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FIELD STUDIES OF ELASTOMERIC BRIDGE BEARINGS

by

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THESIS

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Joseph A. Yura

Richard E. Klingner

To my wife Jessica

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ABSTRACT

FIELD STUDIES OF ELASTOMERIC BRIDGE BEARINGS:

by

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THE UNIVERSITY OF TEXAS AT AUSTIN, 1996

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Elastomeric bearing pads have been utilized extensively in bridge structures for the past forty years. Recently, excessive movement of predominantly natural rubber, tapered pads prompted an investigation to determine the causes of bearing pad slip. Two bridge sites were instrumented and monitored over a three-year time period. Natural rubber and neoprene bearing pads were utilized at both sites under various conditions. The methodology and procedures that were implemented are discussed in detail. The field study results, in conjunction with the laboratory results, indicated that the antidegradant additives in natural rubber bearings, namely waxes, will migrate to the bearing contact surfaces. This viscous leachate reduces the coefficient of friction and, in some cases, the horizontal force is sufficient to overcome the friction force and the bearings “walk out”. Neoprene pads on these waxy surfaces may also demonstrate excessive movement. Neoprene pads on wax-free surfaces have shown no indication of slip.

TABLE OF CONTENTS

	<u>Page</u>
LIST OF TABLES	ix
LIST OF FIGURES	x
<u>CHAPTER ONE</u> - Introduction	
1.1 Elastomeric Bearing Pads	
1.1.1 Natural Rubber and Neoprene	
1.1.2 Bearing Pad Usage	
1.2 Problem History	
1.2.1 TxDOT Survey	
1.2.2 National Survey	
1.3 Previous Research Observations	
1.3.1 Field Studies	
1.3.2 Material Properties	
1.3.3 Bearing Additives	
1.3.4 Analytical Modeling	
1.3.5 Experimental Program	
1.4 Field Research	
1.5 Scope and Objectives	
<u>CHAPTER TWO</u> - Test Program and Material Properties	
2.1 Test Program	
2.1.1 Site Description	
2.1.1.1 Slaughter Creek	
2.1.1.2 Valley Ridge	
2.1.2 Bridge Instrumentation	
2.1.3 Bridge Monitoring	
2.1.4 Lifting Techniques	
2.1.5 Cleaning Methods	
2.2 Material Property Tests	
2.2.1 Hardness	
2.2.2 Shear Modulus Tests	
2.2.3 Slip Tests	
<u>CHAPTER THREE</u> - Presentation and Discussion of Data	
3.1 Slaughter Creek Bridge	

Page

- 3.1.1 History
- 3.1.2 Bearing and Girder Movement
- 3.1.2.1 Phase One
 June 25-October 2, 1992.....
- 3.1.2.2 Phase Two
 October 2-October 23, 1992
- 3.1.2.3 Phase Three
 October 23, 1992-April 22, 1994.....
- 3.1.2.4 Phase Four
 April 22, 1994-November 15, 1995.....
- 3.2 Valley Ridge Boulevard Bridge.....
- 3.2.1 History
- 3.2.2 Bearing and Girder Movement

CHAPTER FOUR - Observations

- 4.1 Natural Rubber and Neoprene Bearings
- 4.2 Bearing Movement
- 4.3 Cleaning Suggestions.....
- 4.4 Bearing Restraints.....
- 4.5 Expansion Joints

CHAPTER FIVE - Summary, Conclusions, and Recommendations

- 5.1 Summary
- 5.2 Conclusions.....
- 5.3 Recommendations to TxDOT

BIBLIOGRAPHY

VITA

LIST OF TABLES

Table 1.1	Direct Comparison of Quad Shear Tests - Manufacturer A
Table 1.2	Summary of 1994 and 1995 Full Scale Tests - Manufacturers A, B, and C
Table 2.1	Comparison of Hardness Values from Two Sites.....
Table 2.2	Shear Modulus Values of Field Bearings
Table 2.3	Friction Coefficients from Slip Tests

LIST OF FIGURES

Figure 1.1	Photograph of a Bearing Walking Out from a Texas Bridge
Figure 2.1	Photograph of Slaughter Creek Bridge
Figure 2.2	Slaughter Creek Bridge in Elevation.....
Figure 2.3	Slaughter Creek Bridge in Plan.....
Figure 2.4	Photograph of Valley Ridge Boulevard Bridges.....
Figure 2.5	Valley Ridge Boulevard Bridge in Plan.....
Figure 2.6	Valley Ridge Boulevard in Elevation.....
Figure 2.7	NR and Neoprene Replacement Pattern at Valley Ridge Boulevard
Figure 2.8	Diagram of Thermal Displacement Gage.....
Figure 2.9	Photograph Demonstrating Connectivity of Gage
Figure 2.10	Sequence of Thermal Cycle of Gage.....
Figure 2.11	Reference Line on a Slaughter Creek Girder
Figure 2.12	Steel Lifting Section
Figure 2.13	Schematic of Lifting Apparatus
Figure 2.14	Steam Cleaning Test Surfaces at the Ferguson Laboratory
Figure 2.15	Steam Cleaning Abutment and Girder Surfaces at Slaughter Creek.....
Figure 2.16	Test Machine for Full Size Bearings.....
Figure 2.17	Major Components of Test Machine.....
Figure 2.18	Typical Load Displacement Curve for a Full Size Bearing
Figure 3.1	Girder 1 Movement During Phase One.....
Figure 3.2	Bearing Movement under Girder 4
Figure 3.3	Bearing Movement under Girder 5
Figure 3.4	Slaughter Creek Bearing Contacting Abutment Wall
Figure 3.5	Slaughter Creek Girder 1 Thermal Cycle, Web Gage.....
Figure 3.6	Slaughter Creek Girder 1 Thermal Cycle, Flange Gage
Figure 3.7	Graph of Slaughter Creek Bearings Movements - Phase Three.....
Figure 3.8	Slaughter Creek Bearing Movements Since April 1994
Figure 3.9	Bearing Movement under Girder 5 For Three Bridge Lifts
Figure 3.10	Valley Ridge Boulevard Bridge Bearing Walking Out.....
Figure 3.11	Girder Movement at Valley Ridge Boulevard Bridge.
Figure 4.1	Typical Steel Collar Encompassing Bearing to Prevent Walking

CHAPTER ONE

Introduction

This study is part of a larger research project at The University of Texas at Austin sponsored by the Texas Department of Transportation (TxDOT), entitled “Elastomeric Bearings.” The purpose of the research is to study the behavior and performance of elastomeric bridge bearings and to recommend practical design procedures for TxDOT. The research was divided into five main phases, namely, field surveys and investigations, basic material tests, development of engineering models, development of design procedures, and a study of bearing pad slip. This report focuses on the field studies that were conducted on two TxDOT bridges that have experienced elastomeric bearing pad problems.

1.1 Elastomeric Bearing Pads

Elastomeric bearings, as designed for use with bridges, accommodate movements between the superstructure and the supports, allow rotations, and transfer loads to the supports in a controlled manner. Movements and rotations occur due to daily and seasonal temperature cycles, bending due to traffic loads, and shrinkage and creep of the girders.

1.1.1 Natural Rubber and Neoprene: Elastomeric materials used in the manufacturing of bearings are derived from natural rubber or man-made substances such as neoprene, urethane, and ethylene propylene dimonomer. Natural rubber and neoprene are by far the most commonly used materials. The

first known usage of neoprene bearings in the United States was on a bridge in Victoria, Texas in 1957. The 1961 American Association of State Highway and Transportation Officials (AASHTO) Specifications named neoprene as the only acceptable elastomeric compound and it remains the most common elastomeric material. In 1973, the specification was amended to include natural rubber (NR) as an alternative material to neoprene (5). TxDOT has utilized both NR and neoprene bearing pads to accommodate bridge movements. The recent decrease in the price of NR, imported primarily from Malaysia, has challenged the market dominance of neoprene bearings. Bearing manufacturers estimate that an NR bearing now costs approximately 75 percent less than a neoprene pad of the same design.

1.1.2 Bearing Pad Usage: The earliest documented use of elastomeric bearing pads were 1/2 inch NR pads which were installed under a railroad viaduct in Melbourne, Australia in 1889 (9). These bearing pads were incorporated to allow rotations due to load conditions and to absorb impacts. After nearly 100 years of service, an inspection showed that these pads were fully functional and had only suffered approximately one millimeter of environmental degradation.

Modern bearings are typically reinforced internally with steel shims and came into widespread usage in the 1950s. Bearings are easy to install, require no maintenance, and are economically competitive with other types of bearing systems. NR bearings, more than neoprene pads, are more susceptible to degradation due to the presence of ozone in the atmosphere. Additives such as wax adequately remedy this problem. Because of their chemical composition, neoprene bearing pads are inherently resistant to environmental degradation, although wax is frequently added.

In the state of Texas, all bearings are designed according to AASHTO specifications. Regarding bearing anchorage, the specification states that if the design shear force exceeds one-fifth of the compressive force due to dead load alone, the bearing shall be secured against horizontal movement (14). Most of the bridges in Texas are concrete structures with large ratios of dead load to shear force which negates the need to anchor the bearings. Most of the bearings are held in place by friction created by the dead weight of the structure.

1.2 Problem History

Since 1987, several bridges in the state of Texas have experienced problems relating to elastomeric bearing movements. Figure 1.1 illustrates a bearing pad demonstrating excessive movement. In some cases, pads have completely moved out from the girder and the bearing seat. These movements generally fall under two categories, “slipping” and “walking out”. Slipping is defined as rigid body movement of the bearing in relation to the girder and the support. Movements are not accommodated by the deformation (shearing) of the elastomer and the bearing pads are displaced from their original positions. Walking out is described as bearing pad movement in one direction due to the accumulation of small movements from the daily and seasonal thermal cycles of the girders. In several instances, bearings have completely walked out from the girders due to the sum of these incremental movements.

Figure 1.1 Photograph of a bearing walking out from a Texas bridge

1.2.1 TxDOT Survey: A survey of all TxDOT district offices conducted in 1992 identified 17 bridges that were experiencing problems associated with bearing movements (5). A similar survey conducted in 1994 identified a total of 38 bridges that exhibited bearing slip. An analysis of the data demonstrated several trends. Bearing pad failures in older bridges were predominantly due to inadequate design. Many bearings contained inadequate elastomer thicknesses. Several failures were due to girder movements greater than that for which they were designed. These larger movements were caused by increasing span lengths by deck overlays or debris clogging the expansion joints creating a fixed end. Of the newer structures, the span lengths were at least 30.48 m (100 ft.) long and

were subjected to significant thermal expansion and contraction. Of greater significance, all but one of the newer bridges incorporated NR bearings under the girders. The one case with neoprene pads was determined to be one of inadequate elastomer thickness. Additionally, all of the bridges that had bearings exhibiting the walking out phenomenon incorporated tapered bearings (3).

1.2.2 National Survey: In 1994-95, a national survey of slip problems was conducted as part of Project 1304. The results indicated that nearly two-thirds of the states that do not fix bearing pads to the bridge or pier cap have bridges that have exhibited some form of bearing movement. Approximately one-third of the states permit and use NR bearings under bridges. Only one in five states allow the use of tapered bearings and nearly two-thirds of these states reported problems with slipping. Many DOT officials attributed slip problems to inadequate design, incorrect placement of bearings, large roadway skews, or long bridge spans. Although the results of this national survey could not conclusively correlate slipping with NR bearings and/or tapered bearings, the results of the TxDOT survey, which targeted the individual districts, strongly indicated a problem with natural rubber bearings that were tapered (3).

1.3 Previous Research Observations

Research on natural rubber specimens was conducted at the Phil M. Ferguson Laboratory at the University of Texas at Austin. The TxDOT survey indicated a tendency of tapered NR bearings to slip, accordingly, the primary focus centered on the effects of tapering and the material properties of natural rubber bearings. Researchers had also noted a dark waxy film on the girders and bearing seats where bearings had slipped or walked out. It was the impression of

several sources that this wax-like material reduced the coefficient of friction at the contact surfaces of the bridge and the bearings and reduced the force necessary to induce slipping. Another phase of the 1304 study, therefore, looked into the nature of the antidegradant additives in natural rubber bearings. A theoretical study that included a finite element analysis of the behavior of reinforced bearings was completed as well. A summary of these studies follows.

1.3.1 Field Studies: An initial field study was conducted by English (5). The results of the TxDOT survey were utilized to identify several Texas bridges where bearing movement was occurring. The findings of this study were that some natural rubber bearings were slipping out from their original positions and that this behavior did not seem to be exhibited by neoprene pads. Particular attention was given to the southbound access road bridge of IH-35 over Slaughter Creek in South Austin, due to its proximity to the Texas campus. NR pads from this bridge were replaced with neoprene pads which were designed under the (then) latest TxDOT design criteria. After this change, the movement appeared to cease. Approximately six months later, these neoprene pads began to slip and the project was extended in order to determine the cause of this movement.

1.3.2 Material Properties: Material property tests for compression, tension, shear, and combined compression and shear were conducted on NR specimens according to the appropriate ASTM standards. These tests were performed by Arditzoglou and Haines (1). NR material was ordered from three different manufacturers by specifying a desired nominal shear modulus (G_n). Tests were conducted primarily on specimens that measured 101.6 x 101.6 mm (4 x 4 in.) and 50.8 x 50.8 mm (2 x 2 in.) with elastomer thicknesses of 25.4 mm (1 in.) and 12.7 mm (0.5 in.). The results of the quad shear tests, ASTM D4014-89, to determine

the shear modulus of the NR specimens indicated that for specimens with G_n of 0.69 MPa (100 psi), the values were significantly higher (up to 60 percent higher for some specimens) than the nominal value. These results are presented in Table 1.1.

Table 1.1 Direct Comparison of Quad Shear Tests - Manufacturer A

Specimen Size	G_n MPa (psi)	Shear Modulus MPa (psi) - Manufacturer A			
		0.69 (100)		1.38 (200)	
		Annex A	20-40%	Annex A	20-40%
50.8 x 50.8 x 12.7 mm (2 x 2 x 0.5 in.)		1.02 (148)	0.89 (127.5)	1.45 (210)	1.29 (184.5)
50.8 x 50.8 x 25.4 mm* (2 x 2 x 1 in.)*		1.03 (148.8)	0.84 (122.1)	1.46 (212.2)	1.23 (178.9)
101.6 x 101.6 x 25.4 mm (4 x 4 x 1 in.)		0.96 (139)	0.825 (118)	1.32 (191.5)	1.13 (162)
101.6 x 101.6 x 25.4 mm* (4 x 4 x 1 in.)*		1.05 (152.3)	0.84 (122.1)	1.51 (218.9)	1.23 (178.5)
152.4 x 152.4 x 25.4 mm* (6 x 6 x 1 in.)*		1.13 (163.7)	0.93 (134.7)	1.47 (212.5)	1.29 (187.3)

* Tests performed one year after initial tests.

Tests conducted on full-scale specimens demonstrated that the shear modulus was less than the nominal value. The implication is that if one relies on the ASTM test for shear modulus, the reported values will be significantly greater than the actual values for full-scale bearings. The shear modulus tests also indicated a tendency of the natural rubber specimens to “cure” over time and become stiffer in shear. Table 1.2 demonstrates that tests conducted one year

later on the exact same specimens and in the exact same manner showed a 20 percent increase in measured shear modulus.

Table 1.2 Summary of 1994 and 1995 Full-Scale Tests - Manufacturers A, B, and C

Manufacturer	Specified G MPa (psi)	G of Flat Specimens MPa (psi)		% Change from 1994
		1994 Results	1995 Results	
A	0.69 (100)	0.68 (98.6)	0.83 (120.7)	+ 22.4
	1.38 (200)	0.84 (122)	1.07 (155.1)	+ 27.1
B	0.69 (100)	0.60 (86.9)	0.71 (102.9)	+ 18.4
	1.38 (200)	0.96 (139.8)	1.08 (156.3)	+ 11.8
C	0.69 (100)	0.60 (87.2)	0.71 (102.7)	+ 17.8
	1.38 (200)	0.82 (119)	0.93 (135.1)	+ 13.5

1.3.3 Bearing Additives: Tests conducted by Chen (3) examined the antidegradant additives in NR bearings. Spectroanalysis of scrapings taken from the surfaces of NR pads showed that the leachate was comprised mainly of different types of wax. It is known that atmospheric ozone and other pollutants degrade natural rubber and that wax seems to provide adequate protection. Waxes are added to NR bearings in order to pass the ozone tests recommended by AASHTO. Waxes are occasionally added to neoprene bearings as well.

It is the opinion of Chen and other researchers that the tests, which were designed to evaluate the performance of elastomeric material used in thin-walled applications, are overly stringent for large, bulky rubber products such as bearings. The tests are also performed with the elastomer in tension, even though

bearing pads are normally subjected to compression and shear. Empirical evidence, such as the previously mentioned railroad viaduct in Melbourne, Australia, suggests that rubber products with a large volume of rubber and a relatively small surface area (i.e. bearings) are not susceptible to ozone degradation. The study also determined that within six months, wax in a “typical Texas” NR bridge bearing will demonstrate a surface wax leachate bloom several times thicker than is recommended for ozone protection. The viscous wax thus coats the concrete contact surfaces of the bearing pads which makes the bearings susceptible to walking out.

1.3.4 Analytical Modeling: A theoretical study that included computer modeling of typical Texas bearings and a finite element analysis on the behavior of these natural rubber reinforced bearings was performed by Hamzeh (7). This study demonstrated that without the wax additive, natural rubber bearings would behave as designed and not walk out under design circumstances. The theoretical study also determined that there is no inherent flaw in the design of tapered bearings and even a conservative estimate of the coefficient of friction of NR pads (0.2) should preclude walking out.

1.3.5 Experimental Program: Muscarella (10) tested full-scale, natural rubber, flat and tapered bearings under a variety of conditions in order to replicate field behavior. A test setup was constructed which applied a compressive force to the bearings while shearing them horizontally to replicate the natural thermal cycle of the girders. The results reaffirmed that there was nothing inherent in natural rubber to cause the bearings to slip. Likewise, tapered bearings were not more likely to induce slipping. Muscarella noted that when the bearings were received from the manufacturer, a waxy film coated the exterior surfaces, and that when

these pads were tested, they left a greasy imprint where they had been positioned. Pads that were tested when the contact surfaces contained wax exhibited slip. Yet when the test surfaces and the pads were steam-cleaned to remove the exterior wax residues, the pads performed as expected with no slipping. Slip tests were also conducted and the results showed that the presence of wax significantly decreased the coefficient of friction of the pads.

Muscarella identified and described the mechanics of walking out. Walking out will occur when the horizontal force on the bearing exceeds the coefficient of friction between the bearing and the surfaces with which it is in contact. There is a threshold strain - a function of the degree of the bearing taper and the amount of wax on the surfaces - below which slipping will not occur.

1.4 Field Research

Field studies have been a critical element of Project 1304 since its inception. The field studies were extremely important because there was initial doubt that the walking out phenomenon could be recreated in a laboratory setting. Although this was accomplished, the actual bearing environment could not be replicated. There also was an opportunity to observe and conduct experiments on functioning structures. Two Texas bridges were thus transformed into “living laboratories.”

In addition to the previously mentioned Slaughter Creek bridge, the Valley Ridge Boulevard bridge over IH-35E in Denton County was studied in-depth. Descriptions and a history of bearing movements at these sites are presented in Chapter’s Two and Three, respectively. The observations,

measurements and experimental results of the field research at these two bridge sites have provided invaluable information. Field investigators noted the slick surfaces where bearing pads had walked out which led to the study of the antidegradant additives in bearings. At the Slaughter Creek site, the behavior of differently designed NR and neoprene pads was observed as the conditions of the contact surfaces were modified. At the Valley Ridge site, researchers had the unique opportunity to observe and directly compare the differences between identically specified NR and neoprene bearings under the exact same conditions at the same time. These results are presented in Chapter Three.

1.4 Scope and Objectives

The evidence indicates that the problem with slip and walking out of elastomeric bridge bearings is due to the presence of wax substances in the bearings which bloom to the contact surfaces. This determination is indicated by theoretical studies and laboratory experiments which have demonstrated that clean or non-waxy surfaces do not experience slip.

Field Studies reported herein were conducted concurrently with the laboratory investigations. The purpose of these studies was to document bearing pad and girder movements in order to understand, explain, and prevent bearing pad slip. An additional goal was to observe and document a direct comparison between identically specified NR and neoprene bearing pads. Chapter Two focuses on the experimental procedures that occurred at two Texas bridge sites as well as the material properties of bearing pads utilized at these sites. Movement history and the data recorded at these bridges are presented and discussed in

Chapter Three. Observations regarding bearing movement are presented in Chapter Four and Chapter Five contains the conclusions and recommendations.

CHAPTER TWO

Test Program and Material Properties

Since the beginning of this project in 1991, project personnel and TxDOT personnel have been monitoring several bridges in the state of Texas in order to document the movement of bearing pads and to understand, explain, and prevent elastomeric bearing pads from walking out. Two bridges in Texas were of particular interest: the Valley Ridge Boulevard bridge over IH-35E in Denton County just north of Dallas and the southbound frontage road bridge of IH-35 over Slaughter Creek in Travis County in South Austin. These bridges were selected because: both utilized natural rubber, tapered bearings; some of the bearings under both bridges had completely walked out; movement was occurring at the abutments where researchers could easily take measurements; and both bridges were conveniently located.

2.1 Test Program

Both sites were instrumented and monitored over the course of three and half years, and various procedures were performed on these bridges during this time. Test procedures were performed in the field. Natural rubber and neoprene bearings from these sites were tested at the Ferguson Laboratory at The University of Texas at Austin. Descriptions of these tests and procedures follows.

2.1.1 Site Descriptions

2.1.1.1 Slaughter Creek Bridge: The Slaughter Creek bridge is a 92.7-m (304-ft) bridge which carries the southbound frontage road for IH-35 over Slaughter Creek in South Austin (Figure 2.1). From north to south, the three spans measure 28.0-m (92-ft), 28.0-m (92-ft) and 36.6-m (120-ft). The bridge inclines upward from north to south as shown in Figure 2.2. It has a continuous cast-in-place deck with five type IV girders over the short spans and six type IV girders over the longer span. When opened for traffic in 1990, 70 durometer (nominal) natural rubber bearings measuring 228 mm x 559 mm x 44.5 mm (9 in x 22.1 in x 1.75 in) with two steel shims of 3.18 mm (0.125 in) were in position beneath the girders.

Figure 2.1 Photograph of Slaughter Creek Bridge

Figures 2.2 and 2.3 illustrate the Slaughter Creek bridge in elevation and plan. The girders at the north and south ends were numbered as indicated. Excessive bearing movements necessitated the lifting of the south end of the bridge and the NR pads were replaced by neoprene pads of the same length and width but with an overall thickness of 50.8 mm (2.0 in.) with four 3.18 mm (0.125 in.) steel shims. These bearings have a nominal hardness of 50 durometer.

Figure 2.2 Slaughter Creek Bridge in Elevation

Figure 2.3 Slaughter Creek Bridge in Plan

2.1.1.2 Valley Ridge Boulevard Bridge: The Valley Ridge Boulevard bridge is actually two separate structures, one carrying westbound and the other eastbound traffic (Figure 2.4). The bridges were opened for use in 1991 and are 140.2 m (460 ft.) in length. There are four spans per bridge which measure from East to West 36.6 m (120 ft), 35.4 m (116 ft.), 32.9 m (108 ft.) and 35.4 m (116 ft.). Each bridge is continuous for two spans with expansion joints located at the ends and approximately in the center of the bridge. The decks are supported by five type IV girders.

Figure 2.4 Photograph of Valley Ridge Boulevard Bridges

Figures 2.5 and 2.6 illustrate the bridge in plan and elevation. The bridge utilized round natural rubber bearings measuring 381 mm (15 in.) in diameter with a nominal height of 44.5 mm (1.75 in.) including two 1.6 mm (1/16 in.) steel shims. The bearings were nominally 60 durometer in hardness and were tapered from 39.7 mm (1 - 9/16 in.) to 49.4 mm (1 - 15/16 in). The girders and bearing locations were numbered as indicated in the figures. After several pads at the ends of the bridges had slipped, 12 of the 20 NR pads were replaced with neoprene pads that were designed to the same specifications as the NR bearings. It was expected that this would allow researchers to directly compare the performance of identically specified neoprene and NR pads. The replacement pattern is illustrated in Figure 2.7. The symbols at the bridge ends (WW, WE, EE, and EW) identify the bridge and the end, for example, WW signifies the Westbound lane, West end.

Figure 2.5 Valley Ridge Boulevard Bridge in Plan

Figure 2.6 Valley Ridge Boulevard in Elevation

Figure 2.7 NR and Neoprene Replacement Pattern at Valley Ridge Blvd.

2.1.2 Bridge Instrumentation: In order to determine the thermal expansion and contraction cycles of these bridges, and to quantify bearing pad movements, it was necessary to develop methods of instrumentation. The field study would span several years, thus, it was important to develop instruments which had the following characteristics:

- Be completely mechanical.
- Require minimal security and maintenance.
- Be easy to build and operate.
- Measure maximum girder and bearing movements over time.

After several trials, the following gage was developed to measure the thermal expansion and contraction of the girders (Figure 2.8). Gages were epoxied to the abutment and connected to the girder at the web, lower flange or upper flange. Figure 2.9 illustrates this connectivity in a field setting.

Figure 2.8 Diagram of Thermal Displacement Gage

Figure 2.9 Photograph Demonstrating Connectivity of Gage

Figure 2.10 demonstrates the functioning of the gage by illustrating a sequence of events. When the gage is installed, the sliding pointers on either side of the protruding fixed screw are pushed together until they are flush with the screw. The pointer positions are then recorded. As the bridge expands, the left pointer is pushed left by the screw which is fixed to the expanding girder. As contraction of the girder begins, contact with the left pointer ceases as the screw moves to the right. The left pointer now marks the maximum expansion of the girder. Contraction brings the screw into contact with the right pointer and further contraction pushes the right pointer to the right. As contraction gives way to expansion, the screw breaks contact with the right pointer and moves to the left. The right pointer now marks the point of maximum contraction.. After recording the maximum expansion and contraction points, the gage is reset, the reset positions are recorded, and the process begins again.

Figure 2.10 Sequence of Thermal Cycle of Gage

A total of twelve gages of this type were installed on the Valley Ridge bridge in June 1993. Six each were mounted on the east and westbound lanes of Valley Ridge Boulevard using a combination of web and flange gages on girders 1 and 5. Three gages were installed on the Slaughter Creek bridge in January 1992; web and flange gages were mounted on girder 6 at south end and a web gage was installed on girder 5 at the north end.

In order to measure bearing movement, a reference point was required. Initial reference points at the Slaughter Creek site were inscribed lines in the concrete abutment on both sides of the bearings. The lines were made by etching the concrete with the metal scribe. Measurements of bearing movement were recorded for the left and right sides. This worked well for months but the line gradually wore away and was difficult to distinguish from other grooves and pitmarks on the concrete surface.

Another system was devised that mitigated this problem. A straight line in black paint was spray-painted across the bottom of the girders approximately 250 mm (10 in.) out from the bearings (see Figure 2.11). Measurements were taken from this reference line to the right and left sides of the bearings. The initial measurements were reference values which were subtracted from subsequent measurements in order to determine the amount of bearing movement.

Figure 2.11 Reference Line on a Slaughter Creek Girder

Although this researcher was not involved in the instrumentation or the regular recording of data from the Valley Ridge bridge, several trips were made to this site and independent data were recorded. Bearing movements at the Valley Ridge site were determined by measuring from crosshair lines drawn on the underside of the girders to the closest edge of a round bearing. This was accomplished by placing a straight-edged ruler on the edge of the bearing flush with the girder and sweeping the ruler across the crosshair until the shortest distance was found. Accumulative movements were calculated as described above.

2.1.3 Bridge Monitoring: The Slaughter Creek bridge was closely monitored from January 1992 until November 1995. The movements of the girders due to thermal cycles were recorded on a weekly basis between January 1992 and December 1992. Bearing movements were recorded on a weekly basis between June 1992 and November 1992. In October 1992, a temperature cycle was recorded by taking measurements every 15 minutes over the course of a 24 hour period.

No measurements were recorded between December 1992 and June 1993 because it appeared that the bearings were no longer walking out. From June 1993 until November 1995, bearing and girder movements were recorded approximately every ten to twenty days.

The Valley Ridge bridge was monitored by TxDOT personnel approximately once a week from June 1993 until August 1994. Researchers from the University of Texas at Austin recorded measurements on three occasions; February 1994, January 1995, and August 1995.

2.1.4 Lifting Techniques: Both the Slaughter Creek and Valley Ridge bridges have been lifted several times in order to reset the bearings or to replace them. Two different methods of lifting have been employed. The Slaughter Creek bridge has been lifted by researchers at The University of Texas at Austin four times. The south end was first lifted in June 1992 and at the beginning of October 1992 in order to reset the NR pads. The same end was lifted in the end of October 1992 to replace the NR pads with neoprene pads. It was also lifted in April 1994 and the neoprene pads as well as the bearing seats and the undersides of the girders were cleaned with high pressure steam.

The lifting apparatus developed to raise the south end of the bridge had to support an end reaction at each girder of approximately 400 kN (90 k). The apparatus had to be constructed in the field without the aid of heavy machinery and had to be economical. The final design consisted of steel lifting sections which were manufactured in four pieces and erected at the bridge site. These lifting sections were placed between the upper flanges of consecutive girders (Figure 2.12). The lifting sections were raised by a series of 534 kN (60 ton) and 267 kN (30 ton) hydraulic rams which were connected to a load maintainer. The load maintainer simply controlled the amount of hydraulic fluid supplied to the different sized rams. This allowed the 534 kN (60 ton) ram to rise at the same rate as the 267 kN (30 ton) ram, thus avoiding excessive differential moments in the slab. Figure 2.13 illustrates the schematic for lifting the bridge. By lifting the entire bridge end, it was possible to raise it high enough to inspect and/or thoroughly clean all the bearings and bearing seats. It also reduced the time that the access road was closed to traffic.

Figure 2.12 Steel Lifting Section

Figure 2.13 Schematic of Lifting Apparatus

Although this researcher was not present for any of the bridge lifts that occurred at the Valley Ridge bridge, the method is documented to contrast the differences. These lifts were supervised by TxDOT personnel from the Dallas office. Hydraulic jacks were placed on either side of the girder that was to be lifted. The girder was lifted only high enough to reset the displaced NR bearing or to slip an old NR bearing out and replace it with a neoprene pad. Where

neoprene pads replaced NR pads, the bearing seats and the underside of the girders were chemically cleaned before the replacement neoprene pads was inserted. The same procedure was then repeated at the next girder.

2.1.5 Cleaning Methods: Two methods were mentioned above as methods of cleaning wax residues from bearings, bearing seats, and girders. Chemical removal and high pressure steam cleaning have been successful in removing wax residues. TxDOT personnel utilized the chemical solvent Trichloroethelene to remove wax residues from the Valley Ridge bridge. When the bridge was lifted, as described above, a cloth wrapped around a pole was soaked with this chemical and the bearings, bearing seats, and the underside of the girders were swabbed with the cloth. Workers applying the Trichloroethelene were required to use protective equipment to avoid skin contact and to avoid breathing the fumes.

The other cleaning method was high pressure steam cleaning which was performed at the Slaughter Creek site and was routinely used at the Ferguson Laboratory to remove wax residues from bearings and from the different surfaces utilized in the test apparatuses (Figure 2.14). Field cleaning of the Slaughter Creek site occurred when the bridge was lifted. A high pressure steam cleaning unit was transported to the site along with a portable generator to supply power to the unit. TxDOT provided a water tank truck which supplied the source of water for the steam unit. Water from the truck was gravity-fed to the steamer. With the bridge raised approximately 10 cm (4 in.), bearings were removed and cleaned. The bearing seats and girders were then cleaned until water did not readily bead on these surfaces (Figure 2.15). The bearings were dried and approximately one half hour was allotted to allow water on the concrete surfaces to evaporate. Bearings were then replaced, their positions noted, and the bridge was lowered.

Figure 2.14 Steam Cleaning Test Surfaces at the Ferguson Laboratory

**Figure 2.15 Steam Cleaning Abutment and Girder Surfaces at Slaughter
Creek**

2.2 Material Property Tests

Material property tests were conducted on field specimens. Tests were conducted to determine the hardness of the elastomers, the shear modulus of the reinforced bearings, and the slip coefficients or coefficients of friction of the pads. These tests were conducted at the Ferguson Laboratory. A description of the test apparatuses and methods as well as the results of these tests follows.

2.2.1 Hardness: Hardness is defined as the “reversible, elastic deformation produced by a specially-shaped indenter under a specified load” (8). A Durometer is the instrument used to perform this measurement. Values are measured in International Rubber Hardness Degrees (IRHD) or Shore “A” Durometer points. While elastomer hardness can indicate a shear modulus range for bearings, it cannot be used in engineering calculations (10).

A Durometer has an indenter protruding approximately 3 mm (1/8 in.) from an otherwise flat bottom surface. The indenter is attached to a spring which is connected to a dial gage. The resistance of the indenter on the elastomer surface is then translated into a hardness and this value is indicated on the dial gage. Measurements were taken by placing the indenter on the elastomer. The Durometer was pushed down until the bottom surface was flush with the bearing

surface and the indicated hardness value was recorded. Measurements were taken at several locations on the bearing surfaces and an average hardness value was calculated for that elastomer.

Durometer readings were recorded for the NR and neoprene bearings that were utilized at the Slaughter Creek and Valley Ridge bridges. The results are given in Table 2.1 and indicate that the measured Slaughter Creek bearings were very close to the nominal values while the NR and neoprene bearings from the Valley Ridge bridge were substantially higher than the nominal value. While the measured hardness values of the Valley Ridge bearings were higher than the nominal values, both the neoprene and the NR pads were similarly higher. The significance of both having similar hardness values is that a direct comparison can be made between the performance of these NR and neoprene pads.

Table 2.1 Comparison of Hardness Values from Two Sites

Hardness	Durometer Measurements - Shore "A" Hardness			
	Slaughter Creek		Valley Ridge	
	Natural Rubber	Neoprene	Natural Rubber	Neoprene
Nominal	70	50	60	60
Actual	68	49	68	66

2.2.2 Shear Modulus Tests: Shear modulus values are very important in the design of elastomeric bearings. Shear modulus tests were conducted on the Slaughter Creek and Valley Ridge NR and neoprene bearings in a test machine constructed at the Ferguson Laboratory. The test machine was constructed to replicate typical field conditions of bearings. The machine was capable of

duplicating the dead load and daily thermal cycle of any bridge girder. Figures 2.16 and 2.17 illustrate the components of this machine. Bearings were set in pairs between the platens as shown in Figure 2.17. The leveling mechanism and the double acting hydraulic rams prevented rotations in the X and Z Axes, respectively. The 5338 kN (600 ton) hydraulic ram applied the desired dead load (compressive force) to the bearings. The screw jacks exerted a horizontal force on the center platen, thus shearing the bearings. The screw jacks were programmed to translate a given distance in both directions in order to simulate the thermal cycle of a girder. Most tests included at least three complete cycles of shearing the specimens to predetermined levels of strain.

Load-displacement curves were recorded electronically and graphically. Electronic motion transducers measured the middle platen displacement while horizontal load was measured by two 222 kN (50 k) load cells which were fitted to the screw jacks. Voltage outputs were saved on a personal computer with data acquisition software. X-Y plotters graphically displayed the load-displacement curves as the bearings were being sheared. Figure 2.18 illustrates a typical load-displacement curve for a bearing. Shear modulus values were calculated by determining the slope of the straight line portion of the graph. A more in-depth discussion of this test machine is presented by Muscarella (10).

Figure 2.16 Test Machine for Full Size Bearings

Figure 2.17 Major Components of Test Machine

Figure 2.18 Typical Load Displacement Curve for a Full Size Bearing

Table 2.3 presents the shear modulus values of the natural rubber and neoprene bearings from the Slaughter Creek and Valley Ridge bridge sites.

Table 2.2 Shear Modulus Values of Field Bearings

Bridge Location	Shear Modulus MPa (psi)	
	Natural Rubber	Neoprene
Slaughter Creek	1.04 (150.2)	0.51 (74.5)
Valley Ridge	0.99 (144.0)	0.85 (123.2)

The results indicated that the shear modulus values of these full size bearings were probably less than the designers had anticipated. For example, according to Table 14.3.1 of the AASHTO Code which relates hardness to shear modulus (14), the expected shear modulus for the natural rubber pads from Slaughter Creek (70 Durometer) was between 1.43 - 2.14 MPa (200 - 300 psi). If an average of this expected value is used, the shear modulus has been overestimated by 66 percent.

2.2.3 Slip Tests: Slip studies on the NR bearings removed from the Slaughter Creek and Valley Ridge bridges were performed by Muscsarella (10) in order to determine the coefficient of friction (μ). Initial tests on these bearings were conducted with the bearings in field condition, that is, the bearings were not cleaned. Tests were conducted in the shearing apparatus under two different levels of compressive stress. A horizontal shear force H was applied and the force required to start the pads walking out was used to calculate $\mu = H/N$. These tests were conducted with the specimens on a Plexiglas surface, which provided a medium for the rapid deposit and accumulation of wax, and a concrete surface.

The test results on the specimens from the Slaughter Creek bridge (Table 2.3) demonstrate the effect wax accumulation on the bearing surface has on the coefficient of friction. Table 2.3 also shows the effect of compressive stress on μ . The results are expected as previous research (13) has demonstrated that an increase in compressive stress reduces the coefficient of friction.

Table 2.3 Friction Coefficients from Slip Tests

σ_c MPa (psi)	Plexiglas Surface		Concrete Surface
	Bearing With Wax	Clean Bearing	Clean Bearing
2.76 (400)	0.104	0.132	0.297
5.17 (750)	0.054	0.079	0.201

Similar tests conducted on the Valley Ridge bearings indicated that wax-saturated pads (the condition of the bearings upon receipt) tested on a smooth concrete surface had a coefficient of friction of 0.107. Additionally, tests on the wax-coated bearings indicated that slip would occur at levels of strain that were lower than the expected service conditions. When the wax was cleaned off the apparatus and the pads, the bearings performed as designed and exhibited no tendency to slip under service conditions.

CHAPTER THREE

Presentation and Discussion of Data

The data in this section was accumulated over the course of three years of field investigations. Bridge lifts delineated the investigations into distinctive phases. The south end of the Slaughter Creek bridge was lifted four times by researchers at The University of Texas at Austin and TxDOT raised the Valley Ridge Boulevard bridge once. A brief history of the investigations accompanies the data presentation.

3.1 Slaughter Creek Bridge

3.1.1 History: A few months after opening, significant movement of the tapered, 70 durometer bearings occurred at the north abutment of the bridge. One of the bearings had completely walked out so that there was no contact between the girder and the bearing pad. In October 1990, TxDOT lifted the bridge and the natural rubber bearings at the north end were reset in their original positions. Steel restraining devices were fabricated and bolted to the abutment to prevent the bearings from walking out. It was observed that the bearings had moved into contact with the restraining devices by the next morning. Steel restraints were also added to the piers to prevent these bearings from walking out.

In June 1991, movement of the bearings on the South end of the bridge was noticed. These bearings were left unrestrained so that their movement and behavior could be studied. Project 1304 was started in September 1991. The

previously discussed expansion/contraction gages were positioned on the north and south ends in January 1992. The gage marks were recorded to understand girder movement (5).

3.1.2 Bearing and Girder Movement

3.1.2.1 Phase One: June 25-October 2, 1992: In June 1992, the south end of the bridge was lifted by the methods discussed in Chapter Two. The natural rubber pads were brushed off and reset to their original positions. At this time reference marks were placed on the abutment to measure the bearing movements relative to the reset positions of the pads. The bridge was monitored on a weekly basis and thermal and bearing movements were recorded. The girder movement was predictable using hand calculations for the change in length due to thermal expansion/contraction. Figure 3.1 illustrates girder movement during this time period. The bearing movement was erratic. One bearing experienced

Figure 3.1 Girder 1 Movement During Phase One

virtually no movement at all (Figure 3.2) while another experienced almost unlimited movement (Figure 3.3). As the bearing movement was toward the abutment, its progress was halted when it came in contact with the abutment wall (Figure 3.4). The other bearings experienced movements between 25 - 50 mm (1 - 2 in.) (5).

Figure 3.1 Bearing Movement under Girder 4

Figure 3.3 Bearing Movement under Girder 5

Figure 3.4 Slaughter Creek Bearing Contacting Abutment Wall

3.1.2.2 Phase Two - October 2-October 23, 1992: On October 2, 1992, the south end was lifted again and the NR pads were reset. Within the span of three weeks, some of the bearings had moved almost 50 mm (2 in.) (5).

3.1.2.3 Phase Three: October 23, 1992-April 22, 1994: On October 23, 1992, the bridge was lifted and the natural rubber pads were replaced by neoprene bearings. These 50 durometer neoprene bearings had the same length and width dimensions as those of the NR pads but had an overall thickness of 50.8 mm (2.0 in.) with four 3.18 mm (0.125 in.) steel shims. No bearing movement occurred in the weeks following this lift. At this time, it was not possible to declare that

neoprene bearings were the solution to the walking out phenomena due to the design differences between the natural rubber and neoprene bearings.

A site visit in March 1993 found no indication of bearing movement. Shortly afterward, TxDOT personnel noticed that a NR bearing on the pier closest to the south end of the bridge had almost completely walked out. This bearing was literally hanging by an edge. The other bearings were not exhibiting movement. This bearing was reset and steel collars were placed around all the bearings on both piers to prevent pads from walking out. It was also noted at this time that the expansion joint at the north end of the bridge was completely closed. This in effect forced all the movement to the south end.

In June 1993, it was observed that the neoprene pads had begun walking out. The movement recorded by the expansion gages was measured every seven to fourteen days. Figures 3.5 and 3.6 illustrate the weekly and seasonal thermal cycles experienced by the girders as measured by the web and flange gages.

Figure 3.5 Slaughter Creek Girder 1 Thermal Cycle, Web Gage

Figure 3.6 Slaughter Creek Girder 1 Thermal Cycle, Flange Gage

The top and bottom marks indicate the relative maxima expansion and contraction experienced during a particular time frame. The interior marks indicate the pin location.

It can be shown that the daily and seasonal bridge movement cycles due to temperature can be calculated utilizing the formula:

$$\Delta L = \alpha L \Delta T \quad (\text{Eq. 3.1})$$

where:

- ΔL = Change in length of the bridge
- α = Coefficient of thermal expansion
- L = Applicable length of the bridge
- ΔT = Change in effective bridge temperature

For the Slaughter Creek bridge, the applicable length of the bridge was 92.7 m (304 ft.). The entire bridge length was utilized because expansion could only occur at the south end, as described above. ΔL was calculated to be 3.35 cm (1.32 in.). Both web and flange gages recorded 3.05 cm (1.2 in.) as the maximum girder movements over the course of a ten month period.

Bi-weekly measurements of bearing pad movement were also recorded over a ten month period. During this time, every bearing pad experienced some movement, as illustrated in Figure 3.7. Bearing displacement values are an average of recorded measurements taken from the right and left sides of the bearing pads. Figure 3.7 also shows that individual bearing movements varied from as much as 45 mm (1.8 in.) to as little as 5 mm (0.2 in.). It was evident that the neoprene pads were also exhibiting a tendency to walk out.

Figure 3.7 Graph of Slaughter Creek Bearings Movements - Phase Three

3.1.2.4 Phase Four: April 22, 1994-November 15, 1995: On April 22, 1994, the south end of the bridge was lifted once again. This time, the neoprene pads were removed and cleaned with pressurized steam. Bearing seats and the girders were also cleaned. The bearings were reset and their positions noted. Measurements taken at the Slaughter Creek bridge since this lift show no significant bearing pad movement. Girder movement remained predictable as described above. As of November 15, 1995, the maximum accumulated movement of any particular bearing pad at the south end of this bridge has been less than 4 mm (0.16 in.) as indicated by Figure 3.8.

Figure 3.8 Slaughter Creek Bearing Movements Since April 1994

Figure 3.9 illustrates the movement of the bearing under girder 5 at the Slaughter Creek bridge after the three most recent bridge lifts. Each line depicts a successive lift. Data points are displacement versus the number of days post-reset. The natural rubber bearings that had the wax coating on the contact surfaces demonstrated immediate movement and the neoprene bearings placed on the uncleaned surfaces indicated a tendency to move over time. The cleaned neoprene bearings on the cleaned contact surfaces have performed as designed; the pads have accommodated girder movements by shearing and have exhibited neither slip nor walking out.

Figure 3.9 Bearing Movement under Girder 5 For Three Bridge Lifts

3.2 Valley Ridge Boulevard Bridge

3.2.1 History: In the summer of 1992, it was observed that some of the bearings were walking out from the abutments of the Valley Ridge bridge (Figure 3.10) and one bearing had completely walked out from between the seat and the girder. In September 1992, the end of the bridge where the bearing had come out was lifted and the pads were reset to their original positions. In the end of September, monitoring of the bearing movements began. As was the case with the Slaughter Creek bridge, it was observed that bearing movement was erratic as some pads were walking out and others not moving at all.

Figure 3.10 Valley Ridge Boulevard Bridge Bearing Walking Out

In June 1993, researchers at Texas and TxDOT officials transformed the Valley Ridge bridge into a full scale test apparatus. Neoprene bearings were ordered to the same specifications as the natural rubber pads. Twelve of the twenty NR pads were replaced as described and illustrated in Chapter Two (see Figure 2.7) and the remaining NR pads were reset to their original positions. Utilizing identically specified NR and neoprene pads at this bridge was an attempt to isolate the causes of walking out.

The positions of the bearings were noted and crosshair reference marks were placed on the underside of the girders. Thermal expansion gages identical to those employed at the Slaughter Creek bridge were also positioned at this site. Regular monitoring of bearing girder movements occurred between June 1993 and August 1995.

3.2.2 Bearing and Girder Movement: After several months of small movements, some of the natural rubber bearings began to walk out again. By April 1994, one

of the NR bearings had walked out over 100 mm (4 in.) and another had walked out nearly 180 mm (7 in.). In the end of April, TxDOT replaced these two NR bearings with neoprene pads. During this time, the neoprene pads showed no evidence of walking out.

Continued monitoring of these movements indicate that the neoprene pads with the cleaned surfaces have moved a total of 3 - 6 mm (0.125 - 0.25 in.). Of the NR pads that remain, some have only moved 13 mm (0.5 in.) while others have moved over 50 mm (2 in.). It is clear, however, that the NR pads have demonstrated a proclivity to walk out while the neoprene pads have performed as designed. TxDOT intends to replace the remaining NR pads with neoprene bearings in the Spring of 1996.

Girder movements were recorded during this time and Figure 3.11 illustrates typical girder movement. Maximum girder movement for the yearly thermal cycle was approximately 2.0 cm (0.79 in.). Utilizing equation 3.1, the calculated change in length, ΔL , for a typical Valley Ridge span (L equal to 70.1 m - 230 ft.) was 2.6 cm (1.02 in.). The applicable bridge length was taken to be half the length of the bridge because expansion could only occur at the center joint. The expansion joints at the ends of these bridges were completely clogged with debris thus preventing movement at the ends.

Figure 3.11 Girder Movement at Valley Ridge Boulevard Bridge.

CHAPTER FOUR

Observations

Since the inception of Project 1304, the performance of elastomeric bridge bearings under a variety of different conditions has been studied. Analytical studies and laboratory experiments conducted in conjunction with the field studies have contributed to the understanding of elastomeric bearing behavior. This chapter discusses the observations culled from the field studies.

4.1 Natural Rubber and Neoprene Bearings

Field studies at the Slaughter Creek bridge were conducted under three distinct bearing pad conditions; natural rubber, neoprene on waxy surfaces, and neoprene on clean surfaces. The results of these investigations, presented in Chapter Three, demonstrated that: NR pads show a proclivity to walk out; neoprene pads will walk out if the contact surfaces contain wax; neoprene pads will not walk out if these contact surfaces are wax-free. It should also be noted that neoprene pads with a wax additive may exhibit a tendency to walk out if the wax blooms to the bearing surface. This study would have been improved had the replacement neoprene bearings been of the same design as the NR pads. The significant differences in hardness between the NR and neoprene bearings (70 versus 50 durometer) and shear modulus [1.04 MPa (150.2 psi) versus 0.51 MPa (74.5 psi)] indicated that the neoprene bearings would require larger forces to demonstrate similar movements. This relationship is presented in the next section.

The Valley Ridge Boulevard field studies presented a unique opportunity to study the differences between NR and neoprene bearing pads. As previously discussed, 12 of the 20 bridge-end NR bearings were replaced with neoprene pads which were designed and ordered to the exact specifications as the NR pads. A direct comparison of NR and neoprene pads was possible because both types of pads exhibited similar material properties. The locations where the 12 neoprene pads were inserted were cleaned of wax residues while the NR pads were simply reset to their original positions. The results were a direct indication that walking out is not a function of bearing taper but rather is directly related to NR bearings.

4.2 Bearing Movement

The movement of the NR pads at Slaughter Creek indicate that these bearings were prone to walk out. Bearing 5, in particular, exhibited virtually uncontrolled movement. It is possible to calculate the coefficient of friction of this pad by utilizing the following relationships:

$$G = H \times h_{rt} / A \times \Delta_s \quad (\text{Eq. 4.1})$$

where:

- G = Shear modulus
- H = Horizontal force
- h_{rt} = Total elastomer thickness
- A = Gross plan area
- Δ_s = Shear deformation in one direction

and: $\mu = H/N$ (Eq. 4.2)

where: $\mu =$ Coefficient of friction
 $N =$ Normal force on the bearing

Using the measured G of 1.04 MPa (150.2 psi), A as 0.127 m² (198 in²), and h_r as 38.1 mm (1.5 in.) and obtaining Δ_s from the girder movement gages, H may be calculated. Given N as 400 kN (90 k), μ may be calculated. Typical girder movement at Slaughter Creek is approximately 1.0 cm (0.394 in.). H is calculated to be 34.75 kN (7.81 k). The coefficient of friction is thus determined to be 0.0867. This value compares favorably with the values of μ reported by Muscarella in Table 2.3. The horizontal force due to the thermal cycle was sufficient to overcome the friction forces holding the pads in place, thus the bearings could walk out virtually anytime.

With regard to the neoprene pads on the uncleaned surfaces, there is some indication that significant movements occur when there are large ambient temperature swings and thus large girder movements. Graphs illustrating bearing movement by date (see Figure 3.7) indicate greatest movements occur in October, November, February, and March. In Texas, these typically are months that have dramatic temperature shifts of 27.8° C (50° F) to 33.3° C(60° F). It is possible that warm temperatures makes the wax more viscous, thus reducing the coefficient of friction. When combined with large temperature shifts, the bearings will tend to walk out.

If wax is present on the contact surfaces and μ (from Table 2.3) is assumed to be 0.1, the expected girder movement (Δ_s), calculated using equations

4.1 and 4.2, is 23.2 mm (0.92 in.). This translates to a temperature shift of 23.2° C (41.8° F) by utilizing Equation 3.1 (thermal movement), which as demonstrated above is certainly possible.

The bearing movement histories recorded at the two sites indicate that some of the neoprene pads on clean surfaces did exhibit some small movements, typically between 2 to 4 mm (0.08 - 0.16 in.) of cumulative movement. Observations from the field and the laboratory suggest that the bearings undergo a settling period during which time they may exhibit small movements. As these movements are extremely small and not one of these bearings has walked out, it is not viewed as a problem.

4.3 Cleaning Suggestions

Two methods were utilized to clean the bearing surfaces, steam cleaning and chemical cleaning. Both methods were apparently successful because the neoprene pads on cleaned surfaces have not exhibited any problems relating to walking out. It was noted during the Slaughter Creek cleaning that it was difficult to clean the bearing seats and the undersides of the girders. It was extremely difficult to reach all the contact surfaces because of the limited space created by lifting the girders combined with the use of a straight nozzle on the steam-cleaning wand. It is suggested that the wand be fitted with a nozzle that is bent at a 90° angle in order to clean the entire surface more easily.

4.4 Bearing Restraints

Several methods of preventing bearing slip and walking out have been previously mentioned. The results of the nationwide survey indicated that 27 states “sometimes or frequently” physically connect the bridge and the bearing (3). Methods of connection include inserting a dowel through the pad into the bearing seat or girder, epoxying the pad to the seat, and vulcanizing the pad to a steel shim which is then bolted to the seat.

The state of Texas primarily relies on friction to hold bearings in place. Where bearings are slipping or have walked out, TxDOT can go to the site, raise the bridge end and reset the pads, as has been done at Slaughter Creek, Valley Ridge, and elsewhere. This method is disruptive to traffic, puts unintended stresses on the bridge, is very costly, and is only a temporary fix.

Another method of restraint is the steel collar placed around the bearing and bolted to the abutment or pier cap in order to prevent the bearing from moving. This method has also been employed at Slaughter Creek. It was noted that by the next morning, some of the bearings had come in contact with these restraining devices. Figure 4.1 illustrates a typical steel collar around a bearing. In several cases, the shear and bending forces that these pads are subjected to when they contact the steel restraints have resulted in severe damage to these bearings. In extreme cases, the pads have to be replaced which again involves lifting the bridge end.

Figure 4.1 Typical Steel Collar Encompassing Bearing to Prevent Walking

4.5 Expansion Joints

At several field sites, the expansion joints were full of debris. In some cases, the accumulation of dirt, pebbles, etc. formed a dense material that prevented the bridge from expanding as designed. In such cases, the girders may experience more rotation than expected. This could cause flat bearings to walk out if the other conditions (waxy surfaces) are present. In other cases, especially on bridges that were inclined, it was noted that the expansion joints on the low sides of these bridges were closed (not capable of handling bridge expansion). If this condition forces all the expansion to one end of the bridge, the bearings may be subjected to movements that cannot be accommodated, again causing the bearings to walk out.

CHAPTER FIVE **Summary, Conclusions and Recommendations**

5.1 Summary

Field studies were conducted at two Texas bridge sites over the course of three and a half years in order to document the movement of bearing pads and to understand, explain, and prevent elastomeric bearing pads from walking out. Significant bearing movements were recorded at both bridge sites. Bearing movement was erratic as some bearings exhibited movements of almost 180 mm (7 in.) while others demonstrated virtually no movement at all. It was demonstrated that girder movements were predictable by utilizing hand calculations. The seasonal bridge movements due to changes in temperature were accurately predicted using this method.

5.2 Conclusions

The field studies demonstrate that natural rubber bearings that are not vulcanized to sole plates will exhibit a tendency to walk out. It is also important to note that the threshold strain (a function of the degree of taper and the amount of wax on the contact surfaces) must be attained in order for the bearings to walk out. Wax additives in these pads will eventually bloom to the surface thus reducing the coefficient of friction. If the shear forces are such to overcome the force of friction, the bearing pads will walk out. Inserting neoprene pads in and of itself is not a suitable solution as the Slaughter Creek study indicated. Installing neoprene pads on wax-free surfaces has succeeded in precluding

walking out. It is also important that bridge expansion joints remain free of debris so that they may accommodate bridge movements as designed.

Cleaning the concrete contact surfaces and the bearings with high-pressure steam or chemicals appears to remove wax residues. If the steam cleaning method is utilized, a wand with an angled nozzle should be used in order to adequately clean the entire contact surface. Steel collars around the bearings anchored to the abutment or pier cap should be viewed as a temporary fix to the problem of bearing movement. Damage to the bearings may result from the pads pressing against the restraints which would necessitate replacement.

5.3 Recommendations

The following recommendations are based on the body of research performed at The University of Texas at Austin.

- New bridge structures: Neoprene bearings should be installed at all new bridge sites. When ordering bearings from a manufacturer, it should be specified that there be no wax additives in these neoprene pads. The TxDOT prohibition of natural rubber bearing pads should continue until wax additives are no longer used in the manufacturing process.
- Structures with pads exhibiting slip: If the problem is not structural, the bridge should be lifted and the contact surfaces thoroughly cleaned. If the existing pads are NR they should be replaced with

neoprene pads as described above. If the existing pads are neoprene, they should be cleaned before repositioning.

- Cleaning methods: Although both cleaning methods (steam and chemical) were successful, steam cleaning is preferable. It is easier to clean the uneven concrete surfaces with high-pressure steam than with a cloth soaked with chemicals. It is also perceived that the public perception of steam cleaning would be more favorable than chemical cleaning.

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