superelevation need not be considered in determining the design forces.

A horizontal force range with magnitude specified in proposed fatigue design specification in Appendix A of *NCHRP Report 402* shall be applied to the top of the centerbeam. For the purposes of design, the total horizontal force range shall be interpreted as a force amplitude equal to one-half of the force range acting in each direction horizontally.

For MBJS installed on vertical grades in excess of 5 percent, the additional horizontal component due to grade shall be added to the horizontal axle load described above.

1.6 Testing and Calculation Requirements

One acceptable method of demonstrating that an MBJS design meets the performance requirements is to subject a full-scale sample of the MBJS to the “Pre-qualification Tests for Modular Bridge Joint Systems,” which is provided in the appendix of the final report from NCHRP Project 10-52. In addition to this prequalification test, several subassemblies of the load-carrying components must be tested according to the proposed fatigue test specification presented in *NCHRP Report 402.* The fatigue test establishes the appropriate fatigue detail categories for the connection or any other critical details. Once the fatigue category of a connection or other detail has been established through a suitable number of tests, this

TABLE B-1 Minimum Movement Range Capability for SSBJS and MBJS

Type of Movement	Minimum Design Movement Range
Longitudinal Displacement	estimated movement +25 mm (1 in.)
Transverse Movement	25 mm (1 in.)
Vertical Movement	25 mm (1 in.)
Rotation around Longitudinal Axis	1 degree
Rotation around Transverse Axis	1 degree
Rotation around Vertical Axis	0.5 degree

NOTE: Total movement ranges presented in the table are twice the plus or minus movement

category is considered applicable to the full range of configurations with different cross-section sizes, different numbers of centerbeams, different centerbeam and support bar spans, and different skew angles.

Once a specific type of design has passed the prequalification performance test and the fatigue testing, it may be used in various configurations with different cross-section sizes, different numbers of centerbeams, and different centerbeam and support-bar spans. Different skew angles may be used, provided the skew angle is less than or equal to the skew angle of the specimen tested in the prequalification test. The material, manufacturer, and cross-sectional dimensions of the centerbeam and support bar; the type, chemistry ranges, and manufacturer of the seals, bearings, and springs; and the type and manufacturer of the equidistant mechanism must be documented for the samples tested. In order to be considered prequalified, the MBJS must be manufactured with the same components from the same suppliers as provided in the specimen tested. Some variations in the components are allowed as discussed in the Performance Test Specifications for Modular Bridge Joint Systems. If an alternative centerbeam or support bar is to be used, the prequalification test and the fatigue testing shall be repeated. If only other new components are used, then only the prequalification test shall be repeated.

In addition to passing the prequalification test and the fatigue testing, each unique configuration, i.e., cross-section size, number and span of centerbeam, and support bar span, must be explicitly designed for strength and fatigue, according to the design specification in Section 14.5.7 of the proposed fatigue design specification in Appendix A of *NCHRP Report 402.* Fatigue design calculations, sealed by a Professional Engineer, shall be submitted with the drawings for each separate unique configuration. Certifications shall be provided that the springs, bearings, and control springs used in the BJS are the same formulation, manufacturer, and configuration used in the Opening Movement Vibration Test and Seal Push Out Test. In each certification, the name and address of the manufacturer of the springs, bearings, and control springs shall be provided.

2. MATERIAL REQUIREMENTS

The materials used for BJS shall have sufficient resistance to fatigue, corrosion, opening movement, vibration, and seal pullout.

2.1 Structural Steel

1. Structural steel shall conform to the requirements of AASHTO M270-GR36, 50 or 50W. Aluminum components shall not be used.

2.2 Stainless Steel

Stainless steel shall conform to ASTM A240 Type 304.

2.3 Bolts, Nuts, Washers

Bolts and other hardware shall conform to the requirements of AASHTO M164 Type 1 or 2 and shall be galvanized in accordance with AASHTO M232 or AASHTO M298 Class 50. Alternate coatings may be used at the discretion of the Engineer.

2.4 Welded Studs

Welded headed studs shall conform to the requirements of ASTM A108.

2.5 Bearings and Springs

The same material composition and formulation, manufacturer, fabrication procedure, and configuration of bearings and springs must be used as was used in the Prequalification Test described in Section 1.6.

2.6 Polytetrafluorethylene (PTFE or teflon)

PTFE shall be 100% virgin teflon, woven PTFE fabric, or dimpled PTFE conforming to the requirements of Section 18.8 of the AASHTO LRFD Bridge Construction Specifications, latest edition.

2.7 Movement Joint Seals

Multiple-web expansion seals (box seals) shall conform to ASTM D3542. Strip-type expansion seals shall conform to ASTM D5973. Seals shall be continuous, and splices are not permitted unless specifically approved by the Engineer of Record.

2.8 Lubricant Adhesive

The same formulation and manufacturer of lubricant adhesive used in the Seal Push Out Test described in Section 1.6 must be used to install the seals. It shall conform to the requirements of ASTM D4070. However, the lubricant should not be the epoxy type or other adhesive that is so strong that it makes replacement of the seals too difficult.

2.9 Control Springs

The same material composition and formulation, manufacturer, fabrication procedure, and configuration of control springs used in the Opening Movement Vibration Test described in Section 1.6 must be provided.

3. FABRICATION REQUIREMENTS

The BJS shall be fabricated in accordance with the dimensions, shapes, details, material specifications, and procedures shown in the approved shop plans. Welding shall be in accordance with the current AASHTO/AWS D1.5 Bridge Welding Code. Fillet welds shall be welded continuously. Intermittent fillet welds are not permitted.

Field splices should be avoided if at all possible and the entire BJS shipped and installed as one unit. If field splices cannot be avoided, it is recommended that the splices be located away from potential wheel paths and preferred that splices be located under the median traffic barrier. Only field splice details that have been fatigue tested in accordance with *NCHRP Report 402* may be used for MBJS. The preferred centerbeam splice detail consists of side plates bolted into recesses machined out of the centerbeam profiles. The nuts are tack welded to the unstressed stickout end of the bolt to prevent the nuts from backing off. This design of this splice detail is described in detail *in NCHRP Report 402.* Typically, the fatigue design will dictate that the span of the centerbeam with the splice must be smaller than the continuous spans; generally it is best to make this span as small as possible.

A full penetration field weld can sometimes be made from the deck when there is only one centerbeam and it can be lifted out enough to access the bottom of the centerbeam. Care must be taken to avoid weld metal getting into the seal retainer grooves, which can lead to seal pullout and leaking. Fillet or partial penetration welds are not permitted. Welded splices are not permitted if there is more than one centerbeam. Edgebeam profiles may be field spliced with fillet welds across only part of the profile.

If it can be assured that a splice will remain under a median barrier and it can be assured that water cannot get to this area, it may be permitted to butt the ends of the two segments of BJS together but not splice them.

Lifting devices shall be provided, and devices to maintain the preset opening of the joint shall be provided at a uniform spacing not greater than 4580 mm (15 ft) along the length of the BJS. At least three devices shall be used per segment of BJS.

When the fabrication is completed, the manufacturer shall perform the pre-installation inspection described in Section 4.2 to ensure that the BJS will pass this inspection.

3.1 Edgebeam Profile and Anchorage

The edgebeams shall be fabricated from structural steel. The web of the edgebeam cross-section shall be at least 9 mm (0.37 in.) in thickness. The same cross section must be used as was used in the Seal Push Out Test. Shop splices in the edgebeam profile shall be two-sided complete-joint-penetration groove welds. In MBJS, the edgebeam shall be continuously fillet welded to the support boxes.

The anchorage shall be designed in accordance with the latest version of the American Concrete Institute Specification ACI-318 to resist the vertical and horizontal forces from traffic, including impact, as given in Section 1.5.4. If there is a horizontal element in the edgebeam cross-section, the horizontal element must also be anchored to resist the full value of the wheel load with impact acting upward (from rebound).

If the skew is greater than 20 degrees and snowplowing is likely, the horizontal force from a snowplow striking the edgebeam shall be assumed in the design of the anchorage.

3.2 Centerbeam and Support Bar Profile for MBJS

The centerbeams and support bars shall be fabricated from structural steel. The same cross-section must be used as was used in the Seal Push Out Test Shop splices in the centerbeam profile shall be two-sided complete-joint-penetration groove welds.

Thin support bars pressing against springs or bearings that are larger than the support bars can cause a groove to get worn into the spring or bearing, thereby leading to premature failure. Therefore, the support bars and stainless steel sliding plate should be detailed wider than the springs or bearings.

In welded multiple support bar MBJS, the weld joint between the centerbeam and support bar shall be a full penetration groove weld that has been fatigue tested in accordance with *NCHRP Report 402.*

After welding, the centerbeam/support bar assembly shall be placed on a flat surface and it shall be verified that the support bars lie in a single plane, with no part of the bottom of any support bars exceeding 6 mm (0.5 in.) off the surface. The subassembly may be straightened. No more than three attempts may be made to heat straighten the subassembly.

Bolted joints shall have a minimum of four ASTM A325 high-strength bolts. The joints shall be configured and fabricated the same as the joints used in the Fatigue Test, the OMV Test, and the Seal Push Out Test. The bolts shall be properly pretensioned to avoid loosening.

3.3 Seals

Seals shall be installed by the manufacturer before shipping, unless centerbeam field splices are used. If field splices are necessary, continuous seals (without splices) shall be installed in the field after the construction is complete. In either case, the same lubricant adhesive as was used in the Seal Push Out Tests shall be used when installing the seals. The seals shall extend out from the ends of the edgebeams and centerbeams by at least 50 mm (2 in.).

3.4 Support Boxes for MBJS

Support boxes shall be made from steel plate or tubes at least 9 mm (0.375 in.) thick continuously welded. If the sup-

port boxes are more than 406 mm (16 in.) wide, the thickness of the top plate shall increase so that the width-to-thickness ratio does not exceed 45, or stiffening must be used. If the support box is made of nested tubes, the diameter or width-to-thickness ratio of each tube shall not exceed 45.

3.5 PTFE Sliding Surface for MBJS

The PTFE shall be virgin material in accordance with AASHTO LRFD Bridge Construction Specifications Section 18.8.1. The PTFE shall be bonded under controlled conditions and in accordance with the instructions of either the PTFE manufacturer or the adhesive manufacturer. After completion of the bonding operation, the PTFE surface shall be smooth and free from underlying bubbles.

3.6 Stainless Steel Sliding Surface for MBJS

The stainless steel shall be polished to a Number 8 mirror finish.

3.7 Corrosion Protection

All steel surfaces, except the surfaces under stainless steel or those to be bonded to PTFE, shall be protected against corrosion. Various paint systems and zinc metallizing have been shown to be satisfactory. Hot-dip galvanizing may cause excessive warping.

3.8 Shop Plans and Other Submittals

The Contractor shall submit details of the BJS, to be used with installation and waterproofing plans, to the Engineer for approval prior to fabrication of the BJS. The shop plans shall include, but not be limited to, the following:

1. Plans and section views of the BJS, for each movement rating and roadway width, showing dimensions and tolerances;
2. All welded and bolted centerbeam to support bar joints and all shop and field splices shall be shown;
3. Complete details of all components and sections showing all material incorporated into the BJS;
4. All ASTM, AASHTO, or other material designations;
5. Corrosion protection system;
6. Lifting locations and lifting mechanisms shall be shown as part of an integral installation plan; and
7. Temperature adjustment devices and opening dimensions relative to temperature.

For MBJS, the Contractor shall also submit the following test reports and certificates for review and approval:

1. Manufacturer's certificate of compliance with the AISC Quality Certification Program, Simple Steel Bridges.
2. Certification that welding inspection personnel are qualified and certified as welding inspectors under AWS QC1, Standard for Qualification and Certification of Welding Inspectors, and documentation that any personnel performing non-destructive evaluation (NDE) are certified by ASNT;
3. Manufacturer's certificate of compliance for the PTFE sheeting and fabric;
4. Certification that the bearings and springs and control springs used for equidistant control are produced from the same manufacturer with the same process and in the same configuration as those used in the OMV Test and Seal Push Out Test. These certifications shall include the manufacturer's name and contact information as well as production date and lot identification;
5. Certification that MBJS subassemblies with similar centerbeam and support bar cross-sections and joints have passed *NCHRP Report 402* fatigue testing requirements.
6. Design calculations sealed by a registered Professional Engineer. The design calculations shall include a fatigue design and a load factor design for all structural elements, connections, and splices;
7. Replacement of parts subject to wear may be allowed for in the design. The Contractor shall submit for the Engineer's approval a written maintenance and part replacement plan prepared by the joint manufacturer. This plan shall include a list of parts and instructions for maintenance inspection, acceptable wear tolerances, methods for determining wear, and procedures for replacing worn parts;
8. Method of installation including, but not limited to, sequence, installation gap setting for various temperatures, support during placement of the concrete, and installation at curbs;
9. Recommendations for storage of MBJS and details of temporary support of joint for shipping and handling;
10. Welding procedure specifications;
11. Any required changes to the blockout reinforcement in order to accommodate the MBJS; and
12. Temporary bridging plan for any MBJS for which construction traffic is anticipated following installation.

4. CONSTRUCTION INSTALLATION AND INSPECTION REQUIREMENTS

The contractor shall follow the manufacturer's written installation guidelines and these guidelines.

4.1 Shipping and Handling

The MBJS shall be delivered to the job site and stored in accordance with the manufacturer's written recommendations

as approved by the Engineer. Damage to the corrosion protection system shall be repaired to the satisfaction of the Engineer. Seals shall not be damaged or cut.

4.2 Pre-Installation Inspection

Immediately prior to installation, the BJS and the blockout shall be inspected by the Engineer, for (1) proper alignment, (2) complete bond between the seals and the steel, and (3) proper placement and effectiveness of studs or other anchorage devices. The proper placement of waterproofing membranes shall be verified, if such membranes are utilized. The clearance specified on the drawings [75 mm (3 in.) is recommended] between the bottoms of the support boxes of MBJS and the surface of the blockout should be verified.

Cutting of bridge deck reinforcing steel can compromise the structural integrity of the block-out and requires approval of the Engineer. The Engineer shall verify that reinforcing mesh or bars are at least 50 mm from the edgebeam or anchorages and do not prevent the flow of concrete around the BJS.

No bends or kinks in the MBJS steel shall be allowed (except as required to follow the roadway crown and grades). Any MBJS exhibiting bends or kinks shall be repaired to the Engineer's satisfaction or replaced, at the expense of the Contractor.

Seals not fully connected to the steel shall be fully connected at the expense of the Contractor. Headed concrete anchors shall be inspected visually and shall be given a light blow with a hammer. Any headed concrete anchor that does not have a complete end weld or that does not emit a ringing sound when struck a light blow with a hammer shall be replaced. Headed concrete anchors located more than 25 mm (1 in.) along the length of the edgebeam from the location shown on the shop drawings and headed concrete anchors located more than 6 mm ($\frac{1}{4}$ in.) too high in elevation (reducing cover) shall be carefully removed and a new anchor welded in the proper location. All anchor replacement shall be at the expense of the Contractor.

4.3 Installation

Prior to installation of the joint, the blockout and supporting system shall be protected from damage and construction traffic.

4.3.1 Setting Gap Opening

The BJS shall be installed at the proper gap opening corresponding to the installation temperature, as shown on the approved shop plans. The opening devices should be removed immediately after the concrete is placed.

4.3.2 Formwork

The Contractor shall ensure that formwork excludes concrete entry into support boxes or in any way impeding free movement of the MBJS.

4.3.3 Supporting BJS During Placing of Concrete

The BJS shall be fully supported during the placement of the concrete. Welds for temporary attachments to the centerbeams or support bars for erection purposes must be removed and the surface ground smooth. The corrosion protection system shall be repaired to the satisfaction of the Engineer using a method approved by the Engineer.

4.3.4 Placing the Concrete

If a BJS is not at the 3 to 6 mm ($\frac{1}{8}$ to $\frac{1}{2}$ in.) recessed placement, the contractor shall not finish the deck to the top of the joint. The concrete shall be controlled, mixed, and handled as specified in AASHTO LRFD Bridge Construction Specifications and/or agency construction specifications. Very-high-slump concrete shall not be used in the blockout. Concrete shall not be deposited in the forms until the Engineer has inspected the placement of the reinforcement, conduits, anchorages, and prestressing steel and has given his approval thereof.

If there is a vertical grade, concrete shall be placed on downhill side of the blockout first. The concrete shall be vibrated thoroughly so as to adequately consolidate the concrete underneath the support boxes and edgebeams. Care should be taken to avoid displacement of the forms and reinforcing steel. The concrete shall not be placed during extremely cold weather or during heavy rain.

4.3.5 Finished BJS Tolerances

The MBJS shall be inspected after installation and again after at least 1 year of traffic loading (or longer if there is a guarantee period) to verify the following:

(1) The top surfaces of the BJS shall be recessed from the finished roadway profile 3 to 6 mm ($\frac{1}{8}$ to $\frac{1}{4}$ in.).
(2) There shall be no more than 3 mm ($\frac{1}{8}$ in.) difference in elevation among the tops of any of the centerbeams or edgebeams. This variation shall be measured vertically from a straight line connecting the top of the deck profile on each side of the MBJS.
(3) There shall be no more than 13 mm ($\frac{1}{2}$ in.) difference among gap widths at either end of a seal or among the multiple gaps of MBJS.

4.3.6 Bridging BJS after Installation

Construction loads shall not be allowed on the MBJS for at least 72 hours after installation is completed. If it is neces-

sary to cross the BJS, the Contractor shall bridge over the MBJS in a manner approved by the Engineer.

4.3.7 Removal of Forms and Debris

All forms and debris shall be removed after installation.

4.3.8 Watertightness Test

If specified in the contract documents, the watertightness test shall be conducted. After the MBJS has been installed and completed, the MJBS shall be flooded for a minimum of 1 hour to a minimum depth of 3 in. If leakage is observed, the MBJS shall be repaired to the Engineer's satisfaction and retested at the Contractor's expense. The repair procedure shall be recommended by the manufacturer and approved by the Engineer.

4.3.9 Acceptance

A BJS that fails inspection or testing shall be replaced or repaired to the satisfaction of the Engineer at the Contractor's expense. Any proposed corrective procedure shall be submitted to the Engineer for approval before corrective work is begun.

4.4 Post Installation Inspection

The BJS shall be inspected as part of the periodic routine condition inspection of the bridge, not to exceed 2 years between inspections.

COMMENTARY TO THE MATERIALS, FABRICATION, AND CONSTRUCTION GUIDELINES

Commentary to Article 1.1 Definitions

Figure B-1 shows a cross section of an SSBJS, which consists of a flexible seal that fits into slots or clips holding it to steel "edgebeams" that are anchored to the concrete deck slab or abutment. SSBJS have one seal element and are typically physically limited to a total movement range of 127 mm (5 in.).

Greater movement ranges can be accommodated by modular bridge joint systems (MBJS). Present designs for MBJS typically use one or more transverse centerbeams to separate two or more seals. Because it must accommodate larger expansion movements, an MBJS must structurally support the wheel loads across the gap between bridge elements. Present MBJS designs include (1) support bars that slide or swivel in and out of support boxes embedded in the concrete deck or abutment (Figure B-2) and (2) a collapsible scissors-type mechanism (Figure B-3).

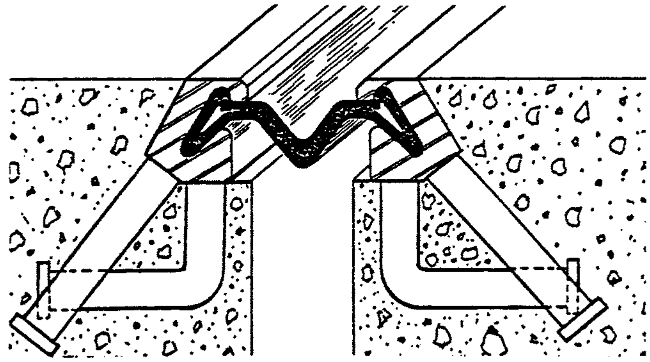

Figure B-1. Cross-section view of typical strip seal bridge joint system (SSBJS).

There are two basic types of support-bar MBJS: multiple-support and single-support-bar systems. Multiple-support-bar (MSB) MBJS, shown in Figure B-2, have centerbeams that are rigidly connected to support bars. Each support bar supports only one centerbeam. For the MSB system, a support box will hold as many support bars as there are centerbeams.

Single-support-bar (SSB) MBJS have transverse centerbeams, which are attached to only one support bar at each support box location using steel yokes and elastomeric springs and bearings, as shown in Figure B-4. One special type of SSB MBJS is the swivel-joist system, in which the support bar swivels as well as slides in the support boxes (Figure B-5).

In MBJS that use a support bar that slides on bearings, the support bar usually has thin stainless steel cover plates joined to the top and bottom of the support bar to provide smooth sliding surfaces. The support bars slide between elastomeric bearings and springs that are fixed in the support boxes, usually by a round boss or protrusion that fits into a hole in the steel plate of the support box. The bearings and springs typically have low friction polytetrafluorethylene (PTFE) pads bonded to the sliding surface of the spring or bearing.

The elastomeric bearings and springs are both precompressed and located atop and below the support bar, with the bearing on the bottom and the spring on top. The springs exert compression to keep the bearing in place. The vertical component of each wheel load applied to the centerbeam and transmitted through the support bar compresses the bearings and reacts against the support box and the deck. There is a significant upward rebound of each wheel load cycle (about 30 percent of the amplitude of the vertical component) that compresses the springs and reacts on the top plate of the support box, imposing an upward load on the deck.

The wheel load may also impart a horizontal force to the centerbeam and an associated rebound that is on the order of 20 percent of the vertical load range. The horizontal load is transmitted through the centerbeam, into the support bar, and into the springs and bearings through friction. Ultimately the horizontal force is resisted by the small bosses in the springs and bearings into the support box and deck. These small bosses

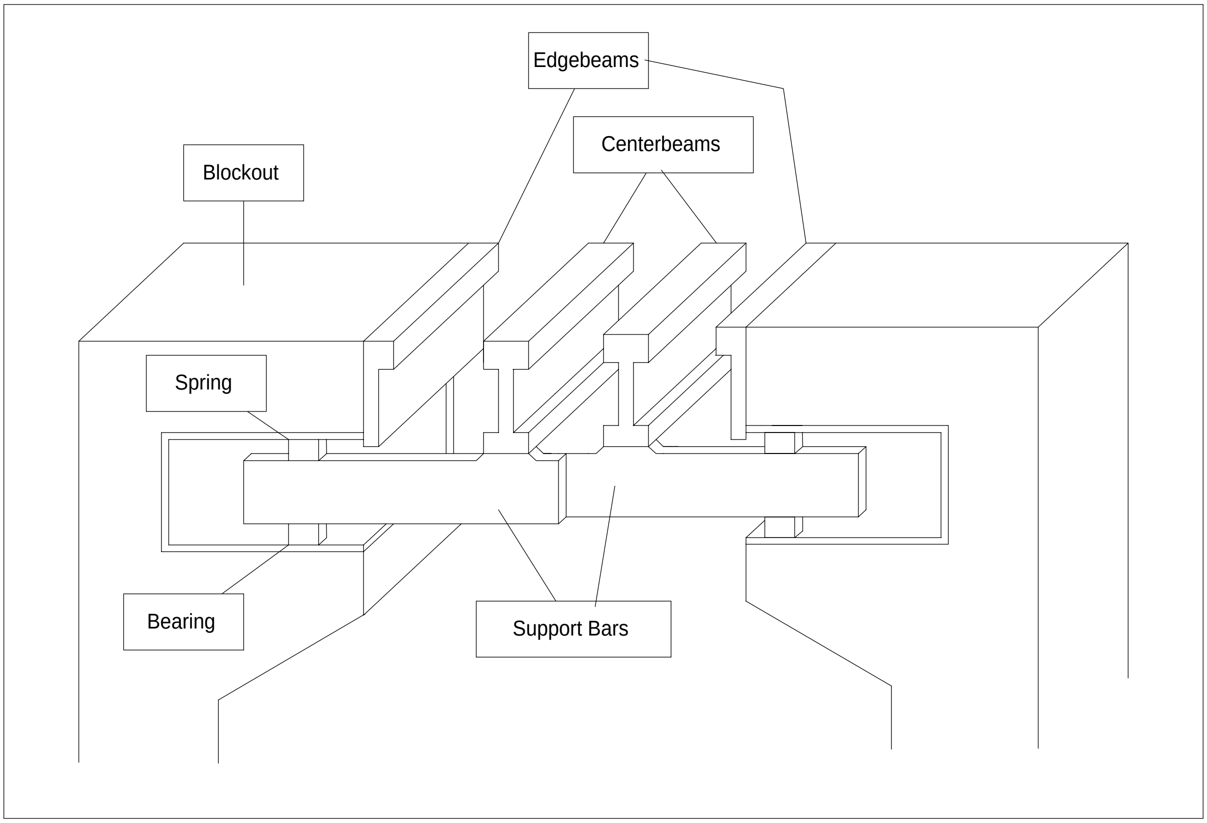

Figure B-2. Cut-away view of typical welded-multiple-support-bar (WMSB) modular bridge joint system (MBJS) showing common support mechanism of support bars sliding within support boxes.

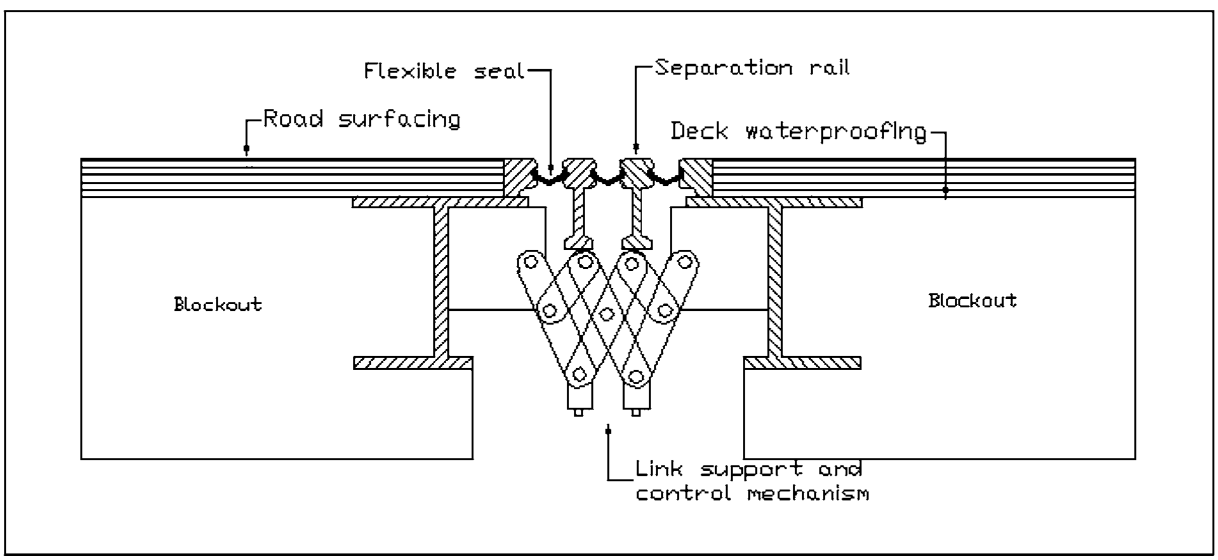

Figure B-3. Cross-section view of a modular bridge joint system (MBJS) showing link support and control mechanism; often called a scissor joint.

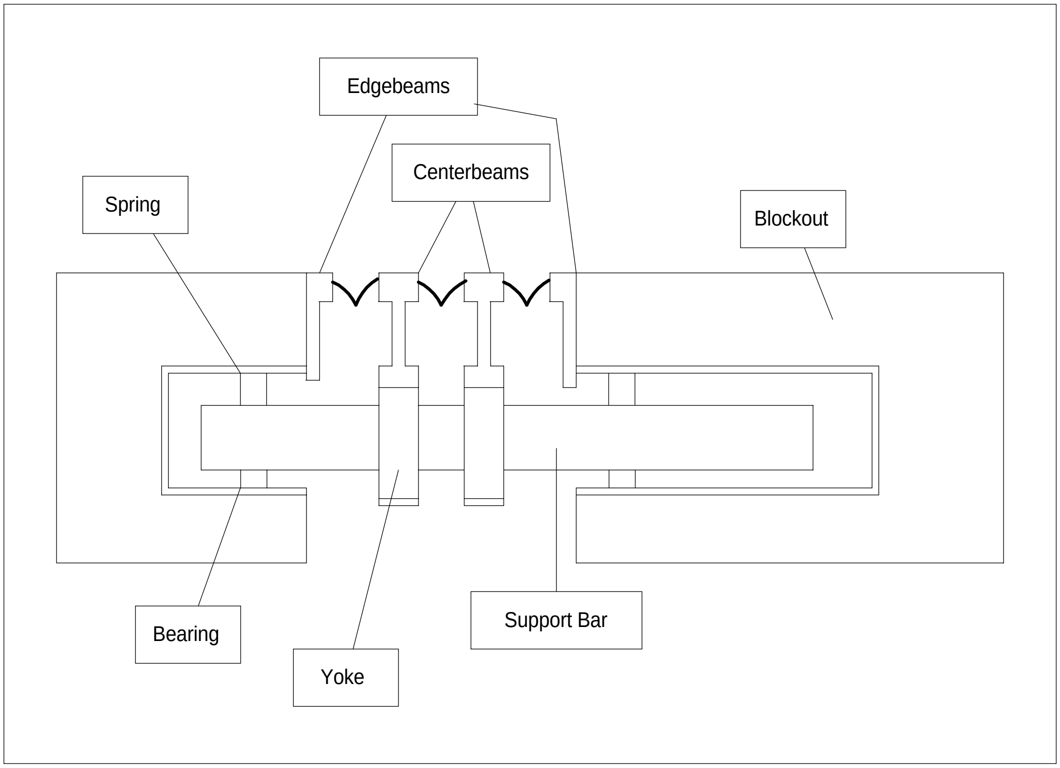

Figure B-4. Cross-section view of typical single-support-bar (SSB) modular bridge joint system (MBJS) showing multiple centerbeams with yokes sliding on a single support bar.

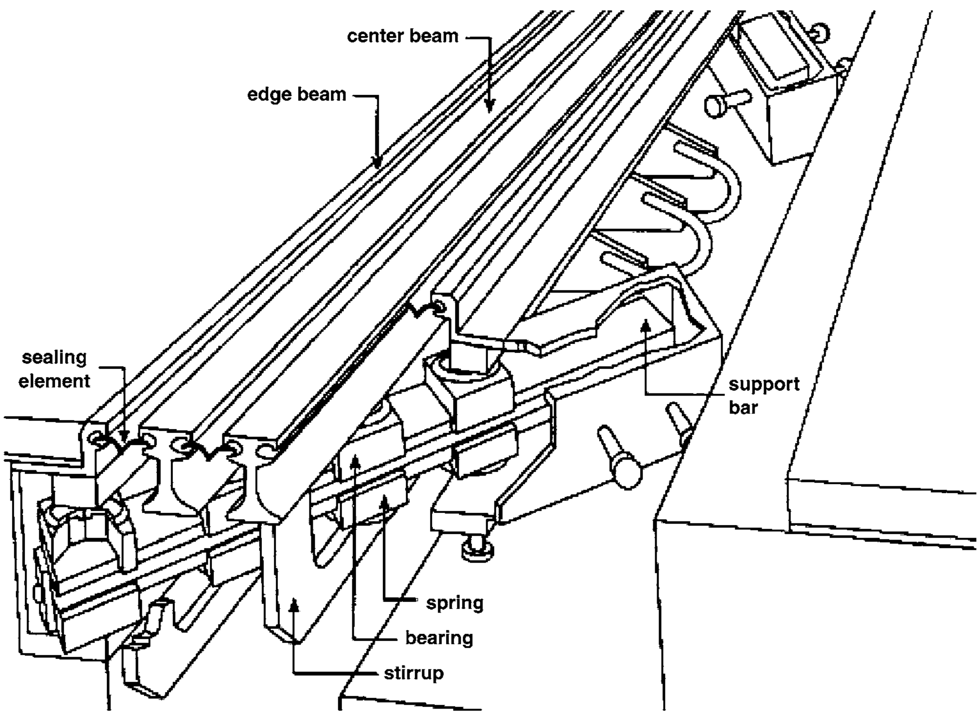

Figure B-5. Cut-away view of a "swivel joint," i.e., a special type of single-support-bar (SSB) modular bridge joint system (MBJS) that can accommodate large transverse movements with a swiveling single support bar.

are subjected to millions of cycles of this reversible shearing action. Shear failure of the bosses leads to systemic failure of the MBJS.

The movements of bridge elements provide the necessary forces to open and close the MBJS. An equidistant system is typically required to maintain an approximately equal gap between centerbeams and between centerbeam and edgebeam. A common equidistant system used in support-bar systems is composed of a series of horizontal elastomeric springs called control springs. In some systems the control springs tend to close the gap; in other cases, the control springs tend to open the gap between centerbeams.

Commentary to Article 1.2 Scope

The support-bar type of MBJS design is most common and, therefore, will be the focus of these guidelines. Certain parts of these guidelines may not be applicable to alternative types of MBJS. These guidelines permit alternative designs that meet the performance requirements in Section 1.2, subject to the Engineer's approval.

Commentary to Article 1.4 Drawing Information

The designer of the bridge must carefully consider the location of the BJS. The BJS should not be located in the middle of curved bridges to avoid unforeseeable movement demands. Preferably, BJS should not be located near traffic signals or toll areas so as to avoid extreme braking forces.

In new construction, the BJS should be placed in one piece whenever possible to avoid field splices of the centerbeams. In this case, the seals shall be installed in the BJS by the manufacturer at the factory. In staged reconstruction, the centerbeam field splices should be minimized. Centerbeam field splices should not be located in the lane with the most trucks and should be located away from likely wheel paths. If possible, locate the centerbeam field splice under the traffic barrier. Field splices of the seals are prone to leaking and other problems and should be avoided (if possible). If centerbeam field splices are used in the BJS, the seals should be installed in one piece in the field after the all field splices are made.

The BJS should be located directly above bridge bearings to limit rotations about the joint.

Generally, skew of the BJS has an adverse effect on performance and, therefore, it is recommended to minimize skew. Support bars should be oriented parallel to the anticipated direction of movement. To ensure good durability of the MBJS, skew should be limited to 45 degrees. In cases of greater skew, it should be recognized that durability of the MBJS may be reduced.

It is common practice to fabricate an upturn in the BJS beneath the curb and/or parapets (Figure B-6) for control of drainage. Debris accumulates at the upturns and can lead to seal pullout and other problems if such debris is not washed out at least yearly. Because of these problems associated with upturns, an alternate detail is to pass the SSBJS or MBJS through the gap in the parapet at the deck level, allowing the deck drainage to run off the ends of the SSBJS or MBJS (Figure B-7). This detail through the parapet reduces the accumulation of debris and avoids the extra cost of the upturn. If

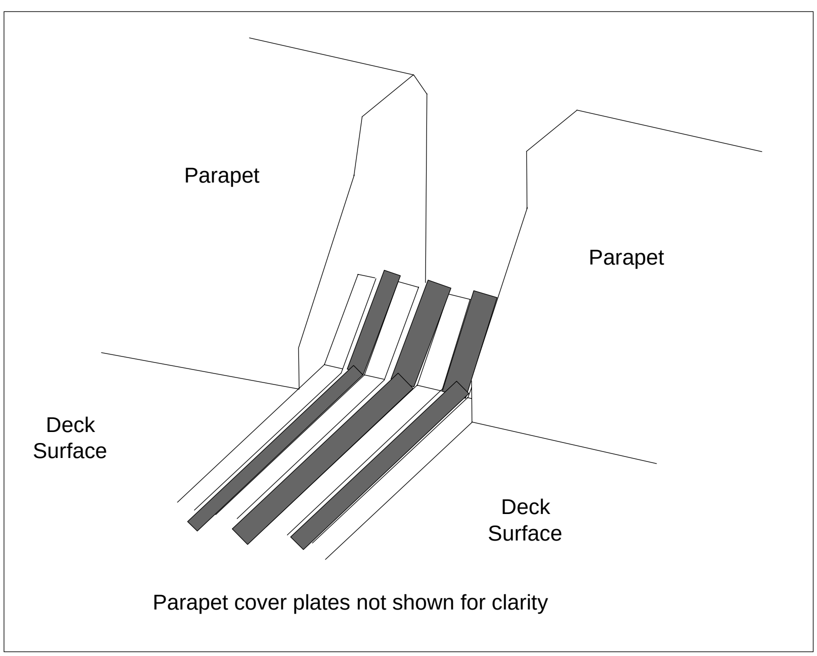

Figure B-6. Typical upturn detail used at curb and/or parapet.

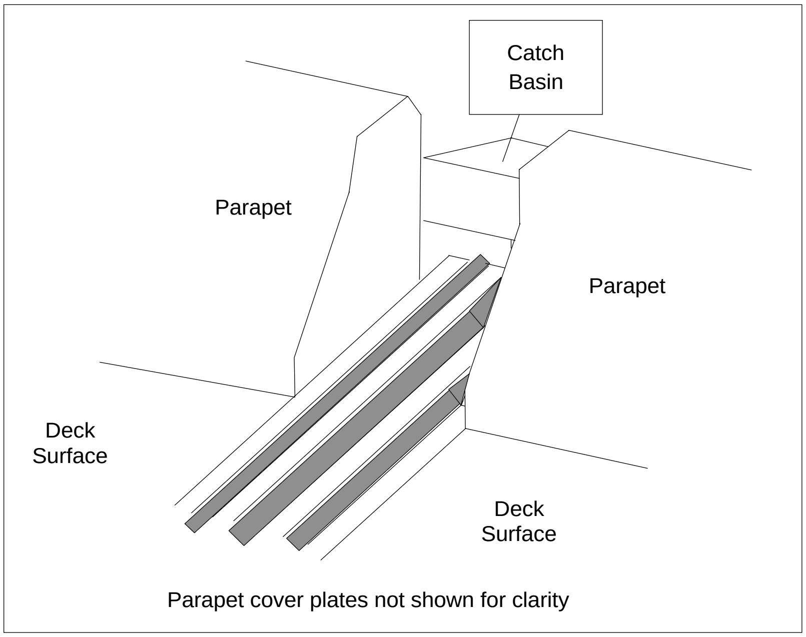

Figure B-7. Alternate pass-through detail used at parapet.

necessary for environmental reasons, scuppers may be provided at the ends of the SSBJS or MBJS to capture the drainage. Particular attention should be focused on preventing water and debris from contacting the bridge elements.

If a deck overlay is installed after construction, MBJS can be retrofitted by continuously fillet welding (or partial-penetration groove welding) a small extrusion to the tops of the existing edgebeams and centerbeams and then placing new strip seals in the small extrusions, as shown in Figure B-8. The top of the new extrusions shall be between 3 and 6 mm ($\frac{1}{8}$ and $\frac{1}{2}$ in.) below the surface of the finished overlay.

Sometimes the ends of steel girders are notched to accommodate the joint. The notches shall be designed for fatigue.

To reduce corrosion of the BJS, it should be electrically isolated by not connecting the bridge deck reinforcement to the BJS.

The support boxes of MBJS are typically 190 mm (7.5 in.) or more in depth and extend 320 mm (12.5 in.) or more beyond

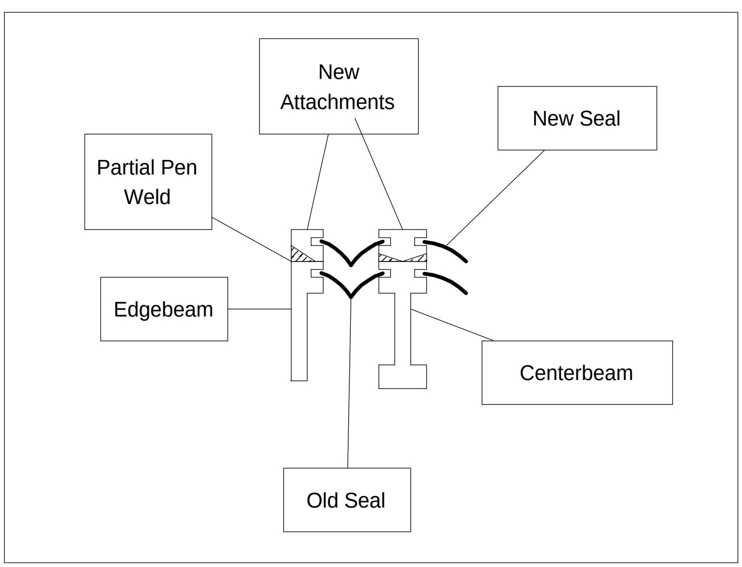

Figure B-8. Overlay extension for Modular Bridge Joints Systems (MBJS).

the edge of the gap. Therefore, a blockout that is 380 mm (15 in.) deep that extends 690 mm (27 in.) beyond the edge of the gap may be required.

Problems can occur when the reinforcing bars are too close to the edgebeams or anchorages, preventing the flow of aggregate under the edgebeam. Part of the problem is that the BJS is a bid item and there are usually several qualified manufacturers. Therefore, the configuration of the BJS is not known at the time the reinforcement is designed. However, some aspects of the BJS configuration may be anticipated and allowances made in the reinforcement. This should be accomplished through appropriate details and/or Contractor submittal of revised reinforcement details.

In steel superstructures, it is acceptable to attach the BJS directly to the end diaphragm, a bulkhead plate, or the girders; although these attachments and the supporting members must be designed for strength and fatigue to resist the repeated large impact forces imparted to the BJS. Any possible differential movements of the deck and the attachment points should also be considered. Short-term differential movements of the deck and the attachment points could cause a fatigue failure and long-term differential movement can cause distortion or a strength failure.

Usually, the abutment shelf or the pier caps provide an adequate work surface for inspection and maintenance.

Commentary to Article 1.5.1 Durability and Service Life

If applicable, the BJS must also withstand de-icing chemicals and scraping and possible impact from snowplow blades. If explicitly required in the contract documents, the Contractor shall provide a 5-year written guarantee for the operation and durability of the BJS.

The following shall constitute unsatisfactory operation:

- Broken welds or bolts;
- Loose bolts;
- Cracks in steel members;
- Damage in springs, bearings, or control springs;
- Displacement of springs, bearings, or control springs;
- Loss of precompression in springs or bearings;
- Debonded PTFE;
- Breakdown of corrosion protection system; or
- Leakage.

The Contractor shall replace or repair any joint parts within the period of the guarantee to the Engineer's satisfaction and at the Contractor's expense.

Condensation and other moisture may be expected underneath the BJS and does not constitute leaking, unless the flow is sufficient to cause continuous dripping at least every 20 seconds or a visible continuous stream of water.

Commentary to Article 1.5.3 Movement

The transverse movement can be estimated by multiplying the anticipated longitudinal movement by the width-to-length ratio of that portion of the bridge contributing to BJS movement. In skewed or curved bridges, the thermal and shrinkage movements occur along a chord between two adjacent moveable bearings or between a fixed bearing and an adjacent moveable bearing. Because this chord is usually not perpendicular to the BJS axis, substantial transverse movements will occur in addition to longitudinal movement. Movement capacity greater than the calculated demand in the longitudinal direction will allow for some unanticipated movement or improper installation. However, excessive movement capacity will prevent the seals from opening fully. It is preferred that the MBJS be designed so that the seals will open almost to their full extent periodically because debris is washed out more easily when the seals are fully open.

Commentary to Article 1.5.4 Loads and Load Factors

More information on the design and analysis of MBJS for fatigue can be found in *NCHRP Report 402.*

MBJS installed on skewed structures may require special attention in the design process. Skew is measured relative to transverse axis, therefore a joint transverse to the longitudinal bridge axis is considered to have zero degree skew. On structures with joint skews more than 14 degrees, it can be shown that the wheels at either end of an axle will not roll over a particular edgebeam or centerbeam simultaneously. This asymmetric loading could significantly affect the stress at critical details, either favorably or adversely. Nevertheless, a skew centerbeam span is subjected to a range of moments that includes the negative moment from the wheel in the adjoining span, followed or preceded by the positive moment from the wheel in the span.

The target reliability level for fatigue is 97.5 percent probability that no fatigue cracks will occur over the service life of the MBJS. The fatigue design specifications are presented in *NCHRP Report 402,* which contains

- Extensive discussion of the loads and measured dynamic response of MBJS and
- The fatigue resistance of common MBJS details.

Fatigue test procedures were developed for the structural details.

Commentary to Article 2.5 Bearings and Springs

If the manufacturer, configuration, or material composition or formulation of the bearings or springs changes after the MBJS model is prequalified through the OMV test, or if a new attachment detail (such as a new support box, new yoke or stirrup) is used, another test shall be conducted.

Commentary to Article 2.7 Movement Joint Seals

Movement joint seals usually have a maximum movement range of 76 mm (3 in.). Seals up to 127 mm (5 in.) have been used successfully. However, the maximum opening for seals is set by AASHTO requirements. Seals used for in-service BJS must be the size that was tested in the Performance Tests as described in Section 1.6.

The ASTM specifications for the seal material appear to be sufficient to assure adequate durability under normal wear and tear and environmental exposure. Improvements in the design of the seals and retainers and in the adhesive/lubricant are believed to have addressed the problem of detachment from centerbeams and edgebeams. Some agencies do not allow the seal to be installed in the field because of the potential for detachment. However, if the BJS is installed in stages, for the rehabilitation of an existing bridge or new installations on wide bridges, a seal field splice will be required if the seal is installed in the shop. Field splices of the seals should be avoided. The performance of spliced seals is not adequate in protecting the bridge superstructure from deck drainage. Therefore, in the case of staged construction, seals should be installed in the field in one continuous piece.

Another common problem is that the seals fill with debris. Traffic passing over the joint can work the seal from its anchorage by "pushing" on this debris. Manufacturers contend that MBJS systems are self-cleaning because as the joint approaches its full open position, debris is expelled from the joint. However, many designers conservatively oversize the MBJS, thus preventing the joint from being self-cleaning. Debris has been observed to be the cause of damage to many MBJS. Debris has been reported in the expansion gap that reduced the effective movement range. When the bridge expands, debris trapped in the seal gaps is compacted and can cause additional stresses and associated damage in both the joint and the structure.

Commentary to Article 2.8 Lubricant Adhesive

If the manufacturer or formulation of the lubricant/adhesive changes, a new test shall be conducted to verify the performance of the new lubricant/adhesive.

Commentary to Article 2.9 Control Springs

Control springs made from urethane foam with the properties shown in Table B-2 (according to ASTM D3574) have performed well.

If the manufacturer, configuration, or material composition or formulation of the control springs changes after an MBJS passes the OMV test, or if a new method of fastening or using the control springs is introduced, a new test shall be conducted to verify the performance of the new control springs.

TABLE B-2 Urethane Control Spring Material Specifications

Property	Test	Requirement
Density	Test A	500 kg/m^3 (31.2 lb/ft^3)
Tensile Strength	Test E	6000 kPa (870 psi)
Elongation	Test E	400 %
Tear Strength	Test F	17.5 N/m (100 lbs/in)
Compression Set 70 hrs @ 70 C	Test D	6 %

Commentary to Article 3. Fabrication Requirements

Whenever possible, fillet welds shall be on both sides of an attachment. The BJS shall be shipped and installed in one piece, wherever possible, to avoid field splicing.

Commentary to Article 3.1 Edgebeam Profile and Anchorage

The use of a horizontal element in the edgebeam cross-section is not recommended because of difficulty with consolidating concrete under the horizontal flanges. If a horizontal element is used, it shall have 19 mm (¾ in.) diameter air holes to improve consolidation of the concrete under the horizontal element. If there is no horizontal element, the top of the profile shall be located between 3 and 6 mm (⅛ and ¼ in.) below the top of the wearing surface of the deck.

Best results have been obtained with solid shapes with machine-cut grooves in the side to retain the seals. One design that satisfies the load requirements and has been designed according to ACI requirements is a 40-mm (1.5-in.) thick edgebeam with no horizontal element and Grade 50 12-mm (½-in.) diameter welded headed concrete anchor studs 152 mm (6.0 in.) long spaced at 305 mm (12 in.) on center. This design requires at least 75 mm (3 in.) of cover above the anchors (measured from the centerline of the anchor to the surface of the concrete). There is no need to bend the studs.

Commentary to Article 3.2 Centerbeam and Support Bar Profile for MBJS

Best results have been obtained with solid bars. For the centerbeam, best results have been obtained with machine-cut grooves in the side to retain the seals. Techniques to avoid loosening of the bolts include using adhesives (i.e., Lock-tite), welding the outer surface of the nut to the exposed threads, or galling the threads.

Commentary to Article 3.4 Support Boxes for MBJS

The top plate is required to support traffic loading. Excessive flexibility can result in reflective cracking above the sup-

port boxes. If 75 mm (3 in.) of cover cannot be provided above the top plate, the top plate may need to be thicker or stiffened to adequately support the traffic loads.

Commentary to Article 3.7 Corrosion Protection

Corrosion of steel sections that have been damaged or exposed has been observed in a number of BJS. Metallic components of MBJS such as bolts, stainless steel sliding plates, and anchors have failed because of corrosion. Accumulation of damp debris in the recesses of the MBJS has been the cause of severe corrosion.

Commentary to Article 3.8 Shop Plans and Other Submittals

The Contractor should also submit a written guarantee, if required, as in Commentary for Section 1.5.1

Commentary to Article 4. Construction Installation and Inspection Requirements

Close coordination among the Engineer, Contractor, and joint manufacturer is necessary to ensure a quality joint installation. Design engineers should work with the manufacturers when detailing the blockout and reinforcement. Unfortunately, it is difficult to specify precise reinforcing bar locations within the blockout during design because the specific BJS and manufacturer have not yet been selected at that point.

Personnel who have experience with BJS installation must be on site at the time of joint installation. It is desirable to have a technical representative (preferably a full-time employee) of the manufacturer present at the time of MBJS installation.

Commentary to Article 4.1 Shipping and Handling

Damage to the joint system during shipping or handling may be cause for rejection of the MBJS.

Commentary to Article 4.2 Pre-Installation Inspection

If the bridge deck or abutment reinforcement has not been designed to accommodate the configuration of the BJS, the reinforcement may have to be altered.

Plastic wrap or foam covers should be placed over the interior opening of the support boxes. These will aid in preventing debris and animals from entering the support box. These should not be added until the MBJS is ready to be installed so that the pre-installation inspection can be performed on the interior components of the support box. The wrap or covers should be easy to remove for future inspections.

Commentary to Article 4.3 Installation

BJS are installed at the time of deck concrete placement or they may be installed after the bridge deck concrete has cured. In the latter case, a blockout is formed in the bridge deck during the initial concrete placement.

Commentary to Article 4.3.3 Supporting BJS During Placing of Concrete

BJS have been supported during installation (prior to placement of the deck concrete) in a number of ways. The preferred method of supporting the MBJS during installation is to suspend it from a series of beams spaced at no more than 3,000 mm (10 ft) spanning the blockout between the deck and abutment or between adjacent decks. These beams allow for more precise setting of the joint height and grade. The deck provides a reference to establish the final BJS profile.

One common practice has been to weld joint anchorages to the deck reinforcing steel for support. This practice is not recommended because it is desired to keep the BJS and the deck reinforcement electrically from each other in order to reduce corrosion and because of concern for cracking in either the reinforcing steel and/or the anchorage. If the BJS is tack welded to deck reinforcement, deflection of the reinforcement must be considered.

In some installations, leveling bolts attached to girder top flanges are used to support the joint. These bolts permit adjustment of the joint height during installation as well as provide support. At least two problems have been reported with the use of leveling bolts. First, some larger MBJS are so heavy that the leveling bolts fail. A second problem with these bolts is that they may carry wheel load directly from the edgebeam to the bridge girder, which may not have been considered in the design. The wheel loads may eventually cause movement of the leveling bolts, which can result in problems.

Temporary connectors between edgebeams (for shipping and handling) should be removed before placing concrete.

Commentary to Article 4.3.4 Placing the Concrete

The bridge deck concrete may be finished to the top of a BJS that is set at a slightly incorrect elevation. The local change in deck profile could cause increased impact forces on the BJS.

If special concrete is specified, the concrete manufacturer's specifications and procedures shall be followed.

Commentary to Article 4.3.6 Bridging BJS after Installation

Movements of the edgebeam prior to complete concrete curing may cause gaps or openings between the edgebeam or

anchorage and the plastic deck concrete. These gaps may result in movement of the edgebeam under traffic loading and associated rapid deterioration.

Commentary to Article 4.3.7
Removal of Forms and Debris

Forms and debris tend to interfere with the free action of the BJS. They may also interfere with the inspection of the BJS.

Commentary to Article 4.4
Post Installation Inspection

Regular inspection of BJS may identify problems in these systems that can be repaired. Maintenance has been shown to significantly extend the life of these systems. Maintenance plans should include seal flushing, repair of wheel ruts and reflective cracks, and replacement of specific components susceptible to premature failure. Unsatisfactory maintenance practices have been responsible for a large number of BJS failures and have accounted for differences in performance between BJS that were identical in all other aspects. BJS designed to be self-cleaning work reasonably well in the wheel path positions. However, in areas where there is little traffic or where parts of the BJS are not subjected to tire contact, the debris is not cleared away and becomes compacted. Therefore, periodic cleaning of seals (e.g., with a hose at least once per year) can significantly prolong BJS life. Deterioration of the deck is also a major factor responsible for many apparent BJS failures. Causes for the deterioration of concrete decks generally are moisture and chloride penetration, inadequate composition, compaction and age of the concrete, corrosion, and insufficient reinforcement. These effects, together with heavy traffic, have led to spalling and failure of the deck at the expansion gap. This affects the BJS anchorage to the concrete.

MBJS & Related Bridge Superstructure Design Checklists

MBJS Selection

MBJS movement range greater than calculated range	
MBJS satisfies performance testing specifications	
MBJS satisfies the fatigue design specifications of *Report 402*	

MBJS Design & Details

No splicing, if possible	
Skew angle < 20 degrees if possible	
Parapet details accommodate MBJS	
Maintenance plan provided by manufacturer	
Corrosion protection of metallic components	

MBJS Placement in Bridge

MBJS directly above bridge bearings, if possible	
Adequate bridge surface drainage system	
Adequate inspection and maintenance access areas under joint	
Blockout size accommodates MBJS	
Deck reinforcement accommodates MBJS	

MBJS Installation Checklists

Pre-Installation

Proper shipping and storage of the MBJS	
Visual inspection of seals, bearings, springs, welds, bolts, etc.	
Limit cutting of bridge steel reinforcement	
Centerbeams are properly spliced (if spliced)	
Centerbeam retainers cleaned before seal installation	
Seal properly inserted into centerbeam and edgebeam retainers	
Add supplemental reinforcing steel around support boxes if required	
MBJS recessed 3 to 6 mm (⅛ to ½ in) below roadway surface	
MBJS set to appropriate grade and cross slope	
Tops of all centerbeams within 3 mm elevation tolerance	
Set overall gap size appropriate for actual bridge temperature per table on approved shop drawings	
Gaps between centerbeams are uniform	

MBJS Installation

Prevention of concrete placement inside support boxes	
If there is a grade, place concrete on downhill blockout first	
Vibrated, proper concrete consolidation under support boxes and edgebeams	
Match blockout concrete elevation to MBJS crown elevation	
MBJS is free to expand as concrete shrinks during curing	

Post-Installation

Prevent construction traffic from traversing MBJS until concrete cures	
Test watertightness by flooding	

Maintenance Checklists

Bridge Statistics

Bridge number	
Bridge name	
Location	
Date of inspection	
Temperature at time of inspection	
Dimensions (Length × Width)	
Skew (each end)	
Superstructure type	
Curvature, grade, crown, superelevation	
Number of lanes (each direction) One-way or two-way	
Truck volume, ADTT or ADT and percent trucks	

Bridge Systems

Location of bearings on bridge	
Number of bearings (abutments and piers)	
Type of bearings (abutments and piers)	
Age of bearings	
Range of bearing movement	
Performance history of bearings	
Distance of nearest scupper to MBJS	
Condition of scupper	
Location of downpipes	
Condition of downpipes	
Debris accumulation on deck near MBJS	
Settling of piers or abutments	

MBJS Statistics
(list data for each MBJS)

MBJS location on bridge	
Vicinity of intersections	
Date of installation	
MBJS manufacturer	
MBJS type	
Movement range/number of seals	
Maintenance history	
Upturn at curb and/or parapet and debris accumulation	
Centerbeam span length	
Roadway surface condition approaching MBJS	
Type of anchorage	
Type of seal	
Dimensions of centerbeam and support bar cross sections	
Seal gap openings at time of inspection (measure at least two locations)	

MBJS Elastomeric Component Problems

Bearings & springs	
Out of place or misaligned	
Creep or permanent deformation	
Cracking or tearing	
Loss of sliding ability	
Loosening or buckling of stainless steel slider plates	
Environmental deterioration	
Keeper bosses sheared off or missing	
Over extension	
Equidistant control springs	
Keeper plate bolt or weld loosened or failed	
Keeper dowel loosened or failed	
Out of place or misaligned	
Permanent deformation	
Cracking or tearing	
Environmental deterioration	
Over extension	
Seals	
Cracking or tearing	
Buckling	
Punctured	
Pulled out of retainers	
Leaking	
Environmental deterioration	
Debris disabling movement	
Field splice failure	
Factory splice failure	
Over extension	

MBJS Metallic Component Problems

Bent or kinked centerbeams	
Significant gouges on edgebeams and centerbeams (from plows?)	
Non-uniform openings between centerbeams	
Corrosion protection failure (expected on top surface of centerbeams)	
Inadequate anchorage	
Anchorage weld failure	
Miss-match of centerbeam heights	
Leakage around edgebeams and anchorages	
Centerbeam cracking	
Support bar cracking	
Centerbeam/support bar weld cracking	
Bolt loosened or sheared	
Centerbeam splice cracking	

MBJS Blockout Problems

Spalling or deterioration near edgebeams and/or anchorages	
Non-consolidation under support boxes	
Reflective cracking above support boxes	
Blockout material inside of support boxes	
Poor blockout material	
Parapet/MBJS interaction problems	
MBJS does not match roadway surface crown	
Wheel rutting in blockout	

Dahir & Mellot Classification (TRB 1118)
Joint Performance

Category	**Rank (0–5)**	**TRB 1118 %**	**TRB 1118 Rank * %**	**10–52 %**	**10–52 Rank * %**
General appearance		9		5	
Condition of anchorage		26		15	
Debris accumulation		9		5	
Watertightness		27		20	
Surface damage		12		10	
Noise under traffic (vibration)		8		15	
Need of maintenance		9		20	
Ease of maintenance				10	
Overall performance					
Weighted Average					

Ranking Values	Weighted Average Values (TRB 1118)
5 = excellent	5.00–4.60 = excellent
4 = good	4.59–4.20 = good
3 = fair	4.19–3.85 = satisfactory
2 = below average	3.84–3.50 = fair
1 = poor	< 3.50 = poor
0 = failure	

APPENDIX C

ANCHORAGE DESIGN EXAMPLE

1. GENERAL

These design calculations are applicable to a welded, headed stud attached to the edgebeam and/or support box of any MBJS. Normal weight concrete is assumed in all calculations. This is the most common blockout material. These calculations can also be used for other bridge expansion devices, such as strip-seal bridge joint systems, that use similar anchorages.

2. DESIGN METHODOLOGY

The following factored loads will be checked: horizontal strength, vertical strength, horizontal snowplow, horizontal fatigue, and vertical fatigue. All forces are assumed to act separately. The vertical load is applied through a truck tire. However, when acting downward, it is not critical because of the large edge distance between the stud and the bottom of the blockout. It does become critical after the tire passes off the edgebeam and a smaller area of blockout material between the anchorage and the top of the deck surface must restrain the rebound vertical forces. The horizontal load is applied while the tire is still on the edgebeam. In this way, they act consecutively, not concurrently. The design fatigue life is selected to be infinite because of the large number of trucks that may pass over an anchorage during its service life.

3. EDGEBEAM PROFILE

Width = 40 mm
Distribution factor = DF = 40 %

NCHRP Report 402 provides distribution factors for centerbeams as a function of their top width with smaller centerbeams receiving smaller proportions of load. The minimum distribution factor is set at 50%. This is acceptable for centerbeams because of the gap between the centerbeam and edgebeam. However, the edgebeam is connected to the blockout material. The blockout will assume some load. The 50% distribution factor is too conservative for edgebeams. By linear interpolation of the *NCHRP Report 402* results, the edgebeam distribution factor was conservatively chosen at 40%.

4. LOADS

All truck axle loads shall be increased by the dynamic load allowance (Impact Factor) of 75% specified for Deck Joints in AASHTO LRFD Table 3.6.2-1.

4.1 Vertical Axle Load for Strength Design

The vertical load for strength design shall be the design tandem axles specified in AASHTO LRFD Article 3.6.1.2.3.

50-kip tandem axle load = $F'_{vs} = 25$ kips

4.2 Vertical Axle Load for Fatigue Design

The vertical load for fatigue design shall be the largest load from the three-axle design truck specified in AASHTO LRFD Article 3.6.1.2.2. The fatigue axle load is based on an HS-20 truck. As discussed in *NCHRP Report 402,* the 32-kip axles in the HS-20 load model actually represent tandem axles, so the actual axle load applied to transverse deck elements like the edgebeam is 16-kips.

Fatigue Truck Axle Load = $F'_{vs} = 16$ kips

4.3 Horizontal Axle Load for Fatigue and Strength Design

The horizontal load for both fatigue and strength design shall be 20% of the amplified vertical axle load. This design example assumes that significant braking and/or acceleration forces are not expected. Nor is the MBJS assumed to be installed on a vertical grade in excess of 5 percent. Either situation would necessitate a greater horizontal load.

$F'_{hs} = (0.2)(F'_{vs})$
$F' = (0.2)(F'_{vf})$

4.4 Snowplow Load

The snowplow load was estimated from snowplow manufacturer information. It is based on the force required to deflect a spring-activated blade with 2 in. of compression and 10 degrees of deflection. This force is conservatively applied to a single anchorage as a horizontal tension force. The Impact Factor is not applied to the snowplow load.

$F'_{hp} = 1.4$ kips/anchor

4.5 Application of Load

Because of the stiffness of an edgebeam anchored in concrete, it is assumed that all the anchors in the lane width participate in resisting the axle load (but not the snowplow load).

Also the eccentricity of the horizontal loads relative to the anchors is ignored.

Lane width = 10 ft
AASHTO LRFD Load Factor for strength
$\gamma_s = 1.75$
AASHTO LRFD Load Factor for fatigue
$\gamma_f = 0.75$
Factored Distributed Vertical Strength Load
$F_{vs} = \gamma\,(F'_{vs})$ (1 + Impact Factor) (DF) / (Lane width)
= (1.75) (25 kips) (1 + 0.75) (0.40) / (10 ft)
= 3.06 kips/ft
Factored Distributed Vertical Fatigue Load
$F_{vf} = \gamma\,(F'_{vf})$ (1 + Impact Factor) (DF) / (Lane width)
= (0.75) (16 kips) (1 + 0.75) (0.40) / (10 ft)
= 0.84 kips/ft
Factored Distributed Horizontal Strength Load
$F_{hs} = (0.20 * F_{vs}) = 0.61$ kips/ft
Factored Distributed Horizontal Fatigue Load
$F_{hf} = (0.20 * F_{vf}) = 0.17$ kips/ft
Factored Horizontal Snowplow Strength Load
$F_{hp} = \gamma\,(F'_{hp})$ = (1.75) (1.4 kips/anchor) = 2.45 kips/anchor

5.0 Anchorage Design

The following values were assumed for this example and will now be checked:

Diameter of stud = 0.5 in.
Head diameter = 1 in.
Cross-sectional area = 0.196 in.^{2}
Length after welding = 6 in.
Spacing = 12 in.

Therefore 1 anchor per foot and kips/ft = kips/anchor

$F_y = 50$ ksi
$F_u = 60$ ksi
$f'_c = 4000$ psi
min concrete cover depth = 2.5 in.

6.0 Anchorage Strength Check

6.1 Shear Strength

$$Q_n = (0.5)(A_{sc})(f'_c * E_c)^{0.5} < (A_{sc})(F_u)$$
$$\phi = 0.85$$
$$\phi\,Q_n = 10 \text{ kips}$$
$$\phi\,(A_{sc})(F_u) = 10 \text{ kips}$$
$$\phi\,Q_n > F_{vs} = 3.06 \text{ kips, OK}$$

6.2 Tensile Strength

$$T_n = A_{sc} * F_u$$
$$\phi = 0.85$$
$$\phi\,T_n = 10 \text{ kips}$$
$$\phi\,T_n > F_{hs} = 0.61 \text{ kips}$$
$$\phi\,T_n > F_{hp} = 2.45 \text{ kips, OK}$$

7.0 Anchorage Fatigue Check

7.1 Shear Fatigue Strength

$Z_r = a * d^2 > 5.5 * d^2$

For infinite life, use $5.5 * d^2 = 1.38$ kips

$Z_r > F_{vf} = 0.84$ kips, OK

7.2 Tensile Fatigue Strength

Category E′ fatigue threshold = 2.6 ksi
Tensile stress range $(f) = F_{hf} / A_{sc} = 0.85$

For infinite life, compare stress range to half the fatigue threshold

$f < 2.6$ ksi/2 = 1.3 ksi, OK

8.0 Concrete Strength Check

The strength of the concrete to resist the applied force is calculated. It is calculated by the latest ACI standard, Code CB-30 (2000).

For anchors governed by the steel the load factors are

$\phi_{tension} = 0.8$
$\phi_{shear} = 0.75$

For anchors governed by the concrete the load factors for Condition A, supplemental reinforcement in the failure area, are

$\phi_{a\ tension} = 0.85$
$\phi_{a\ shear} = 0.85$

For anchors governed by the concrete the load factors for Condition B, no supplemental reinforcement, are

$\phi_{b\ tension} = 0.75$
$\phi_{b\ shear} = 0.75$

8.1 Tensile Loading

8.1.1 Steel strength tensile

$N_s = n * A_{se} * f_y = 9.82$ kips
$\phi N_s = 7.85$ kips

8.1.2 Concrete breakout strength of anchor

$N_{cb} = (A_n/A_{no})\ \psi_2\psi_3\ N_b$
$\psi_3 = 1.25$ for cast-in-place anchors
$h_{ef} = 5.69$ in.
$1.5 * h_{ef} = 8.53$ in.
$c_{\min} = 2.5$ in.
$c = 2.75$
$\psi_2 = 0.7 + 0.3(c_{\min}/h_{ef})$ if $c_{\min} < 1.5h_{ef} = 0.79$
$A_{no} = 9h_{ef}^2 = 291.13$ in.^{2}
$A_n = 192.49$ in.^{2}
$N_b = k(f_c')^{1/2}\, h_{ef}^{1.5} = 20588.44$ lbs
$N_{cb} = 13406.82$ lbs
$\phi_b\ N_{cb} = 10.06$ kips

8.1.3 Pullout strength of anchor

$N_{pm} = \psi_4\ N_p$
$\psi_4 = 1.4$ for no cracking of concrete
$A_b = 0.20$ in.^{2}
$N_p = A_b\ 8\ f_c' = 6283.19$ lbs
$N_{pm} = 8796.46$ lbs
$\phi_b\ N_{pm} = 6.60$ kips

8.1.4 Concrete side-face blowout strength

$N_{sb} = 160c\ (A_b)^{0.5}\ (f_c')^{0.5} = 12330.98$ lbs
$\phi_b\ N_{sb} = 9.25$ kips

Pullout strength governs,

$\phi_b\ N = 6.60$ kips $> F_{hp} = 2.45$ kips, OK

8.2 Shear Loading

8.2.1 Steel shear strength

$V_s = n * A_{se} * f_y = 9.82$ kips
$\phi V_s = 7.36$ kips

8.2.2 Concrete breakout strength of anchor

$V_{cb} = (A_v/A_{vo})\ \psi_6\psi_7 V_b$
$\psi_6 = 1$ for $c_2 > 1.5c_1$
$\psi_7 = 1.4$ for no cracking of concrete
$A_{vo} = 4.5c_1^2 = 34.03$ in.^{2}
$l = 8do$
$A_v = 34.03$ in.^{2}
$V_b = 7(l/d_o)^{0.2}(d_o)^{0.5}\ (f_c')^{0.5} c_1^{1.5} = 2472.99$ lbs
$V_{cb} = 3462.18$ lbs
$\phi_b V_{cb} = 2.60$ kips

8.2.3 Concrete pryout strength of anchor

$V_{cp} = k_{cp} N_{cb}$
$k_{cp} = 2$
$V_{cp} = 26813.63$ lbs
$\phi_b\ V_{cp} = 20.11$ kips

breakout governs,

$\phi V = 2.60$ kips $< F_{vs} = 3.06$ kips NOT OK

8.2.4 Redesign

Because the concrete breakout strength of the anchor is the value that limits the shear strength, it must be increased. There are several options to increase the shear strength. One is to add supplemental reinforcement above the anchorage. Another option is to increase the cover depth of the anchorage. Both will be investigated.

Adding reinforcement with cover depth of 2.5 in.

$\phi_a V_{cb} = 2.94$ kips
$\phi V < F_{vs}$ NOT OK

Increase cover depth to 3.0 inches but do not add supplemental reinforcement

$V_{cb} = (A_v/A_{vo})\ \psi_6\psi_7 V_b$
$\psi_6 = 1$ for $c_2 > 1.5c_1$
$\psi_7 = 1.4$ for no cracking of concrete
$A_{vo} = 4.5c_1^2 = 47.53$ in^2
$l = 8d_o$
$A_v = 47.53$ in^2
$V_b = 7(l/d_o)^{0.2}(d_o)^{0.5}\ (f_c')^{0.5} c_1^{1.5} = 3177.23$ lbs
$V_{cb} = 4448.12$ lbs
$\phi_b V_{cb} = 3.34$ kips
$\phi V > F_{vs} = 3.06$ kips OK

With a cover depth of 3.0 in. and supplemental reinforcement

$\phi_a V_{cb} = 3.78$ kips

This is a conservative design to protect against surface concrete breakout

9.0 Concrete Fatigue Design

The basis for this design is to use the same formulas but reduce fc′ to one-half of its original value. The anchorage design with 3.0 in. of cover but with no supplemental reinforcement will be used to check the concrete fatigue design.

9.1 Tensile Loading

9.1.1 Steel strength tensile

$N_s = n * A_{se} * f_y = 11.78$ kips
$\phi N_s = 9.42$ kips

9.1.2 Concrete breakout strength of anchor

$N_{cb} = (A_n/A_{no})\ \psi_2\psi_3\ N_b$
$\psi_3 = 1.25$ for cast-in-place anchors
$h_{ef} = 5.69$ in.
$1.5 * h_{ef} = 8.53$ in.
$c_{\min} = 2.5$ in.
$c = 2.75$
$\psi_2 = 0.7 + 0.3(c_{\min}/h_{ef})$ if cmin < $1.5h_{ef} = 0.79$
$A_{no} = 9h_{ef}^2 = 291.13$ in.^{2}
$A_n = 192.49$ in.^{2}
$N_b = k(0.5f'_c)^{1/2}\ h_{ef}^{1.5} = 14558.22$ lbs
$N_{cb} = 9480.05$ lbs
$\phi_b N_{cb} = 7.11$ kips

9.1.3 Pullout strength of anchor

$N_{pm} = \psi_4\ N_p$
$\psi_4 = 1.4$ for no cracking of concrete
$A_b = 0.20$ in.^{2}
$N_p = A_b *\ 8 * 0.5f'_c = 3141.59$ lbs
$N_{pm} = 4398.23$ lbs
$\phi_b N_{pm} = 3.30$ kips

9.1.4 Concrete side-face blowout strength

$N_{sb} = 160\mathrm{c}\ (\mathrm{A_b})^{0.5}\ (0.5f'_c)^{0.5} = 8719.32$ lbs
$\phi_b N_{sb} = 6.54$ kips

Pullout governs, compare to double the AASHTO LRFD fatigue load for infinite life

$\phi N = 3.30$ kips $> 2 * F_{hf} = 0.34$ kips, OK

9.2 Shear Loading

9.2.1 Steel shear strength

$V_s = n * A_{se} * f_y = 9.82$ kips
$\phi V_s = 7.36$ kips

9.2.2 Concrete breakout strength of anchor

$V_{cb} = (A_v/A_{vo})\ \psi_6\psi_7 V_b$
$\psi_6 = 1$ for $c_2 > 1.5\mathrm{c}_1$
$\psi_7 = 1.4$ for no cracking of concrete
$A_{vo} = 4.5c_1^2 = 47.53$ in.^{2}
$\mathrm{l} = 8d_\mathrm{o}$
$A_v = 47.53$ in.^{2}
$V_b = 7(\mathrm{l}/d_\mathrm{o})^{0.2}(d_\mathrm{o})^{0.5}\ (0.5f'_c)^{0.5}c_1^{1.5} = 2246.64$ lbs
$V_{cb} = 3145.29$ lbs
$\phi_b V_{cb} = 2.36$ kips

9.2.3 Concrete pryout strength of anchor

$V_{cp} = k_{cp}N_{cb}$
$k_{cp} = 2$
$V_{cp} = 18960.1$ lbs
$\phi_b V_{cp} = 14.22$ kips

Breakout governs, compare to double the AASHTO LRFD fatigue loads for infinite life

$\phi V = 2.36$ kips $> 2 * F_{vf} = 1.68$ kips, OK

10.0 Final Design Summary

Welded Headed Anchor
$F_y = 50$ ksi = 34.5 MPa
Length of anchor = 6 in. = 152 mm
Minimum cover depth = 3 in. = 75 mm
Diameter of anchor = ½ in. = 13 mm
Spacing between anchors = 12 in. = 304 mm
Edgebeam width at deck surface = 1.5 in. = 40 mm

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Abbreviations used without definitions in TRB publications:

AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
FAA	Federal Aviation Administration
FHWA	Federal Highway 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
SAE	Society of Automotive Engineers
TCRP	Transit Cooperative Research Program
TRB	Transportation Research Board
U.S.DOT	United States Department of Transportation

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