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16. Abstract <p><i>This report deals with Phase One of TxDOT Project 1304 (Behavior of Elastomeric Bearings). The overall objectives of that project are (1) to recommend procedures for designing elastomeric bearings used by TxDOT and (2) to recommend practical guidelines and procedures for inspecting existing and future elastomeric bearings. The overall objectives of Phase One of that project are: to verify field reports; to conduct field surveys; and to document bearing and girder movements.</i></p> <p><i>To accomplish the Phase One objectives, the following tasks were carried out: a comprehensive literature review was conducted; field reports were verified by site visits (Slaughter Creek, Beaumont, Paris, and Alanreed) and by coordination with the BRINSAP database; two bridges were selected for field instrumentation and study (Slaughter Creek and Alanreed) with emphasis on bearing and girder movement; and the BRINSAP database was used to identify bridges that might have bearing problems.</i></p> <p><i>The results of the field study can be summarized as follows:</i></p> <ul style="list-style-type: none"> <i>-- Two bridges were instrumented and monitored.</i> <i>-- Bearing and girder movement was monitored on both bridges. The effect of resetting the original natural rubber bearings at the Slaughter Creek bridge was compared with the effect of replacing the rubber bearing with a neoprene bearing.</i> <i>-- Girder movement was measured up to 3/8 inch (1 cm) in contraction and expansion, due to temperature changes; both daily and seasonal variations were recorded. It was shown that these movements were easily predicted with simple engineering models.</i> <i>-- After the various resetting and replacement operations, the bearing movement measured at Slaughter Creek was inconsistent and not reproducible. Movement was found to be zero at one time and then unlimited at another time, with no apparent change in loading conditions. However, when it did occur, bearing movement was immediate.</i> <i>-- Resetting with natural rubber bearings was ineffective. However, when the natural rubber was replaced with neoprene bearings, bearing movement stopped.</i> <p><i>The principal conclusions were:</i></p> <ul style="list-style-type: none"> <i>-- Bearing movement is primarily driven by girder thermal movement.</i> <i>-- Girder thermal movement consistently agrees with simple calculations.</i> <i>-- Bearing movement is inconsistent, not stopped by resetting, but stopped by replacement with neoprene.</i> <i>-- Correctly designed neoprene bearings are not moving and natural rubber bearings are moving under the same loading conditions.</i> 					
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**ELASTOMERIC BEARINGS:
BACKGROUND INFORMATION AND FIELD STUDY**

by

B. A. English, R. E. Klingner, and J. A. Yura

Research Report No. 1304-1

**Research Project 3-5-92/4-1304
“ELASTOMERIC BEARINGS”**

conducted for the

Texas Department of Transportation

in cooperation with the
**U.S. Department of Transportation
Federal Highway Administration**

by the

**CENTER FOR TRANSPORTATION RESEARCH
BUREAU OF ENGINEERING RESEARCH
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IMPLEMENTATION

The majority of bearing movement problems have involved natural rubber bearings. Thus far, no clear relationship has been established between bridge characteristics and the likelihood of bearing movement. As a result, it is not now possible to specify those bridge characteristics which would be associated with satisfactory performance of natural rubber bearings.

Therefore, because it is impossible to predict which bridges will experience no problems with movement of natural rubber bearings, and because practically no movement problems have been experienced with neoprene bearings, the most logical recommendation at this time seems to be a continuation of the current TxDOT prohibition against the use of natural rubber bridge bearings. Laboratory tests conducted as part of Phase Two will be able to determine whether the problem is with the material of the bearings or with the design of the bearings.

Prepared in cooperation with the Texas Department of Transportation and the U.S. Department of Transportation, Federal Highway Administration.

The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official view or policies of the Federal Highway Administration or the Texas Department of Transportation. This report does not constitute a standard, specification, or regulation.

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BIDDING, OR PERMIT PURPOSES

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TABLE OF CONTENTS

Page

CHAPTER 1 - INTRODUCTION	1
1.1 General	1
1.2 Recent Changes to AASHTO Design Provisions	1
1.3 Significance of Changes to AASHTO Design Provisions	1
CHAPTER 2 - SCOPE AND OBJECTIVES	5
2.1 Overview	5
2.2 Scope and Objectives	5
2.2.1 Field Surveys	6
2.2.2 Tests of Basic Behavior	6
2.2.3 Engineering Models	6
2.2.4 Procedures and Guidelines	6
2.3 Scope and Objectives of this Report: Phase One	6
CHAPTER 3 - BACKGROUND	9
3.1 General	9
3.2 Case Studies of Bearing Performance	9
3.2.1 Performance of Neoprene	9
3.2.2 Performance of Natural Rubber	10
3.3 Design Considerations for Elastomeric Bearings	11
3.4 Failure Modes of Elastomeric Bearings	12
3.4.1 Fatigue	12
3.4.2 Stability	12
3.4.3 Delamination/Separation of the Elastomer from the Reinforcement	12
3.4.4 Yield/Rupture of the Reinforcement	12
3.4.5 Serviceability	12
3.5 Bearing Material and Design Specifications	13
3.6 Bearing Friction and Slip	14
3.7 Bridge Movements	14
3.7.1 Changes in Ambient Temperature	14
3.7.2 Shrinkage and Creep of Concrete	15
CHAPTER 4 - PRELIMINARY FIELD INVESTIGATION	17
4.1 General	17
4.2 Questionnaire	17
4.3 Site Visits	17
4.4 Investigation of Slaughter Creek Bridge	19
4.4.1 Location of Slaughter Creek Bridge	19
4.4.2 History of Slaughter Creek Bridge	19
4.5 Investigation of Beaumont Bridge	20

4.5.1	Location of Beaumont Bridge.	20
4.5.2	History of Beaumont Bridge.	20
4.6	Investigation of Paris Bridge	21
4.6.1	Location of Paris Bridge.	21
4.6.2	History of Paris Bridge.	21
4.6.3	Pertinent Information on Paris Bridge.	22
4.7	Investigation of Alanreed Bridge	22
4.7.1	Location of Alanreed Bridge.	22
4.7.2	History of Alanreed Bridge.	22
4.7.3	Pertinent Information on Alanreed Bridge.	23
CHAPTER 5 - IN-DEPTH FIELD INVESTIGATION		25
5.1	General	25
5.2	Thermal Displacement Gages	25
5.2.1	Instrumentation Characteristics	25
5.2.2	Instrumentation Materials	25
5.3	Instrumentation of Slaughter Creek Bridge	27
5.4	Instrumentation of Alanreed Bridge	30
5.5	Results of In-Depth Field Study	30
5.5.1	Slaughter Creek Results	30
5.5.2	Alanreed Results	35
CHAPTER 6 - USE OF BRINSAP TO IDENTIFY BRIDGES WITH POSSIBLE BEARING PROBLEMS		37
6.1	General	37
6.2	Components of the Bridge Search	37
6.2.1	Preliminary Bridge List	37
6.2.2	Bridge Characteristics	37
6.2.3	Item #59	38
6.3	BRINSAP Search Procedure and Results	38
6.3.1	Bridge Characteristics (Criteria)	38
6.3.2	Item #59	38
6.3.3	Refinement of Search Criteria	38
6.4	Summary of BRINSAP Study	39
CHAPTER 7 - SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS		41
7.1	Summary	41
7.2	Conclusions	42
7.3	Recommendations	42
APPENDIX A		43
APPENDIX B		63
APPENDIX C		81
REFERENCES		89

LIST OF FIGURES

	Page
Figure 1.1	Current AASHTO rotation provision 2
Figure 1.2	Implications of current AASHTO rotation provisions 2
Figure 3.1	Bearing movements 9
Figure 3.2	Typical bearings 9
Figure 4.1	Plan and elevation of Slaughter Creek Bridge 19
Figure 4.2	Profile of Beaumont Bridge (elements E and F) 20
Figure 4.3	Profile of Paris Bridge 21
Figure 4.4	Plan and elevation of Alanreed Bridge 22
Figure 4.5	Appearance of gaps below and above bearing at north end of Girder #6 24
Figure 5.1	Thermal displacement gage 26
Figure 5.2	Location of gages on girder 26
Figure 5.3	Sequence of reading pin position 27
Figure 5.4	Wooden lifting section 27
Figure 5.5	Steel lifting section 28
Figure 5.6	Schematic of lifting apparatus 28
Figure 5.7	Steel section loaded by rams 29
Figure 5.8	Elevation of steel section spanning between girders 29
Figure 5.9	Position of thermal displacement gages 30
Figure 5.10	Girder movement at Slaughter Creek 31
Figure 5.11	Daily temperature movement at Slaughter Creek 32
Figure 5.12	Daily rotation at Slaughter Creek 32
Figure 5.13	Zero bearing movement at Slaughter Creek 33
Figure 5.14	Unlimited bearing movement at Slaughter Creek 34
Figure 5.15	Inconsistent bearing movement at Slaughter Creek 35
Figure 5.16	Typical girder movement at Alanreed 35
Figure 5.17	Typical bearing movement at Alanreed 36
Figure 6.1	Search components 37
Figure 6.2	Item #59 (superstructure) 38

LIST OF TABLES

Tables	Pages
Table 3.1	10
Table 3.2	11
Table 4.1	18
Table 6.1	42

SUMMARY

This report deals with Phase One of TxDOT Project 1304 (Behavior of Elastomeric Bearings). The overall objectives of that project are: to recommend procedures for designing elastomeric bearings used by TxDOT; to recommend practical guidelines and procedures for inspecting existing and future elastomeric bearings. The overall objectives of Phase One of that project are: to verify field reports; to conduct field surveys; and to document bearing and girder movements.

To accomplish the Phase One objectives, the following tasks were carried out: a comprehensive literature review was conducted; field reports were verified by site visits (Slaughter Creek, Beaumont, Paris, and Alanreed) and by coordination with the BRINSAP database; two bridges were selected for field instrumentation and study (Slaughter Creek and Alanreed) with emphasis on bearing and girder movement; and the BRINSAP database was used to identify bridges that might have bearing problems.

The results of the field study can be summarized as follows:

- Two bridges were instrumented and monitored.
- Bearing and girder movement was monitored on both bridges. The effect of resetting the original natural rubber bearings at the Slaughter Creek bridge was compared with the effect of replacing the rubber bearing with a neoprene bearing.
- Girder movement was measured up to 3/8 inch (9.5 mm) in contraction and expansion, due to temperature changes. Both daily and seasonal variations were recorded. It was shown that these movements were easily predicted with simple engineering models.
- After the various resetting and replacement operations the bearing movement measured at Slaughter Creek was inconsistent and not reproducible. Movement was found to be zero at one time and then unlimited at another time, with no apparent change in loading conditions. However, when it did occur, bearing movement was immediate.
- Resetting the natural rubber bearings was ineffective. However, when the natural rubber was replaced with neoprene bearings, bearing movement stopped.

The principal conclusions were:

- Bearing movement is primarily driven by girder thermal movement.
- Girder thermal movement consistently agrees with simple calculations.
- Bearing movement is inconsistent, not stopped by resetting, but stopped by replacement with neoprene.
- Correctly designed neoprene bearings are not moving and natural rubber bearings are moving under the same loading conditions.

CHAPTER 1 INTRODUCTION

1.1 General

Elastomeric bridge bearings are frequently used in bridge construction to accommodate bridge superstructure movements. These bearings are normally made of vulcanized blocks of elastomer internally reinforced with steel plates. They are designed to function under a wide range of compressive and shear forces, require no maintenance, and are corrosion and ozone resistant. They are easy to install, and are economically competitive with alternative bearing systems. This type of bearing was introduced over 30 years ago in Great Britain; the first known use in the United States was on a bridge in Victoria, Texas.

Elastomeric bearings have also been used in many other applications, including:

- Column to footing isolation
- Isolation of long-span, cast-in-place and precast concrete beams
- Isolation of "floating" roofs
- Acoustical insulation between floors
- Sound and vibration isolation of laboratories and testing facilities

Recently, elastomeric bearings have also been used for base isolation systems intended to protect buildings and equipment from seismic forces.

1.2 Recent Changes to AASHTO Design Provisions

The original elastomeric bearing specification in the US was promulgated in 1961 by the American Association of State Highway and Transportation Officials (AASHTO) [1], based on experimental research [2] performed on unreinforced elastomeric bearings. For 25 years this specification was the governing authority, with only minor changes. In 1981, NCHRP Project 10-20 was undertaken at the University of Washington, with the intent of updating the AASHTO specification. The initial phase of that project concentrated on evaluating then-current theoretical and experimental design specifications. That report concluded that AASHTO provisions differed from those of other codes. Based on that conclusion, in 1982, NCHRP Report No. 248 [3] recommended changes to the AASHTO Specification, which were adopted as the interim 1985 AASHTO Specification [4].

1.3 Significance of Changes to AASHTO Design Provisions

The following changes were adopted into the 1985 AASHTO Specifications [4]:

- 1: Reinforced bearings are 80% stiffer in shear than unreinforced bearings

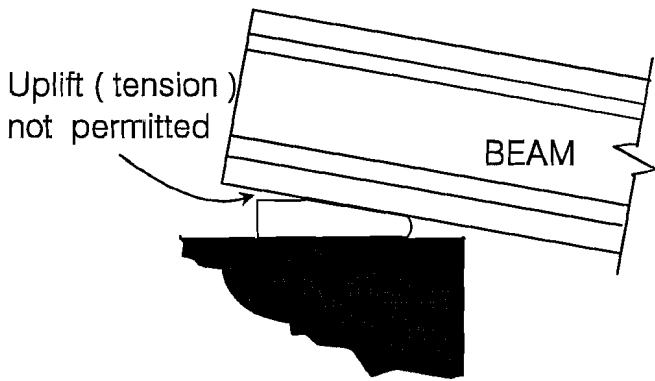


Figure 1.1 Current AASHTO rotation provision

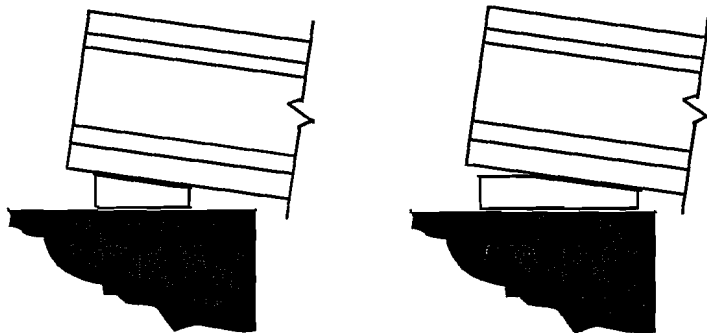
- 2: Maximum permissible transverse and longitudinal end rotation are limited by the compressive strain in the bearing
- 3: Alternate design procedures may be used

The effect of the first change depends on the stress-strain relationship used by the engineer for design. If the stress-strain curve is similar to the 1985 plain bearing relationship, then no change occurs in plain bearing thickness; reinforced bearings would be about

50% thinner. The opposite would be true if the old design curve was similar to the current reinforced bearing stress-strain curves.

The purpose of the second provision is supposedly to prevent uplift at the edge of the bearing (Fig. 1.1) so that tensile stresses cannot develop in the bearing. According to the Commentary to the 1985 AASHTO Specification [4], tensile stresses are critical to bearing fatigue resistance. However, NCHRP Report 248 [3] states (p.37) that there is questionable evidence to support this conclusion. Since the bearings are not fixed to any portion of the structure, it is not certain that tensile stresses are developed in the bearing should liftoff occur. In addition, the economic implications of this provision do not seem reasonable. If an 8- x 12-inch (203.2 mm x 304.8 mm) bearing, 1/2 inch (12.7 mm) thick with a hardness of 50, satisfies all provisions for a given end reaction, then increasing the bearing size to 12- x 12-inch (304.8 mm x 304.8 mm) would result in a violation of the rotation requirements; and the bearing thickness would have to be increased to 1.2 inches (30.5 mm). This does not seem reasonable. A 12- x 12- x 1/2-inch (304.8mm x 304.8 mm x 12.5 mm) bearing should not be less desirable than a 8- x 12- x 1/2-inch (203.2 mm x 304.8 mm x 12.5 mm) bearing (Fig.1.2).

Current AASHTO provisions require that the end rotations in the transverse and longitudinal directions be added. In the last two NCHRP 10-20 Reports [5,6], the rotation provision has been changed. In Report No. 298 [5], a new alternative design method was introduced, "Method B," which considers only rotation about the transverse axis (rotation about the longitudinal axis is to be avoided).



SMALL BEARING OK LARGE BEARING NG

Figure 1.2 Implications of current AASHTO rotation provisions

"Method A" of that report is the same as the current AASHTO Specification. In Report No. 325 [6], the rotation requirement in Method A is changed so that the rotation provision in each direction is checked separately, not added. These changes have not been supported by experimental evidence.

In a summary of their NCHRP study [7], Roeder and Stanton indicate that bearing size and cost can be significantly reduced by following their Method B approach which requires verification of the bearing's properties.

Their comparisons, however, are only between Methods A and B. Comparisons with designs of AASHTO prior to 1985 show that bearing thicknesses are substantially increased, thus increasing cost.

The implication of the current code is that early designs are inadequate, and that bearings should be replaced. Strict compliance with the revised specifications will be expensive. Therefore, it has been recommended that additional research be conducted to determine whether these changes are warranted. Also, one important element in the design of elastomeric bearings is movement of the bridge. These movements can be very complex, due to the interaction of camber, temperature changes, grade, and substructure flexibility. There is reason to believe that these movements are being underestimated in some cases. There is a need to measure and monitor the movement of selected prestressed concrete beam units in order to realistically determine the design requirements for elastomeric bearings.

CHAPTER 2

SCOPE AND OBJECTIVES

2.1 Overview

The changes discussed in the previous section have caused concern among many designers, because bearing designs that have been used successfully in the past are no longer acceptable according to these new specifications. Likewise, bearings that are currently in place will have to be modified to conform to the new specifications, causing additional expense. As a result of these concerns, a need for further research was perceived. Reports produced by NCHRP Research Project 10-20 [3,5,6] recommend that a field survey of existing bearings be performed to determine their actual behavior. In response to this recommendation and to questions of their own, regarding "walking out" of the elastomeric bearings, the Texas Department of Transportation (TxDOT) started Project 1304 (Behavior of Elastomeric Bearings) in the Fall of 1991.

2.2 Scope and Objectives

The scope of TxDOT Project 1304 (Behavior of Elastomeric Bearings) is to determine the actual behavior of elastomeric bearings, with the following objectives:

1. to recommend procedures for designing elastomeric bearings used by TxDOT
2. to recommend practical guidelines and procedures for inspecting existing and future elastomeric bearings.

Specifically, Project 1304 will attempt the following:

- To determine the condition of existing bearings already in place
- To determine the effects of end rotations about the longitudinal and transverse axes on bearing serviceability and strength
- To determine the actual movements of the bearings by measuring existing bearings under some prestressed concrete bridge beams

According to the original proposal submitted for Project 1304 [8], these objectives were to be accomplished in four phases:

Phase 1: Conduct field surveys

Phase 2: Conduct tests of basic bearing behavior

Phase 3: Develop engineering models for bearing behavior

Phase 4: Develop practical design procedures and inspection guidelines

2.2.1 Field Surveys: Field surveys will be carried out on several bridges in the Central Texas area by means of a questionnaire sent to all TxDOT districts. This questionnaire will attempt to ascertain a list of all bridges which had experienced or were experiencing bearing problems. At the start of the project, a preliminary field study will be conducted on two bridges. The focus of the preliminary field study will be to establish whether the bearings have problems, and to catalog and quantify the movements of those bearings. Based upon the data that will be obtained from those bridges, an in-depth survey of bridges in Texas will be conducted using BRINSAP (Bridge Inventory, Inspection, and Appraisal Program). The results obtained from the field studies will be used as input for the experimental and analytical phases of the study.

2.2.2 Tests of Basic Behavior: Using various loading histories actually experienced in the field, laboratory tests will be conducted on bearings to develop engineering models which will provide a realistic means of estimating the behavior of elastomeric bearings. Laboratory tests will include static and fatigue tests, and the test setups will allow the elastomeric bearing to be subjected to axial loads, shear loads, and multi-directional rotations. The load histories to which these bearings are subjected will be the actual movements determined in Phase One, and also histories used in other research. Additional tests will be run on tapered bearings in comparison with non-tapered bearings and tests will be run to determine the cause and effect of bearings "walking out," as has been observed in the field study.

2.2.3 Engineering Models: Engineering models will be developed for determining stresses and strains in elastomeric bearings. These models will aid in assessing the current and optional design procedures for elastomeric bearings, and will help to guide laboratory tests on the bearings. State-of-the-art analytical methods can be used to develop and test simple analytical procedures for this study. Based upon this Phase Two work, simple analytical procedures will be developed to aid the designer. Using those procedures, an extensive parametric study will be run to ascertain the bearing parameters and loading characteristics that will most likely cause problems in the field. Finally, time-dependent functions will be added to the models so that the effects of long-term changes in material behavior can be evaluated.

2.2.4 Procedures and Guidelines: With the completion of Phases One through Three, rational design procedures and inspection guidelines will be produced for elastomeric bearings, including the effects of multi-axial rotations and of tapered bearings. The procedures of the current and proposed AASHTO specifications will be assessed, along with the procedures used in other countries. Criteria to identify "problem" bridges will be developed in the form of inspection guidelines, and will be used to identify bridges in Texas which should be more closely scrutinized for potential bearing problems.

With the completion of this study it will be determined whether elastomeric bridge bearings in Texas and elsewhere are safe, and therefore whether they should have to comply with the new AASHTO Specifications.

2.3 Scope and Objectives of this Report: Phase One

The scope of this report will include only Phase One of Project 1304, dealing with the field surveys and testing. The objectives of this part of the study were to:

- Perform a literature review

- Verify field reports
- Select two bridges to be monitored
- Document bearing and girder movement of these bridges
- Evaluate field results and provide the necessary information for laboratory and model studies
- Use BRINSAP to determine and locate bridges in Texas with the potential of having bearing problems
- Make recommendations for resolving bearing problems

A comprehensive literature review was carried out and will be discussed in Chapter 3. Chapter 4 contains information pertaining to the preliminary field investigation of bridges in Central Texas. From this preliminary investigation, two bridges were chosen for in-depth field investigation. Chapter 5 discusses the process, instrumentation, and results of the in-depth field investigation. Chapter 6 discusses the use of BRINSAP in identifying bridges with potential bearing problems using the characteristics determined from the results of the field study. Chapter 7 gives the summary, conclusions, and interim recommendations.

CHAPTER 3 BACKGROUND

3.1 General

Bearings are used to restrain and isolate a load bearing surface from a support, while permitting movement due to temperature changes or other effects. The three types of movement that can occur are shearing deformation, rotation, and axial deformation, as shown in Figures 3.1(a), 3.1(b), and 3.1(c), respectively. Bridge bearings are designed to maintain compressive support while allowing horizontal movements. Elastomeric bearings are either reinforced or unreinforced, as shown in Figures 3.2(a) and 3.1(b), respectively. The two most common elastomeric materials in such bridge bearings are neoprene and natural rubber.

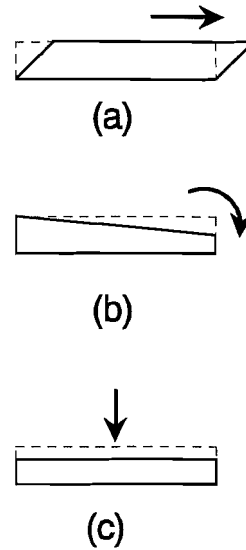


Figure 3.1 Bearing movements

3.2 Case Studies of Bearing Performance

Development of elastomeric bearings in Europe dates back to the end of World War II. Bridge bearings of natural rubber and neoprene have been used in the United States since the mid-1950's, and their performance has been documented [9,10,11,12].

3.2.1 Performance of Neoprene: Neoprene has exhibited satisfactory performance in the past, as documented [9] for sites including those listed below:

- New York State - 29 years performance
- Idaho - 31 years performance
- Illinois - 29 years performance
- Texas - 32 years performance
- Japan - 28 years performance

Specifically, Texas has the oldest known U.S. bridge resting on neoprene bearings. This bridge is a 340-foot (103.63 m) prestressed concrete bridge on Route FM237 over Coletto Creek in Victoria County. In 1955, the Texas State Highway Department initiated a program for developing elastomeric bearings to replace mechanical bearings. A neoprene compound was developed and tested for use in this

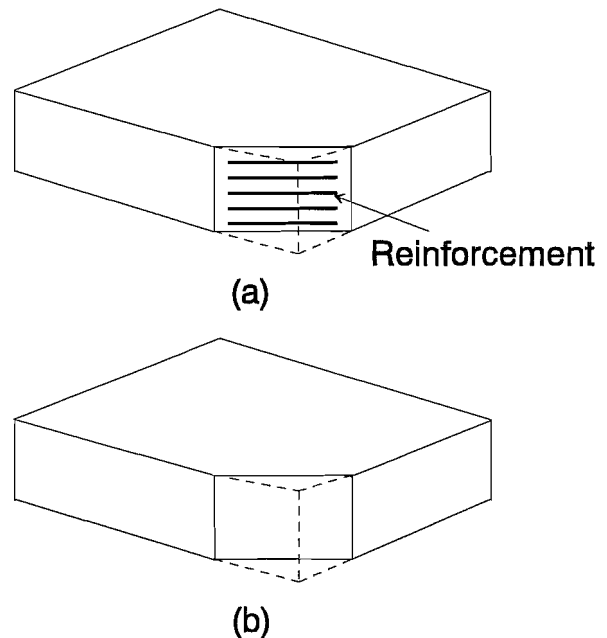


Figure 3.2 Typical bearings

bridge, and was approved in 1957. In 1988, four bearings were removed from this bridge by Burpulis, Seay, and Graff [9], and were tested to determine how their current physical properties compared with past and current specifications. The results of those tests are shown in Tables 3.1 and 3.2, respectively.

These comparisons indicate satisfactory bearing performance. Where the old bearings failed to match specifications, advances in neoprene compounding over the years have solved these deficiencies.

3.2.2 Performance of Natural Rubber: Natural rubber has also exhibited satisfactory performance over the years. A case study [11] was carried out on a bridge carrying the M2 Motorway in Kent, England. The results of that study showed that under normal operating conditions rubber bearings will perform adequately in service for 20 years with no apparent deterioration. That study also indicated that the service life of a natural rubber bearing would be several times greater than the expected 20 years.

Another example [12] of the reliability of natural rubber can be found in Australia. In 1889 plain compression bearings of natural rubber were laid on top of the piers supporting a low-level viaduct in Australia. These bearings provided a flexible bedding and permitted small relative movements to occur between piers and superstructure without either element experiencing damage. Inspection of these bearings revealed that the degradation of the rubber at the exposed surface was only 1 mm deep. This viaduct is still in use today. This case study shows that with good design and construction, natural rubber bearings can perform satisfactorily for at least one hundred years.

Table 3.1 Comparisons of current properties with original design specifications, 32-year-old bridge bearings (Coletto Creek Bridge, Texas)

Property	1958 AASHTO Specification Requirement	Bearing 2		Bearing 4	
		Value	Difference	Value	Difference
Hardness (Duro A) (ASTM D 2240)	70 ± 5	64	-6	72	+2
Tension strength at break psi (ASTM D 412)	2250 min	1256	56% retained	1442	64% retained
Elongation at break % (ASTM D 412)	405 min	143	35% retained	161	40% retained
Compression set % after 22h at 70C (ASTM D 395-B)	25 max	34	+38%	46	+88%
Low temperature brittleness at -26C (ASTM D 746)	Pass*	Passed	...	Passed	...

*Young's modulus at -26C originally specified.

Table 3.2 Comparisons of current properties with current AASHTO design specifications, 32-year-old bridge bearings (Coletto Creek Bridge, Texas).

Property	Current AASHTO Specification Requirement ^a	Bearing 2		Bearing 4	
		Value	Difference	Value	Difference
Hardness (Duro A) (ASTM D 2240)	70 ± 5	64	-6	72	+2
Tension strength at break psi (ASTM D 412)	2500 min	1256	50% retained	1442	58% retained
Elongation at break % (ASTM D 412)	300 min	143	48% retained	161	54% retained
Compression set % after 22h at 100C (ASTM D 395-B)	35 max	34	0	46	34%
Low temperature brittleness at -40C (ASTM D 746)	Pass	Did not pass ^b	...	Did not pass ^b	...

^a1983 AASHTO Specifications.

^bLowest temperature which samples passed using D 746 was -27C.

3.3 Design Considerations for Elastomeric Bearings

Many factors are important in the design of elastomeric bearings and several of the more critical parameters are listed below:

- Shape factor
- Type of reinforcement
- Effective rubber thickness
- Hardness/Shear modulus
- Compressive creep

The shape factor is probably the most important single parameter used in bearing design, because it largely determines vertical flexibility of the bearing. The shape factor is defined as the ratio of the surface area (plan area) of one loaded face to the perimetral area between layers of reinforcement. As shape factor increases, the axial flexibility of the bearing also increases. However, no consistent relationship has been found between shape factor and compressive modulus: a bearing with a shape factor of 4 is not twice as flexible, for example, as a bearing with a shape factor of 2.

Steel is the most common reinforcement used in bearings. The yield point and tensile strength of the reinforcement largely determines the ultimate compressive strength of a bearing. The amount of horizontal movement permitted is determined by the effective rubber thickness (ERT), defined as the combined thickness of all the elastomeric materials in a bearing [9]. A general rule of thumb that has proved effective in design is that the shear deflection should not exceed 50 percent of the ERT [13]. The hardness of a bearing, expressed in terms of durometer, is a relative measure of the stiffness of the bearing in compression and shear. Hardness is measured by a durometer, and it is related to the depth of elastic indentation under a given load. Usually, as hardness increases deflection decreases. However, with increasing hardness compressive creep increases.

3.4 Failure Modes of Elastomeric Bearings

There are many modes of failure for elastomeric bridge bearings:

- Fatigue
- Stability
- Delamination or separation of the elastomer from the reinforcement
- Yield or rupture of the reinforcement
- Serviceability

3.4.1 Fatigue: Bearing performance can be significantly influenced by fatigue. Fatigue is caused by cyclic loading induced by traffic and daily temperature cycles. Tests [5] with compressive load combined with cyclic shear deformations have shown that fatigue cracking can occur, usually in the interface between the elastomer and the steel surface. The rate of crack growth is dependent on the rate of loading, the stress and strain magnitude, and the material properties of the elastomer.

3.4.2 Stability: Tests [5] have shown that buckling will occur if the bearings are too tall. Shear deformation controls the buckling. To control buckling, early specifications limited the height of the bearing to a part of its smallest base dimension. Existing theories are quite conservative for practical bearing sizes and tests are being performed at the University of Washington to determine theoretical estimates of bearing buckling capacity.

3.4.3 Delamination/Separation of the Elastomer from the Reinforcement: Delamination of elastomer is not a critical failure mode, because the bearing can still support loads and movements. However, the delamination causes deterioration and reduces the service life of the bearing. Improvements in manufacturing and quality control have practically eliminated this failure. Also, bearings are currently required to be proofloaded beyond their maximum service load. This requirement has proved to be effective in controlling delamination failures.

3.4.4 Yield/Rupture of the Reinforcement: Reinforcement restrains the Poisson expansion of the bearing, producing large transverse tensile stresses in the reinforcement when the bearing is loaded in compression. When the tensile stress is exceeded, yielding or rupturing of the reinforcement will occur. Yield or rupture of the reinforcement usually occurs at loads and stresses much larger than those required to cause delamination. Unlike delamination, failure of the reinforcement will cause immediate and disastrous degradation in bearing performance.

3.4.5 Serviceability: Serviceability is an important consideration when designing bearings. Creep, slip, and deterioration of the bearing are some important bearing serviceability issues. Bearing slip has become a major serviceability issue. Slip is controlled by friction between the bearing and its contact surfaces. This serviceability issue will be discussed in greater detail in section 3.6.

3.5 Bearing Material and Design Specifications

Elastomeric bearings have been used for many years [10,11] with satisfactory results. Initially, these bearings were designed by trial and error. No formal specification existed until 1961, when AASHTO published the first design specification [1], based on experimental work [2] performed by the DuPont Company. These specifications were intended for plain (unreinforced) polychloroprene bearings. The provisions were based exclusively on elastomer hardness. The specification limited the average compressive stress of the bearings to 800 psi (5.5 MPa), and the average compressive strain to 7 percent. Height limitations were also imposed on the bearings: the total elastomer thickness had to be at least twice the maximum translational movement to control the maximum strain in the elastomer, and less than 25 to 33 percent of the bearing's smallest plan dimension, to assure that the bearings would not buckle in compression. These design procedures were used for several years; as noted in the previous section, they have performed very well.

However, in the early 1970's ASTM formed a task group to deal with specifications concerning the type of bridge bearings, elastomeric materials, material tests and performance tests. This group concentrated their work [14] on the four following aspects:

- Bearing materials
- Specific quality control tests for elastomeric materials
- Performance requirements and tests for the finished bearings
- Minimum requirements for elastomeric compounds used in bearings

That work laid the foundation for an improvement in the AASHTO bridge design code.

In 1981, the National Cooperative Research Program (NCHRP) Project 10-20 was undertaken to develop improved design procedures. The results of that study indicated many inconsistencies with the current design specifications, and a new design procedure was recommended. This procedure, adopted as the 1985 AASHTO Specification [4], uses a factor β to account for behavior differences between reinforced bearings and unreinforced bearings. Reliance upon the hardness of the elastomer was reduced and the concept of elastomer stiffness through the shear modulus of the elastomer G was introduced. The result of these two provision resulted in the compressive stress σ being limited to:

$$\sigma \leq \frac{GS}{\beta} \quad (3.1)$$

where S is the shape factor. The average compressive stress was limited to 800 psi (5.5 MPa) for plain elastomeric bearings and fabric-reinforced bearings, and 1000 psi (6.89 MPa) for steel-reinforced bearings. Slip frequently occurs in unreinforced bearings which will increase the compressive strain in the elastomer, possibly causing failure. Based on this, a β of 1.8 was used for unreinforced bearings, 1.4 for top and bottom cover layers of reinforced elastomeric bearings, and 1.0 for interior layers of reinforced elastomeric bearings. These provisions resulted in a significant increase in the rated load capacity of reinforced bearings, and a decrease in the rated load capacity of unreinforced bearings with small shape factors.

3.6 Bearing Friction and Slip

In recent years bearing slip has become a significant serviceability issue for TxDOT. Bearings will slip if they are subjected to excessive horizontal forces. Causes of such forces include the following:

- Insufficient allowance for shrinkage and creep of prestressed concrete girders
- Girder placement at extreme temperatures
- Construction misalignment

Usually a single occurrence of bearing slip will not cause any damage. However, cyclic slip can cause the surface of the elastomer to deteriorate and perhaps crack. The most serious problem occurs if the bearing slips out of its original position. It has been shown [3] that plain bearings are more susceptible to slipping than reinforced bearings. One of the main problems in analyzing bearing slip is that the coefficient of friction of rubber against steel or concrete varies with normal stress and the compounding of the elastomer. Some of the compounded waxes and oils of natural rubber bearings will migrate to the bearing surface over time thus affecting the surface condition of the rubber. Also, some authorities have stated that friction is less under dynamic loads, so that temperature forces on the substructure are alleviated by the bearing slipping as a result of dynamic traffic loads. Cyclic shear loads will cause increased vertical deflections and may cause the bearing to "walk" out of place. Research [3] has shown that plain bearings subjected to compression will not slip at their edges if the shape factor is less than or equal to half of the coefficient of friction. However, lower values of the coefficient of friction found by others, combined with the effects of dynamic live load which further reduce them, make some slip almost inevitable for bearings of practical shape factors. Obviously, there is diversity in the accepted causes of slipping of the bearing and more research is needed to clarify these problems.

3.7 Bridge Movements

The magnitude and range of movement experienced by a bridge during its service life influences the type of bearing necessary to accommodate this movement. Longitudinal movement of a concrete bridge deck is produced by factors such as the following:

- Changes in ambient temperature
- Shrinkage and creep of concrete

3.7.1 Changes in Ambient Temperature: Measurements of bridge movement are sparse. It has been shown [15] that values of the daily coefficient of thermal expansion or contraction can exhibit large and random fluctuations. These values are not necessarily an accurate indication of the effective coefficient of thermal expansion of the structure. Also, by using measured annual ranges of effective bridge temperatures and movements to calculate the coefficient of thermal expansion may result in values which are too low. The value of the coefficient of thermal expansion of the aggregate from which the concrete is constructed is a relative indicator of the effective coefficient of thermal expansion of the structure. It has also been shown that it is possible to estimate the extreme range of movement likely to occur during the life of a bridge if the extreme values of the shade temperature are known.

3.7.2 Shrinkage and Creep of Concrete: Shrinkage is volume change that is unrelated to load application. Creep is the property of concrete by which it continues to deform with time under sustained loads at unit stresses within the accepted elastic range. Frequently creep is associated with shrinkage, since both are occurring simultaneously and often provide the same net effect: increased deformation with time. In general, the same factors have been found to influence shrinkage strain as those that influence creep. Several of these factors are listed below:

- Constituents
- Proportions
- Curing temperature and humidity
- Relative humidity during period of use
- Duration of loading
- Magnitude of stress
- Slump

CHAPTER 4 PRELIMINARY FIELD INVESTIGATION

4.1 General

In this project, a preliminary field investigation was carried out to determine which bridges should be included in the in-depth field study. This was accomplished by means of a questionnaire distributed to all TxDOT district offices, requesting lists of all bridges for which bearing movement had been noted. The second step was to verify that those bridges were actually experiencing problems. This was accomplished by site visits to selected bridges. Finally, two of those bridges were selected for in-depth field investigation. Some of the material in this chapter is taken verbatim from field reports prepared by the Principal Investigators for this project.

4.2 Questionnaire

To determine which bridges in Texas were experiencing bearing problems a questionnaire was sent to all the Districts. This questionnaire asked for the following:

- A list of all bridges within that district which had experienced or were experiencing bearing problems, particularly bearing movement;
- For each such bridge, a brief history of the problem (how and when had it come to the District's attention, what did they do, and has the problem re-occurred);
- Were samples of slipping bearings still available?
- Did the District anticipate removing or resetting any bearings during 1992-93?

4.3 Site Visits

Based on the information obtained from the Districts, a list was compiled of all the bridges which were experiencing bearing problems (Table 4.1). Several bridges were then selected for field verification. The bridges selected and the dates they were visited are as follows:

- | | | |
|-----------------------------------|---|--------------------|
| ● Slaughter Creek (Travis County) | - | September 1, 1991 |
| ● Beaumont (Jefferson County) | - | February 17, 1992 |
| ● Paris (Lamar County) | - | March 24, 1992 |
| ● Alanreed (Gray County) | - | September 25, 1992 |

Table 4.1

"PROBLEM" BRIDGES		
DESCRIPTION	COUNTY	DISTRICT
SH 360 over Mayfield Road	Tarrant	2
SH 360 over East Park Row	Tarrant	2
Lake Ridge Parkway over Joe Pool Lake	Tarrant	2
ATSF Overpass	Lubbock	5
US 83 at Concho River	Concho	7
US 290 at Cypress Creek	Harris	12
US 290 Left Frontage Road at Cypress Creek	Harris	12
Barker Cypress Road Overpass	Harris	12
IH 10 Under SH 71	Colorado	13
IH 10 at County Road	Gonzales	13
SH 97 at Stahls Lake	Gonzales	13
US 59 at SH 60	Wharton	13
IH 35 at Slaughter Creek	Travis	14
IH 20 Overpass	Dallas	18
North Sulphur River	Lamar	1
IH 40 Overpass (#142)	Gray	4
IH 10 and US 69 Interchange	Jefferson	20

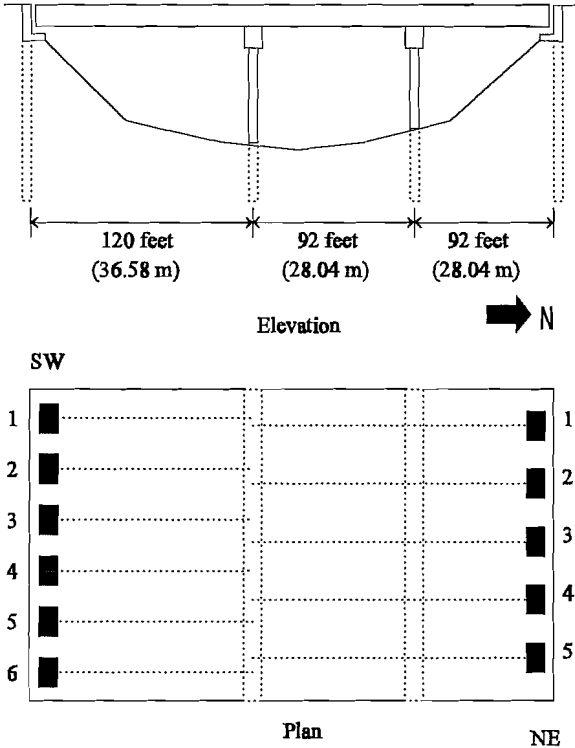


Figure 4.1 Plan and elevation of Slaughter Creek Bridge

4.4 Investigation of Slaughter Creek Bridge

4.4.1 Location of Slaughter Creek Bridge.

The Slaughter Creek Bridge supports the southbound lanes of I-35 frontage road over Slaughter Creek, approximately one mile (1.61 km) south of Slaughter Lane in South Austin.

4.4.2 History of Slaughter Creek Bridge.

Construction of the bridge was finished in 1990. Elevation and plan views of the bridge are shown in Figure 4.1, and pertinent information is summarized below:

- The bridge has three spans (120/92/92), for a total length of 304 feet (92.7 m). It is continuous for live load (continuous cast-in-place deck over six Type IV girders). It has a movement joint at each end. At the two exterior supports, the bridge has 2-inch (50.8 mm) natural rubber laminated bearings tapered to 1-3/4 inches (44.5 mm), measuring 9 by 22 inches (229 mm by 559 mm) in plan.
- Bearing movement was first noticed after the bridge was opened for traffic in early 1990. The bearing under Girder #5 on the northeast end of the bridge had completely fallen out; the bearing under Girder #1 had barely moved; the bearings between #1 and #5 had experienced more movement the closer they were to the northeast end of the bridge.
- Bearing movement was not occurring on the south end of the bridge at this time.
- In October 1990, the bridge was lifted and the existing bearings were reset to their original places. Steel cages were also placed around the bearings to control movement. The bearings had moved against the steel cages by the next morning.
- Bearing movement was not occurring on the south end of the bridge at this time.
- In June 1991, bearing movement was observed on the south end of the bridge.
- In September 1991 this project was started.

4.5 Investigation of Beaumont Bridge

4.5.1 Location of Beaumont Bridge. The Beaumont Bridge is located at the interchange of IH 10 and US 69, in the center of Beaumont. A profile of the bridge is shown in Figure 4.2. The bents of Element F are numbered from Bent 1 (at the north abutment) through Bent 4. The freeway from Bent 1 to Bent 4 is uphill. Bearings are tapered slightly. All bearings have moved uphill; that is, in the direction of a vector from their thin end to their thick end.

4.5.2 History of Beaumont Bridge. The bridge had experienced problems with movement of its natural rubber bearings for several years. In Element E, bearing movement occurred over two bents. In Element F, bearing movement was experienced over one bent.

In Element E, the bearings moved before the bridge was opened to traffic. The bearings were replaced with neoprene, and have experienced no movement since. Because of the problems in Element E, TxDOT has replaced the natural rubber bearings with neoprene bearings in all elements in this interchange where there are more than three continuous spans, and where the slope exceeds 1.5%.

In Element F, bearings were moving on Bent 4. These bearings were replaced during our visit. Based on construction and pay records, the bearing movement had the following sequence:

11/15/89	Beams placed on Bent 4
04/19/90	Slab cast on Spans 3 and 4
04/19/90	Slab cast on Span 5
01/31/91	The slab was swept of nails and was sealed
02/xx/92	Bearing movement was noted because of roughness at armor joint
04/25/91	The bearings were glued in place with an epoxy adhesive of the same type used in Arkansas for new bearings
05/09/91	The bridge was opened to traffic
05/13/91	Inspection showed cracks in the epoxy joint around the edges of the bearings (Element E, Bent #11 and Element F, Bent #4)
05/20/91	No change
05/30/91	No change

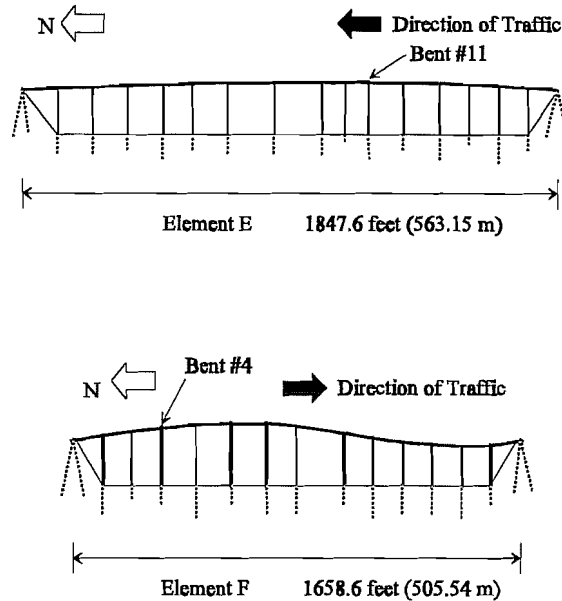


Figure 4.2 Profile of Beaumont Bridge (Elements E and F)

07/29/91	No change
08/29/91	No change
09/23/91	Inspection showed no change in Element F, Bent #4; In Element E, Bent #11, Bearing #5 had moved 3 inches (76.2 mm)
10/07/91	Inspection showed the beginning of bearing movement in Element F, Bent #4; In Element E, Bent #11, Bearing #5 moved 2-1/2 inches (63.5 mm) more and the other four bearings began to move.

4.6 Investigation of Paris Bridge

4.6.1 Location of Paris Bridge. The Paris Bridge supports the southbound lanes of State Highway 19/24 over the North Sulphur River, about 10 miles (16.1 km) south of Paris, Texas.

4.6.2 History of Paris Bridge. Chalk marks on the girders indicated that they were cast in January 1977, so the bridge was probably built early in that year. A profile of the bridge is shown in Figure 4.3. It is unique in several respects:

- It has a very long section (seven spans at 80 ft (24.38 m)) of "poor boy" continuous construction (continuous deck over simply supported Type C girders)
- It has only a single movement joint at Bent 2, near the north end. The armor joint there is open about 4 inches (101.6 mm) in cold weather, and closes to about 3 inches (76.2 mm) in hot weather
- It is subjected to heavy truck traffic in the southbound direction (gravel trucks with total weights possibly exceeding 120,000 lbs., or 534 kN. Impact of these trucks against the south edge of the armor joint at Bent 2 may keep that joint open.
- It was constructed with 1-inch (25.4 mm) thick unreinforced neoprene bearings, 70 durometer.

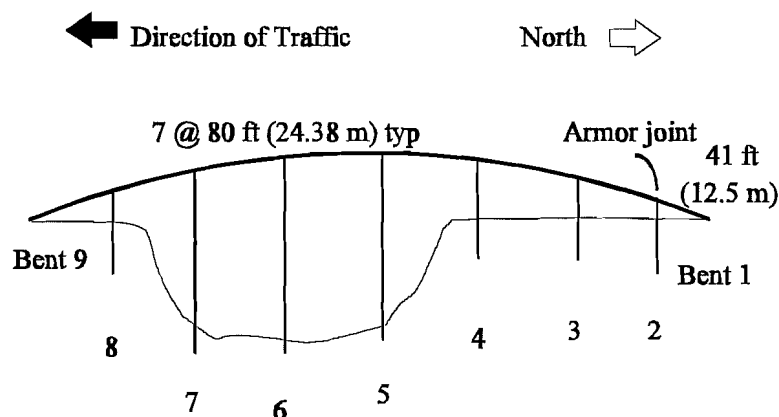
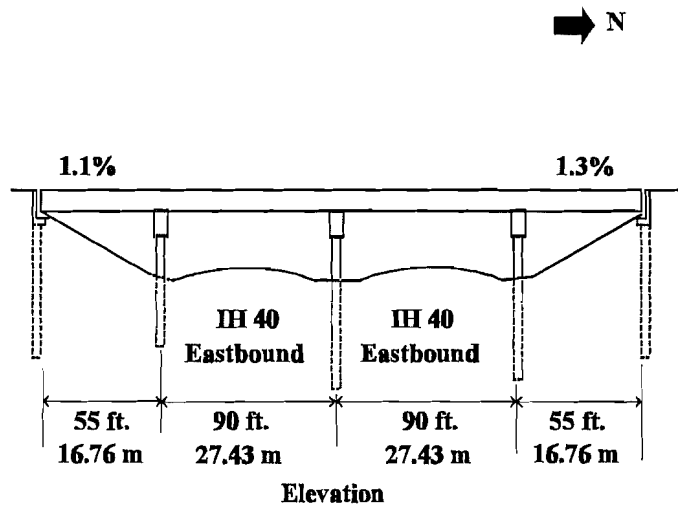


Figure 4.3 Profile of Paris Bridge

Inspection photographs taken in 1989, 1990 and 1991 showed bearing movement, which could have started before then, and which was worst near Bent 2. Bearings at Bent 2 moved 4 to 6 inches (101 to 152 mm), and are beginning to come out. On the north side of Bent 3, one bearing came out, and the bent cap is spalled where the girder is resting on it. Where dowels are used to hold the exterior girders in place, several bearings are torn in half. However, torn bearings are also visible at interior girders, which do not normally have dowels. Possibly the tearing is also caused by digging of the end of the girder into the bearing.

4.6.3 Pertinent Information on Paris Bridge. In this project this bridge is the first one studied with slipping neoprene bearings. Although the bearings were under-designed by current standards for the amount of movement they must accommodate, it is clear that slip is possible in some circumstances with neoprene bearings as well as natural rubber ones. At several bents, bearings on the two girders slipped towards each other, so that their free ends are curved upwards into the space between the girders. This clearly shows that the bearings on each side of the bent have moved in opposite directions. Again, it is possible that this is due to the ends of the cambered girders digging into the bearings.



4.7 Investigation of Alanreed Bridge

4.7.1 Location of Alanreed Bridge. The Alanreed Bridge is located in Gray county, 2 miles (3.22 km) east of Alanreed (about 60 miles (96.6 km) east of Amarillo) on IH 40. It is designated as Bridge #142. It supports Country Road 142, which crosses over IH 40 in the north-south direction there.

4.7.2 History of Alanreed Bridge. The bridge was constructed in 1982. Elevation and plan views of the bridge are shown in Figure 4.4, and pertinent information is summarized below:

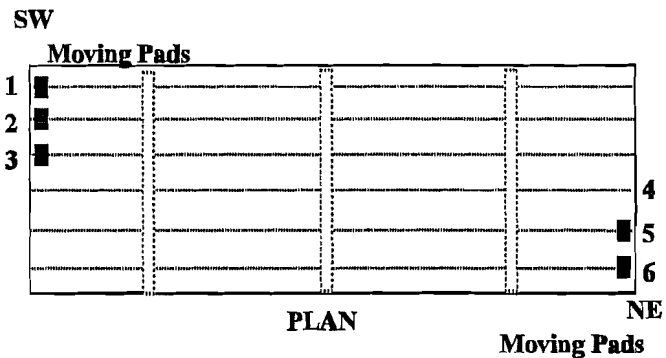


Figure 4.4 Plan and elevation of Alanreed Bridge

- The bridge has four spans (55/90/90/55) for a total length of 290 feet (88.4 m). It is continuous for live load (continuous cast-in-place deck over six Type C girders). It has a movement joint at each end. At the three interior supports, the bridge has 1-inch (25.4 mm) neoprene bearings. At the two exterior supports, it has 1-3/4-inch (44.45 mm) laminated bearings, measuring 9 by 19 inches (228.6 by 482.6 mm). The bridge has a 5° 27' skew.

- The bridge carries heavy truck traffic. Gray County uses CR 142 for hauling caliche fill.
- Bearing movement was first noticed in July 1990, at the northeast and southwest ends, as shown in Figure 4.4. The bridge runs north-south, and the girders are numbered from west to east. At the northeast end of the bridge, bearings under Girders #5 and #6 were moving away from the abutment. At the southwest end, bearings under Girders #1, #2 and #3 were moving away from the abutment. Movement was as much as 6 inches (152 mm).
- In July 1990, the girders were raised and the same bearings reset to their original positions.
- In December 1990, inspection revealed that the bearings had moved from those positions.
- In July 1992, the girders were again raised. The bearings were replaced with apparently identical bearings removed from a nearby bridge that had been hit by a truck.
- On September 25, 1992 (this investigation), the new bearings appeared to have moved from their July 1992 positions. Bearings at the northeast end of the bridge (Girders #4 and #5) appear to have moved toward the abutment about 1 inch (25 mm), and bearings at the southwest end (Girders #1, #2, and #3) appear to have moved away from the abutment about 1 inch (25 mm).

4.7.3 Pertinent Information on Alanreed Bridge. Along IH 40, just to the west of this bridge, are two other bridges that are quite similar to Bridge #142. Neither one has experienced bearing movement:

- One mile (1.6 km) west of Bridge #142 lies Bridge #143. It is similar to Bridge #142. It is almost identical to Bridge #142. It has five spans (55/95/95/80/40) and Type 54 girders.
- About two miles (3.2 km) west of Bridge #142, just east of Alanreed, lies Bridge #144. It has four spans (55/90/90/45) and Type C girders. It has essentially no skew. In Spring 1992, its center bent was hit by a helium truck. The bridge was severely damaged and is being replaced.

In Bridge #142, some bearings that are moving seem to be associated with girders that do not sit squarely on them. For example, the bearing at the north end of Girder #6 (the northeast corner of the bridge, Figure 4.4) has been photographed with daylight showing both above and below it. The approximate shape of the gaps is shown in Figure 4.5. This implies that lack of uniform contact between the bearing and the girder, or possibly girder rocking, may have a significant effect on bearing movement.

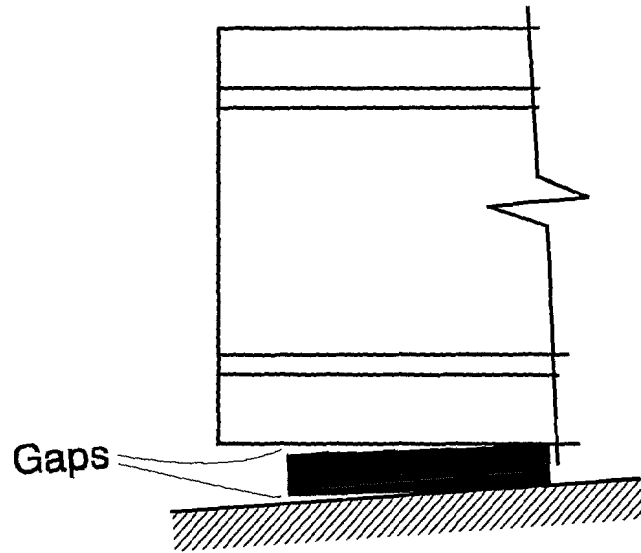


Figure 4.5 Appearance of gaps below and above bearing at north end of Girder #6

CHAPTER 5 IN-DEPTH FIELD INVESTIGATION

5.1 General

Based on the information obtained from the preliminary field study, two bridges were chosen for an in-depth field study. The bridge at Slaughter Creek was chosen for its convenient location, wide range of bearing movements (none to unlimited), and because all bearings have moved. The bridge at Alanreed was chosen for its past history of bearing movement, because of the two nearby bridges which are similar in design but whose bearings have not moved, and because its geographical location is different from that of Slaughter Creek. For both bridges, data were collected on girder thermal movement (daily and seasonal), and on bearing movement. In addition to these data, for the Slaughter Creek bridge thermal displacement and girder rotation were measured in 15-minute intervals over the 24-hour period immediately after resetting the bearings. Also, an attempt was made to videotape the "walking out" phenomena at Slaughter Creek. Unfortunately, this last effort was not successful.

5.2 Thermal Displacement Gages

5.2.1 Instrumentation Characteristics. Based on the fact that this was a field study spanning several years, it was necessary to develop an inexpensive gage to monitor the thermal movement of the bridge girders. The desired characteristics of the gage should be as follows:

- It should be completely mechanical
- It should require minimal maintenance
- It should require minimal security
- It should be easy to build
- It should be easy to operate
- It should be able to measure maximum girder movement over time

5.2.2 Instrumentation Materials. After several tries the gage shown in Figure 5.1 was developed. It consists of the following parts:

Part A: Two sewing hem gages riveted back to back

Part B: Attached pointers

Part C: An aluminum angle riveted to the hem gages

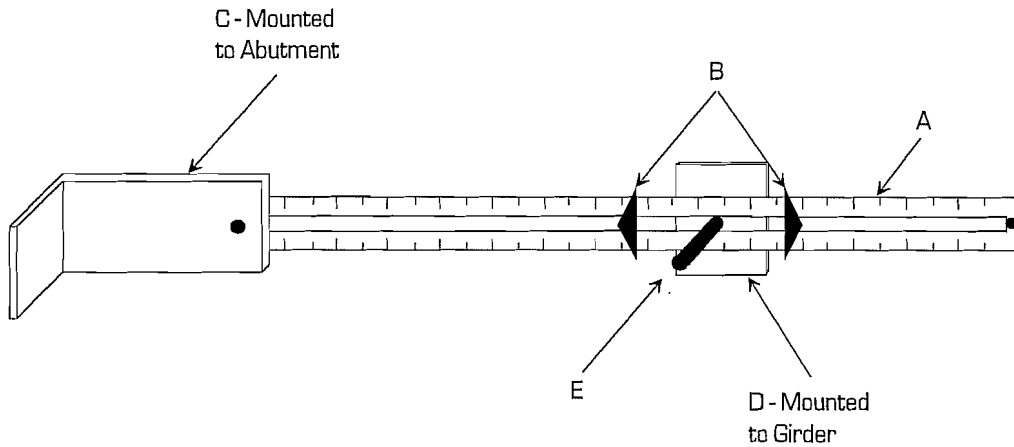


Figure 5.1 Thermal displacement gage

Part D: An aluminum base plate

Part E: A 2-inch (50.8 mm) screw passing through a hole in the center of the base plate, and which acts as a needle to move pointers (Part B)

This gage records the maximum girder thermal movement experienced over time. Daily or seasonal maxima can be measured with this gage. The girders were numbered from West to East or North to South. Gages were placed on the web, lower flange, upper flange, or a combination, as shown in Figure 5.2. Figure 5.3 shows how the gage operates. Figure 5.3(a) shows the initial position of the gage. As the girder expands the screw pushes the pointer to the left, Figure 5.3(b). Then as the girder contracts the screw will push the other pointer to the right, Figure 5.3(c). The difference of these two readings will be the total thermal movement experienced by the girder.

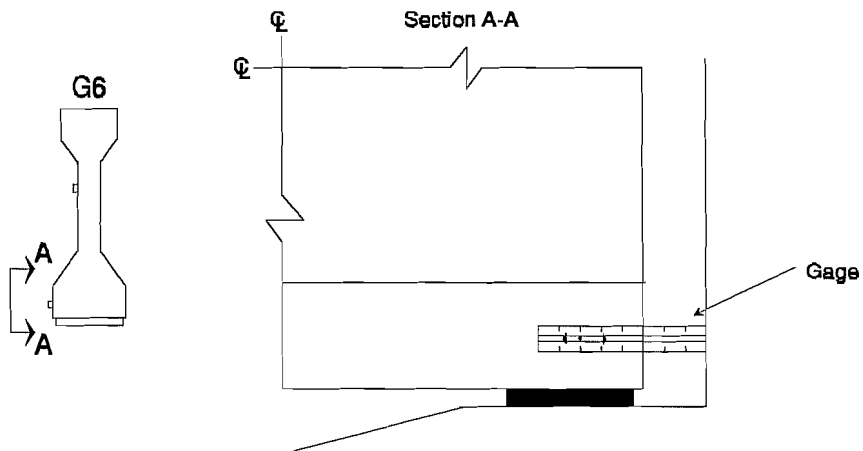
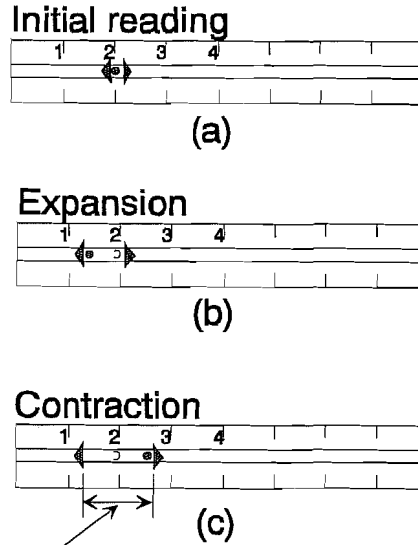


Figure 5.2 Location of gages on girder



Total Thermal Movement

Figure 5.3 Sequence of reading pin position

reference point. Accomplishment of this task required that the South end of the bridge be lifted so that the bearings could be reset. The lifting device developed for this task had to support an end reaction at each girder of approximately 90 kips. In addition, the system had to be erected without the aid of heavy machinery and be economical. Two designs were developed to lift the bridge. The first design utilized a wooden lifting section (Figure 5.4). This design failed during

5.3 Instrumentation of Slaughter Creek Bridge

As mentioned previously, the bridge at Slaughter Creek (Figure 4.1) supports the southbound frontage road along I-35 over Slaughter Creek, approximately one mile South of Slaughter Lane. This bridge has experienced bearing problems since its construction in 1990. Specifically, the bearings, which are of natural rubber, have been "walking out." Previous work on the bearings at Slaughter Creek prior to the start of this project was discussed in the previous chapter. Observations have been made regarding bearing movement since September 1, 1991. Thermal displacement gages were mounted on the web and lower flange of Girder 6 on the south end and on the upper flange of Girder 6 on the north end (Figure 4.1) (January 13, 1992). To measure the movements of the bearings at Slaughter Creek, a reference point needed to be established. The initial position of the bearings as placed in construction was chosen as the

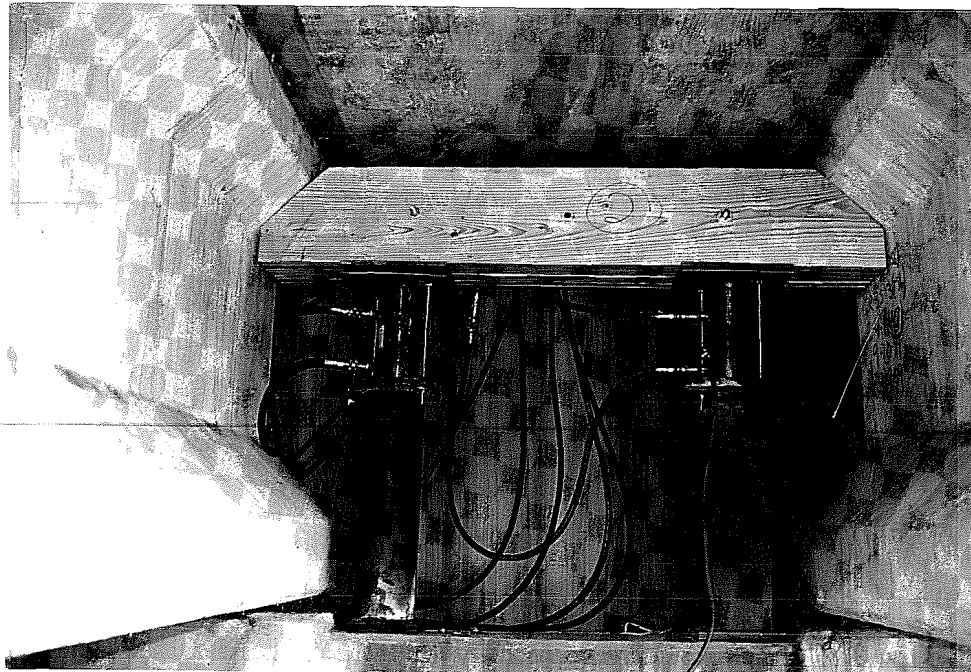


Figure 5.4 Wooden lifting section

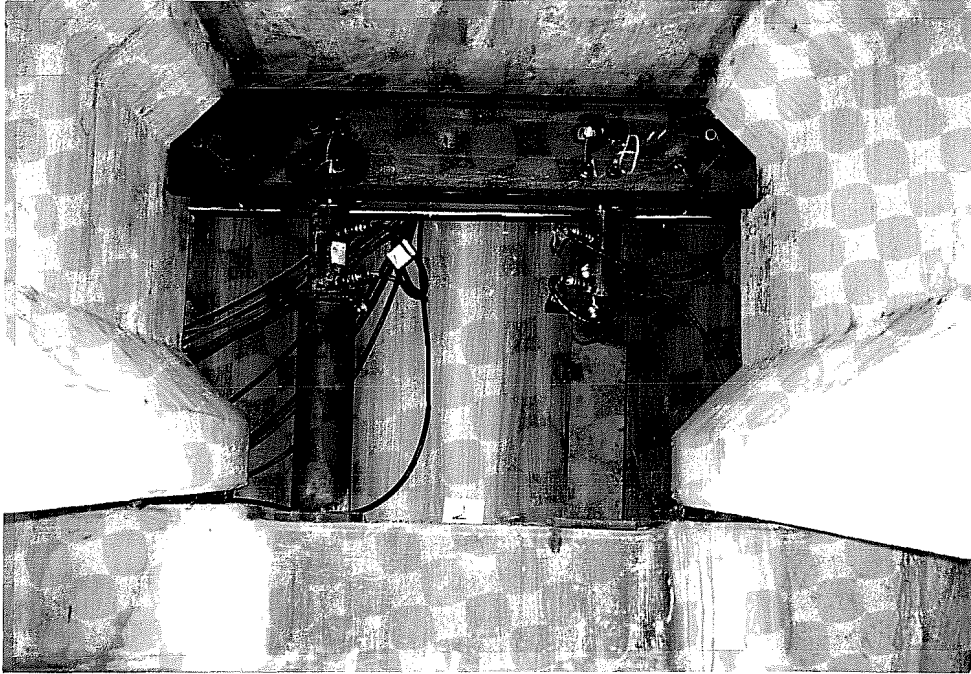


Figure 5.5 Steel lifting section

Bridge Lift I. The second design utilized a steel lifting section (Figure 5.5). This design was successful and was used during Bridges Lift II, III, and IV. The lifting apparatus is shown in Figure 5.6.

- | | |
|------------------------------|---|
| 1) A gas-powered generator | 6) Eight 30-ton (267 kN) hydraulic rams |
| 2) An electric pump | 7) Two 60-ton (534 kN) hydraulic rams |
| 3) An Edison Load Maintainer | 8) Steel lifting sections |

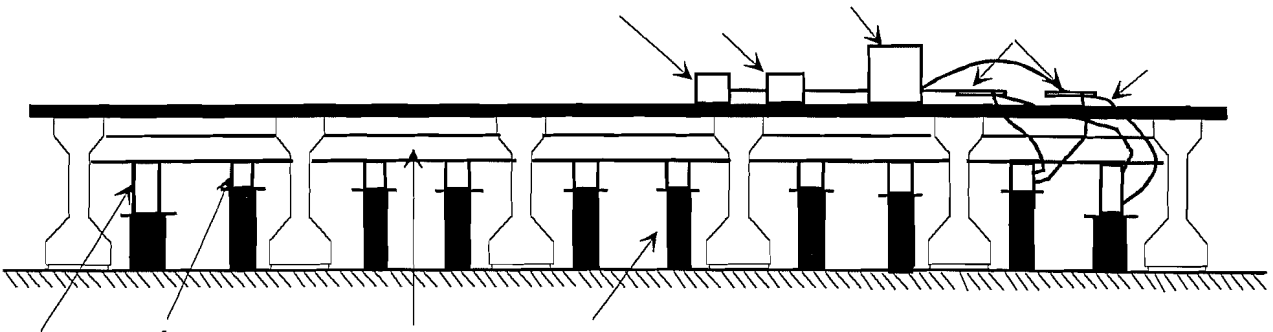
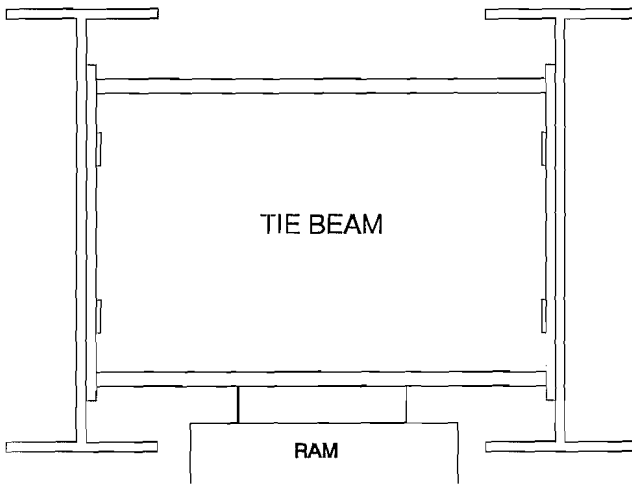


Figure 5.6 Schematic of lifting apparatus

- 4) Pressure and return manifolds
- 5) Hydraulic hoses
- 9) Bases to support the rams



The exterior girders were lifted with one 60-ton (534 kN) ram and the interior girders were lifted with two 30-ton (267 kN) rams. The gas-powered generator was used to power the electric pump and the Edison Load Maintainer, which was used to control the amount of hydraulic oil supplied to the different sized rams. This control allowed the two 60-ton (534 kN) rams to rise at the same rate as the 30-ton (267 kN) rams, thereby avoiding excessive differential moments in the slab. The steel lifting sections, shown in Figures 5.7 and 5.8, were manufactured in four pieces, allowing for easy assembly at the bridge site. Figure 5.7 shows the section against which the rams acted, and Figure 5.8 shows the elevation of the section spanning between the girders.

Figure 5.7 Steel section loaded by rams

This lifting apparatus was used three times (Bridge Lifts II, III, and IV) at Slaughter Creek. In Bridge Lifts II and III, the bearings were reset to their original position; in Bridge Lift IV, the natural rubber bearings were replaced with neoprene bearings.

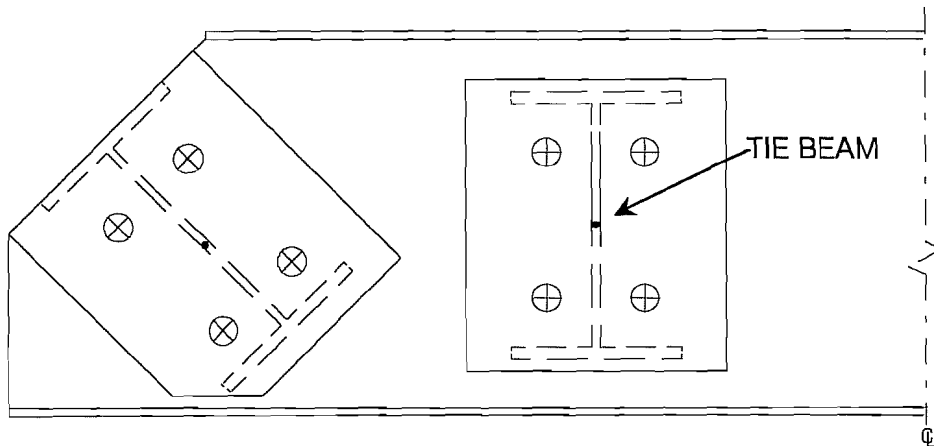


Figure 5.8 Elevation of steel section spanning between girders

5.4 Instrumentation of Alanreed Bridge

As mentioned previously, Bridge #142 (Figure 4.4) is located in Gray County, 2 miles (3.22 km) east of Alanreed (about 60 miles (96.6 km) east of Amarillo) on IH 40. It supports Country Road 142, which crosses over IH 40 in the north-south direction. This bridge was constructed in 1982, and bearing movement was first noticed in July 1990. The history of this bridge was discussed in the previous chapter. The monitoring of this bridge occurred after the natural rubber bearings were replaced with the neoprene bearings from the nearby bridge. The work completed since September 25, 1992 is as follows:

- Thermal displacement gages were mounted on the web and lower flange of Girders 1, 2, and 3 on the South end and the North end of Girders 4, 5, and 6 (Figure 5.9)
- Reference marks were made on the abutments near Bearings 1, 2, and 3 and the southwest end of the bridge, and Bearings 4, 5, and 6 on the northwest end (Figure 4.4)

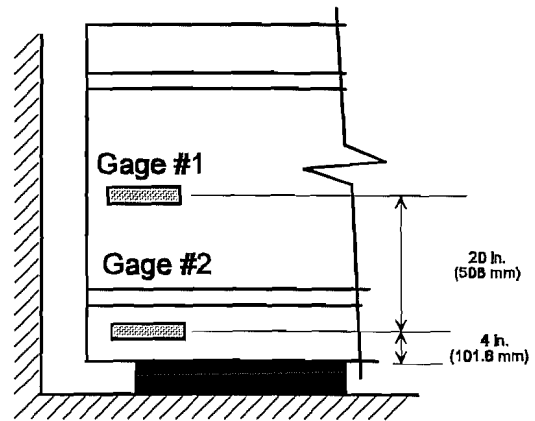


Figure 5.9 Position of thermal displacement gages

The gages and reference marks were only used in the above positions, since the other positions had not exhibited any evidence of movement since the bridge was built in 1982.

5.5 Results of In-Depth Field Study

5.5.1 Slaughter Creek Results. Girder movement has been monitored for over a year, and typical movements are shown in Figure 5.10. The work completed at Slaughter Creek is as follows:

- The south end was lifted (Bridge Lift I and II), and bearings on the south end were reset (June 25, 1992)
- The south end was lifted again (Bridge Lift III), and bearings were reset (October 2, 1992)
- The south end was again lifted (Bridge Lift IV), and the natural rubber bearings were replaced with neoprene bearings (October 23, 1992)

Figure 5.10 shows girder movement of the lower flange of Girder 1 at the south end (Y axis) as a function of time (X axis). The figure shows the maximum displacement recorded by the thermal displacement gage between June 25, 1992 and September 21, 1992. The vertical axis in Figure 5.10 is the displacement reading. For example, between August 10, 1992 and August 17, 1992 the girder contracted approximately 0.25 inches (6.35 mm) and expanded 0.25 inches (6.35 mm). This is shown on the graph as movement away from the abutment and movement toward the abutment, respectively. The gage was then reset to the pin position, as shown by the middle portion of the bar on the graph. Also, the figure

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Slaughter Creek Bridge

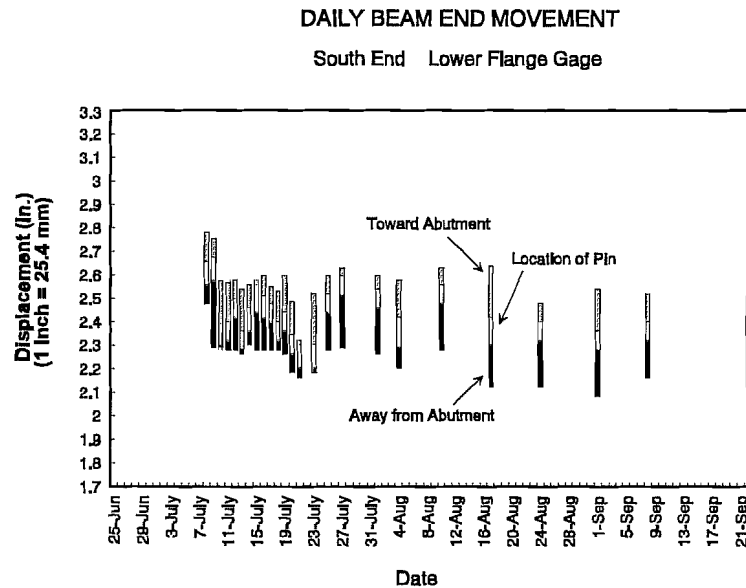


Figure 5.10 Girder movement at Slaughter Creek

shows seasonal temperature change. This is represented by the change between the relative positions of the bars. During the period shown, the total thermal seasonal movement (maximum - minimum) was 2.8 minus 2.1 equals 0.7 inches. Results for each gage can be found in Appendix A.

The daily temperature change and rotation of Girder 2 at the South end of Slaughter Creek is shown in Figures 5.11 and 5.12, respectively. This data was taken on October 2 and 3, 1992 at 15-minute intervals. Figure 5.11 shows that the rate of movement may not be the same for shrinkage and contraction but it is dependent on the ambient temperature. The dashed lines represent the amount and rate of thermal movement that the girder might experience if the ambient temperature does not remain constant. Girder movement was predicted by estimating the maximum range of temperature experienced by the girder and multiplying by the thermal coefficient and the length of the girder. This calculation is illustrated in Appendix C.

Girder movement at Slaughter Creek has exhibited the following characteristics during this study:

- Movement is as much as $\pm 3/8$ inch (9.525 mm)
- Movement is primarily due to temperature changes (daily and seasonal)
- Movement is predictable with hand calculations

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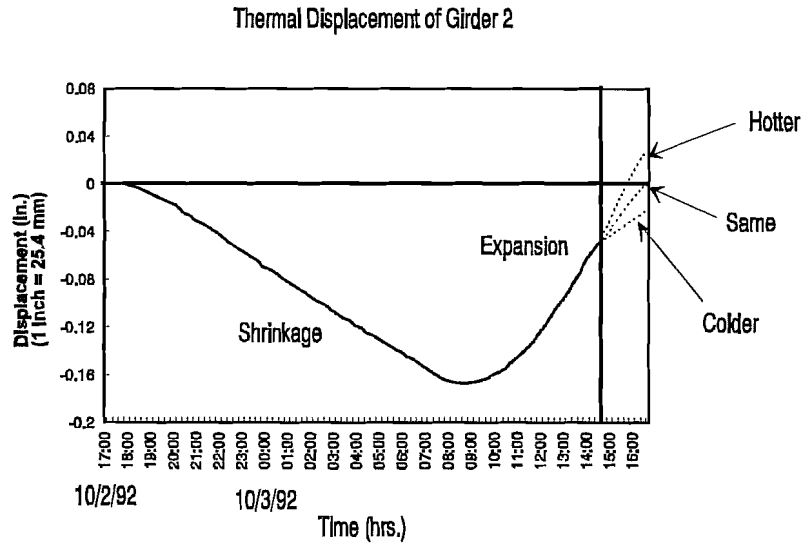


Figure 5.11 Daily temperature movement at Slaughter Creek

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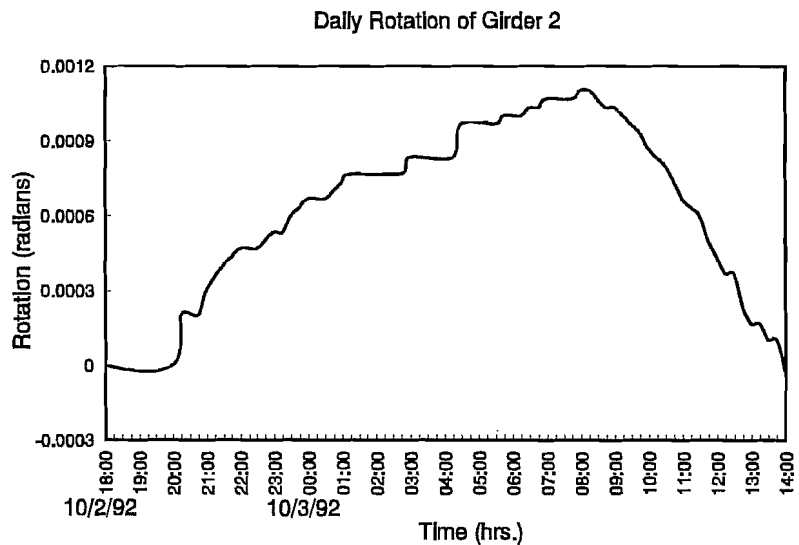


Figure 5.12 Daily rotation at Slaughter Creek

The bearings were monitored after each bridge lift. After each bridge lift a reference mark was made on the abutment beside the bearing to mark the original position. The amount of movement experienced by the bearing was the distance between the original reference mark and the current position of the bearing when the reading was taken. When the bearings were reset the bearing surface was brushed; no chemicals were used to clean the surface. Figures 5.13 through 5.15 show bearing movement on the Y axis as a function of time on the X axis. Figure 5.13 shows that bearing movement was zero in some positions, while bearings in other positions moved. Figure 5.14 indicates that bearing movement stopped around September 5, 1992. However, the bearing had reached an obstruction, namely the abutment. If this bearing had been moving in the opposite direction, its amount of movement would have been unlimited, and the bearing would have come out from underneath the girder. Figure 5.15 shows bearing movement at Position 9 of Girder 5, this figure shows that bearing movement is inconsistent. Inconsistencies also occur because of construction errors, for example, during Bridge Lift III it was discovered that the bearing under Girder 1 was in backwards. As can be seen from Figures 5.13 through 5.15, resetting the natural rubber bearings was ineffective in stopping such movement.

Since Bridge Lift IV (October 23, 1992), when the natural rubber bearings were replaced with neoprene bearings, the bearings have not shown any evidence of movement. However, the neoprene bearings which replaced the natural rubber pads were not the same design. The new neoprene bearings had 5 layers of steel and a Durometer of 50 and the natural rubber bearings had 4 layers of steel and a Durometer of 70. This does not allow for any conclusions to be made regarding natural rubber vs. neoprene.

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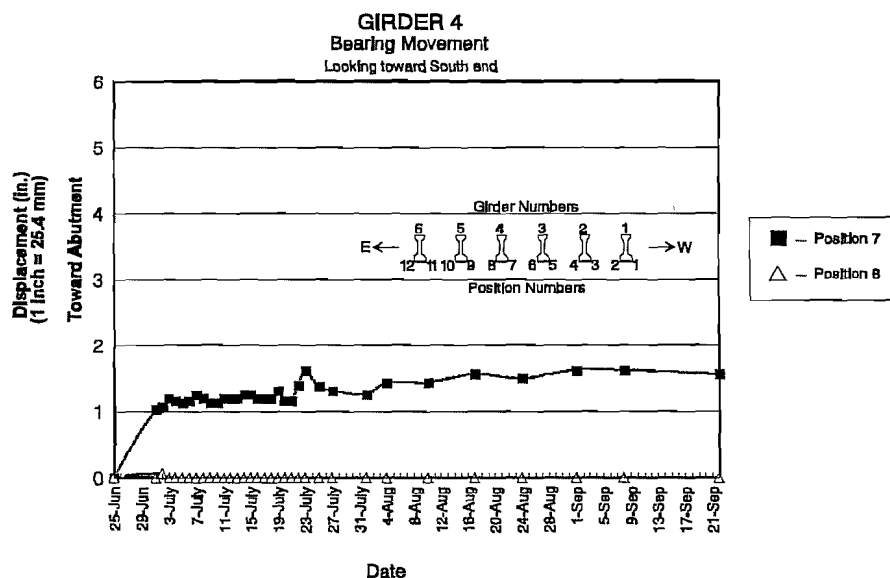


Figure 5.13 Zero bearing movement at Slaughter Creek

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 Slaughter Creek Bridge

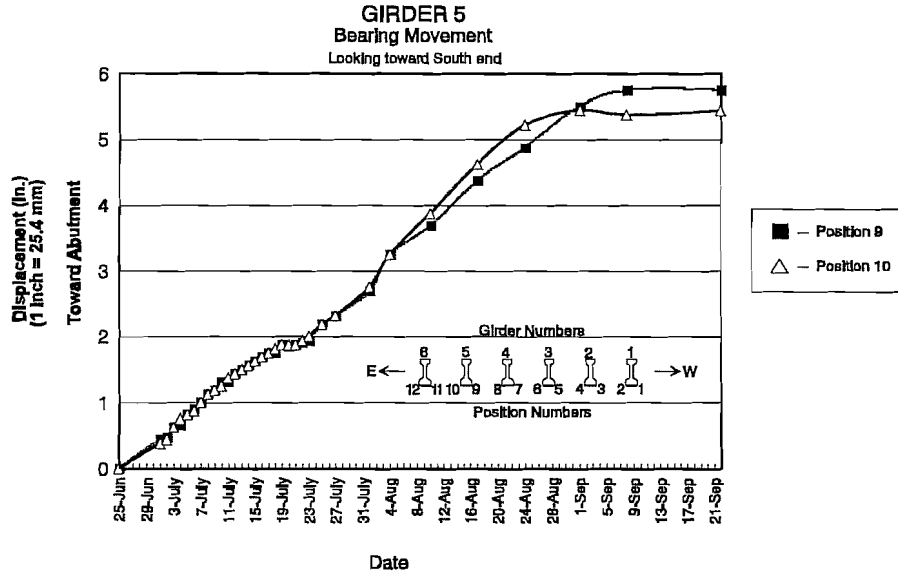


Figure 5.14 Unlimited bearing movement at Slaughter Creek

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 Slaughter Creek Bridge

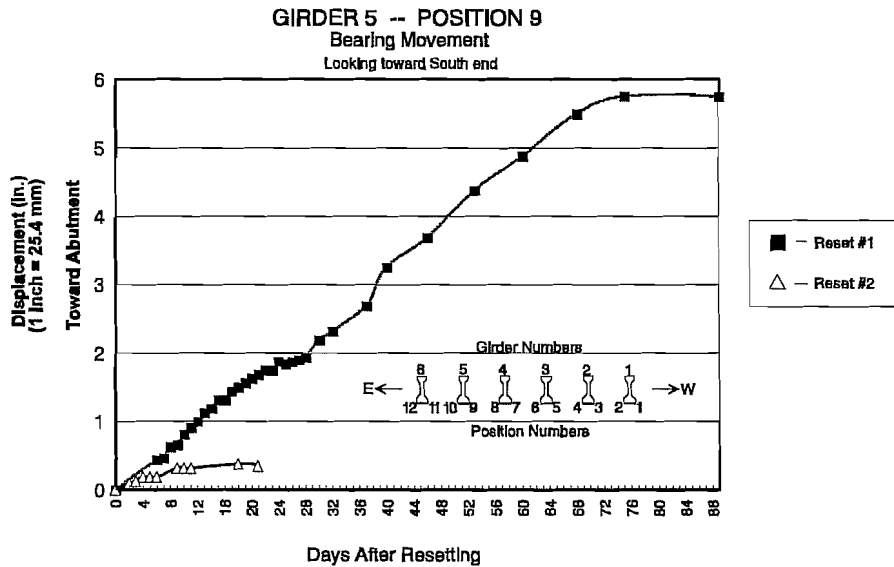


Figure 5.15 Inconsistent bearing movement at Slaughter Creek

Bearing movement at Slaughter Creek was found to be:

- Sometimes zero
- Sometimes unlimited
- Inconsistent

5.5.2 Alanreed Results. Girder movement has been monitored for approximately four months, and typical movements are shown in Figure 5.16. Girder movement at Alanreed has exhibited the same characteristics seen at Slaughter Creek. Results for each gage can be found in Appendix A.

Bearing movement at Alanreed occurred only on the Northeast side of the bridge. Typical bearing movement is shown in Figure 5.17; bearing movement for Girders 4, 5, and 6 (Figure 4.4) can be found in Appendix B. The bearings appear to be "walking" in both directions, toward and away from the abutment. This type of behavior was not observed at Slaughter Creek. As mentioned in the preliminary study, the Alanreed girders do not sit squarely on the bearings (Figure 4.5); this implies that lack of uniform contact between the bearing and the girder, or possibly girder rocking, may have a significant effect on bearing movement. In other words, rocking of the girder causes the bearing to "walk" back and forth. By extrapolation of the data and from past experience, the bearings at the Northeast end will eventually need to be replaced or reset.

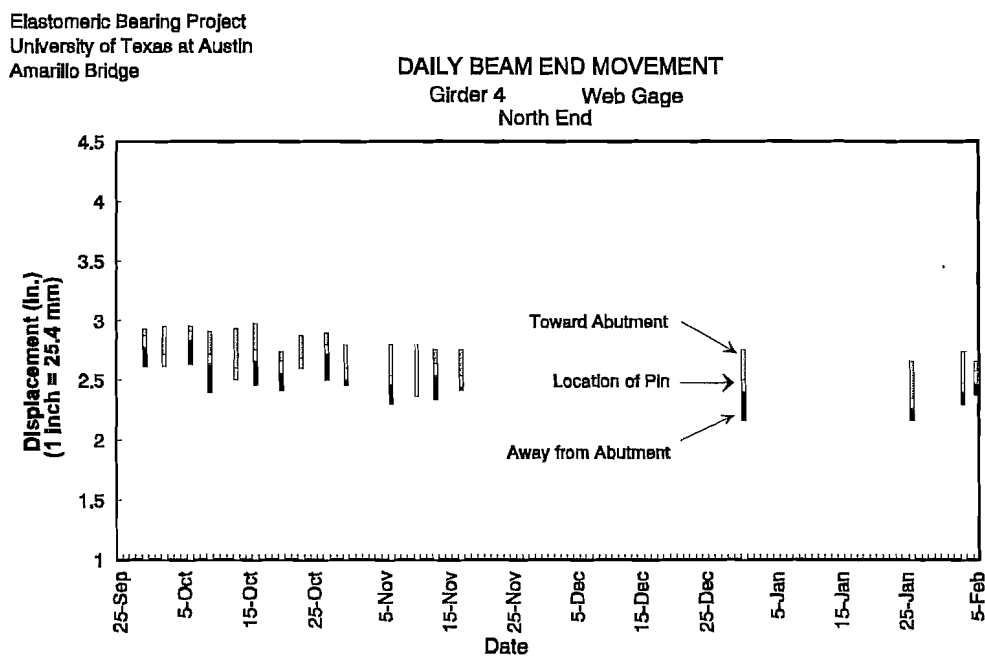


Figure 5.16 Typical girder movement at Alanreed

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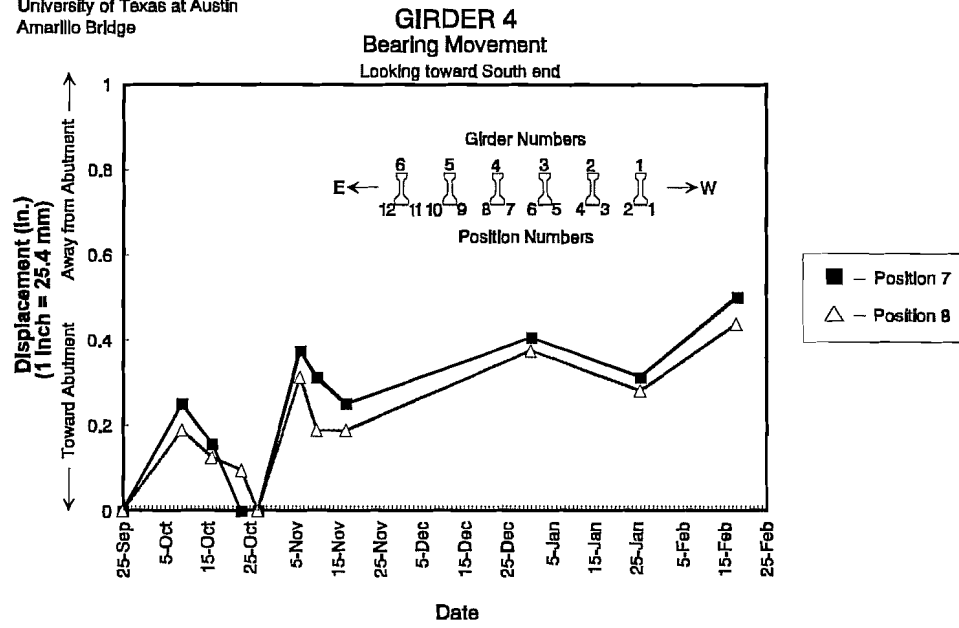


Figure 5.17 Typical bearing movement at Alanreed

CHAPTER 6

USE OF BRINSAP TO IDENTIFY BRIDGES WITH POSSIBLE BEARING PROBLEMS

6.1 General

BRINSAP (Bridge Inventory, Inspection, and Appraisal Program) is the TxDOT program to implement the National Bridge Inspection Standards [16] issued by the Federal Highway Administration. The objectives [17] of BRINSAP are as follows:

- To ensure the prompt discovery of any deterioration or structural damage that could become hazardous to the traveling public or that could become more costly to repair if corrective measures are not taken.
- To maintain an up-to-date inventory which indicates the condition of all bridges on public roadways.
- To maintain service records from which to appraise the relative value of various types of construction and repair.
- To determine the extent of minor deterioration requiring routine maintenance and repair work as the basis for planning bridge maintenance programs.
- To determine the extent of major deterioration requiring rehabilitation or replacement as the basis for planning bridge replacement and rehabilitation programs.

The objective of this part of the field study was to determine potential "problem" bridges based upon the characteristics of the bridges which are found in BRINSAP. BRINSAP is in the form of a database; dBASE IV [18] was used to manipulate the data.

6.2 Components of the Bridge Search

As shown in Figure 6.1, three components were involved in the search for "problem" bridges. Each is described below.

6.2.1 Preliminary Bridge List. The bridges noted in the preliminary study as having bearing problems (Table 4.1) were located in BRINSAP. Those bridges were then used as the starting point from which to determine characteristics of "problem" bridges.

6.2.2 Bridge Characteristics. The Preliminary Bridge List was carefully examined. Any BRINSAP characteristics which seemed to be shared by "problem" bridges were identified. As is

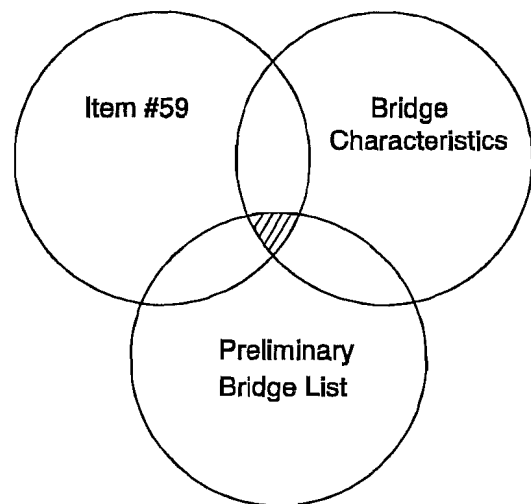


Figure 6.1 Search components

explained later, those characteristics were used as search parameters to try and find additional bridges in the entire BRINSAP data base that might be experiencing bearing problems.

6.2.3 Item #59. Item #59 in BRINSAP contains information about the condition of the bridge superstructure, as obtained from the inspection record shown in Figure 6.2. The minimum rating that each component can receive is listed on the left (under Min.), and the overall component rating is the minimum rating of the components. The minimum rating allowed for bearings is six. An overall component rating of six or less could indicate possible bearing problems.

Min.	Superstructure (Item 59)	Rating
0	Main Members - Steel _____	<input type="text"/>
0	Main Members - Concrete _____	<input type="text"/>
0	Main Members - Timber _____	<input type="text"/>
0	Floor System Members _____	<input type="text"/>
1	Floor System Connections _____	<input type="text"/>
1	Secondary Members _____	<input type="text"/>
5	Secondary Member Connections _____	<input type="text"/>
5	Expansion Bearings _____	<input type="text"/>
6	Fix Bearings _____	<input type="text"/>
6	Steel Protective Coating _____	<input type="text"/>
6	Other _____	<input type="text"/>

Component Rating _____

Comments _____

6.3 BRINSAP Search Procedure and Results

6.3.1 Bridge Characteristics (Criteria). Based on the analysis described in Section 6.2.2, the following search criteria were established:

- The number of spans ≥ 3
- The type of deck construction (continuous, simple, etc...) = simple
- The total length of bridge ≥ 200 feet (60.96 m)
- The year designed ≥ 1970

Figure 6.2 Item #59 (superstructure)

These criteria were based upon original recommendations by TxDOT, that natural rubber bearings should not be used in bridges that have long spans, high grades, and "poor-boy" slabs. In these recommendations "poor-boy" slab referred to a continuous deck over simply supported girders. However, bridges known to have this type of construction are listed in BRINSAP as having a simple deck construction. Based on this fact, the type of deck construction used for the search criterion was "simple." Using these criteria, a search was conducted on BRINSAP, and a list of bridges having these characteristics was output. The list comprised several thousand bridges. Therefore, it was considered necessary to develop a refined set of search criteria.

6.3.2 Item #59. The next step was to explore the possibility of a correlation between Item #59 and "problem" bridges. Item #59 was checked for all the bridges listed in Table 4.1. The use of Item #59 proved to be unsuccessful, because most of the bridges had a rating of seven (good condition) or higher. This indicates that the inspectors either do not properly monitor the bearings, or that "walking out" of the bearings is not considered a problem by the inspectors.

6.3.3 Refinement of Search Criteria. The final step was to develop better search criteria and to reduce the number of potential "problem" bridges. The search criteria were expanded by locating each "problem" bridge in BRINSAP. Every characteristic contained in BRINSAP was studied for each "problem" bridge, and any item which was the same for a majority of the "problem" bridges, regardless of the significance to actual bridge characteristics, was

included in an expanded list of search criteria. The final search criteria used are shown in Table 6.1. By expanding the search criteria to include more items, the list of potential "problem" bridges was significantly reduced. However, the list was still not reduced to a reasonable number; therefore, "problem" bridges could not be determined using the characteristics which are contained in BRINSAP.

6.4 Summary of BRINSAP Study

Therefore, it may be concluded that either BRINSAP does not contain the bridge characteristics which cause bearing movement, or bearing movement is largely independent of the characteristics of the bridge. It is recommended that Item #59 should be broken down in subsections with each component having its own section and inspectors should increase the scope of their inspection to include bearing movement and to include it as a problem.

Table 6.1

Final Search Criteria			
Item	Condition	Item	Condition
Year Built	≥ 1970	Number of Main Spans	≥ 2
Lanes on the Structure	≥ 2	Number of Minor Approach Spans	= 0
Lanes under the Structure	≤ 8	Total Number of Spans	≥ 4
Average Daily Traffic	≤ 26000	Length of Maximum Span	≥ 70
Design Load	= HS20	Structure Length	≥ 300
Approach Roadway Width	≤ 70	Type of Loading	= HS
Bridge Median	= No	Gross Loading Tons	= 49
Structure Flared	= No	Approach Roadway Alignment	= 8
Load Restriction	= 0	Deck Structure Type, Main Span	= Concrete Cast-in-Place
Structure Type	= Prestressed Concrete Simple Span	Direction of Traffic	= 1 or 2 way traffic
Wearing Surface, Main Span	= Concrete	Average Daily Truck Traffic	≤ 20

CHAPTER 7 SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

7.1 Summary

This report deals with Phase One of TxDOT Project 1304 (Behavior of Elastomeric Bearings). The overall objectives of that project are:

- to recommend procedures for designing elastomeric bearings used by TxDOT
- to recommend practical guidelines and procedures for inspecting existing and future elastomeric bearings.

The overall objectives of Phase One of that project are:

- to verify field reports
- to conduct field surveys
- to document bearing and girder movements

To accomplish the Phase One objectives, the following tasks were carried out:

- A comprehensive literature review was conducted
- Field reports were verified by site visits (Slaughter Creek, Beaumont, Paris, and Alanreed) and by coordination with the BRINSAP database
- Two bridges were selected for field instrumentation and study (Slaughter Creek and Alanreed) with emphasis on bearing and girder movement
- The BRINSAP database was used to identify bridges that might have bearing problems

The results of the field study can be summarized as follows:

- Two bridges were instrumented and monitored
- Bearing and girder movement was monitored on both bridges. The effect of resetting the original natural rubber bearings at the Slaughter Creek bridge was compared with the effect of replacing the rubber bearing with a neoprene bearing.
- Girder movement was measured up to 3/8-inch (9.53 mm) in contraction and expansion, due to temperature changes, both daily and seasonal variations were recorded. It was shown that these movements were easily predicted with simple engineering models.

- After the various resetting and replacement operations the bearing movement measured at Slaughter Creek was inconsistent and not reproducible. Movement was found to be zero at one time and then unlimited at another time, with no apparent change in loading conditions. However, when it did occur, bearing movement was immediate.
- Resetting the natural rubber bearings was ineffective. However, when the natural rubber was replaced with neoprene bearings, bearing movement stopped.

7.2 Conclusions

- Bearing movement is primarily driven by girder thermal movement.
- Girder thermal movement consistently agrees with simple calculations.
- Bearing movement is inconsistent, not stopped by resetting, but stopped by replacement with neoprene.
- Correctly designed neoprene bearings are not moving and natural rubber bearings are moving under the same loading conditions.

7.3 Recommendations

The majority of bearing movement problems have involved natural rubber bearings. Thus far, no clear relationship has been established between bridge characteristics and the likelihood of bearing movement. As a result, it is not now possible to specify those bridge characteristics which would be associated with satisfactory performance of natural rubber bearings.

Therefore, because it is impossible to predict which bridges will experience no problems with movement of natural rubber bearings, and because practically no movement problems have been experienced with neoprene bearings, the most logical recommendation at this time seems to be a continuation of the current TxDOT prohibition against the use of natural rubber bridge bearings. Laboratory tests conducted as part of Phase 2 will be able to determine whether the problem is with the material of the bearings or with the design of the bearings.

APPENDIX A - GIRDER MOVEMENT FOR IN-DEPTH FIELD STUDIES

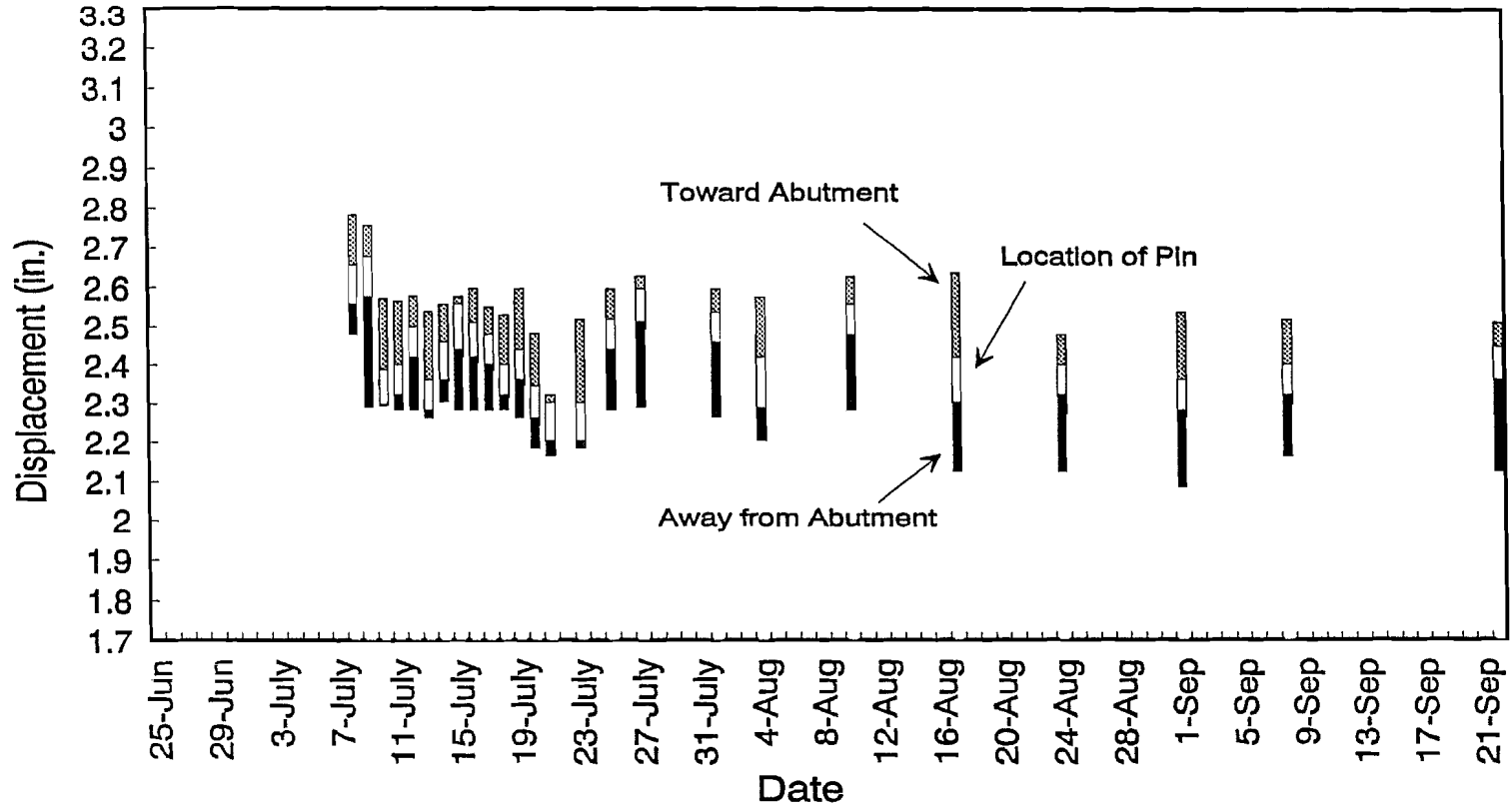
A.1 - Slaughter Creek Girder Movement

Elastomeric Bearing Project
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Slaughter Creek Bridge

Bridge Lift II

DAILY BEAM END MOVEMENT

South End Lower Flange Gage

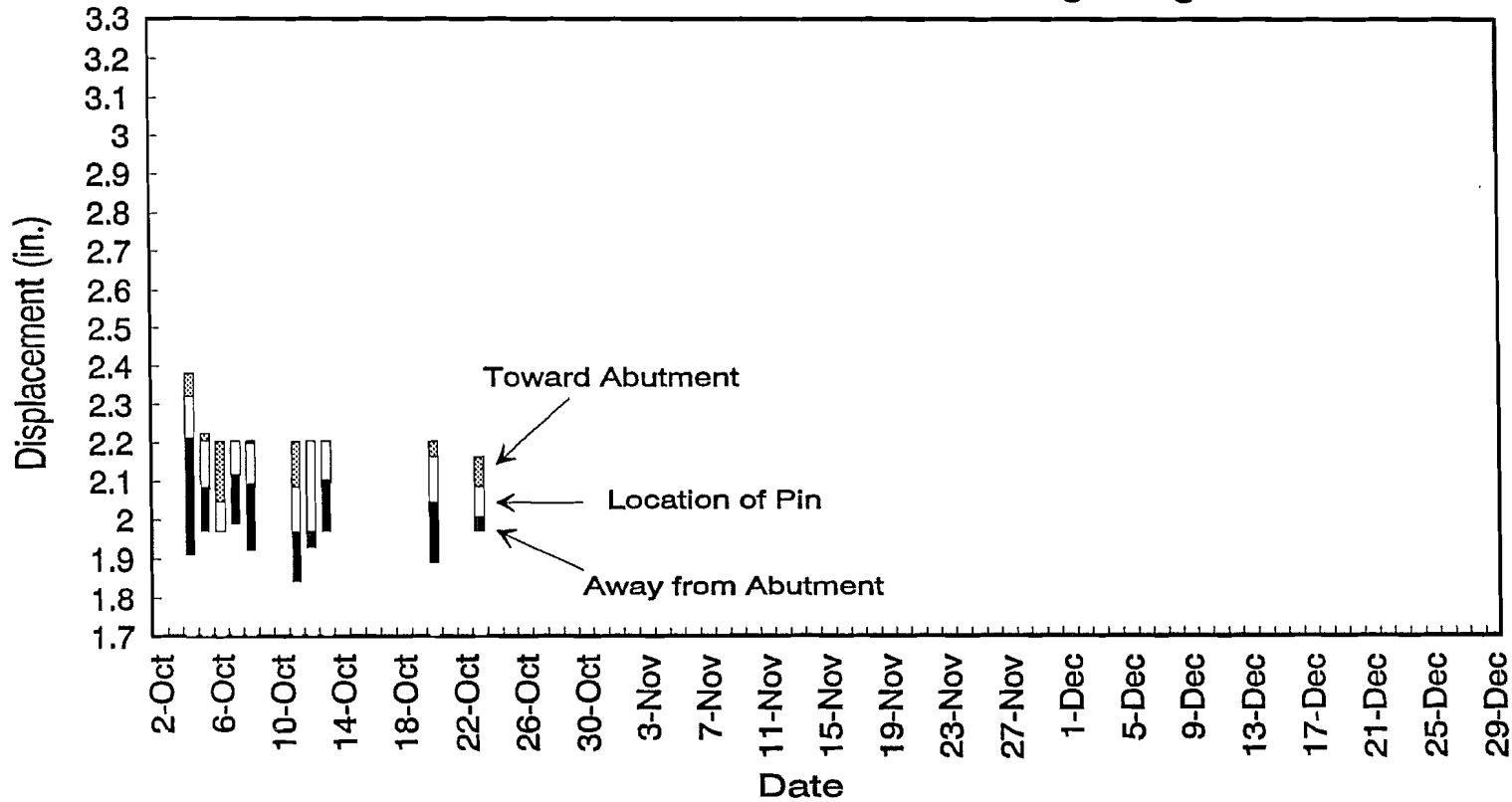


Note: 1 inch = 25.4 mm

Bridge Lift III

DAILY BEAM END MOVEMENT

South End Lower Flange Gage



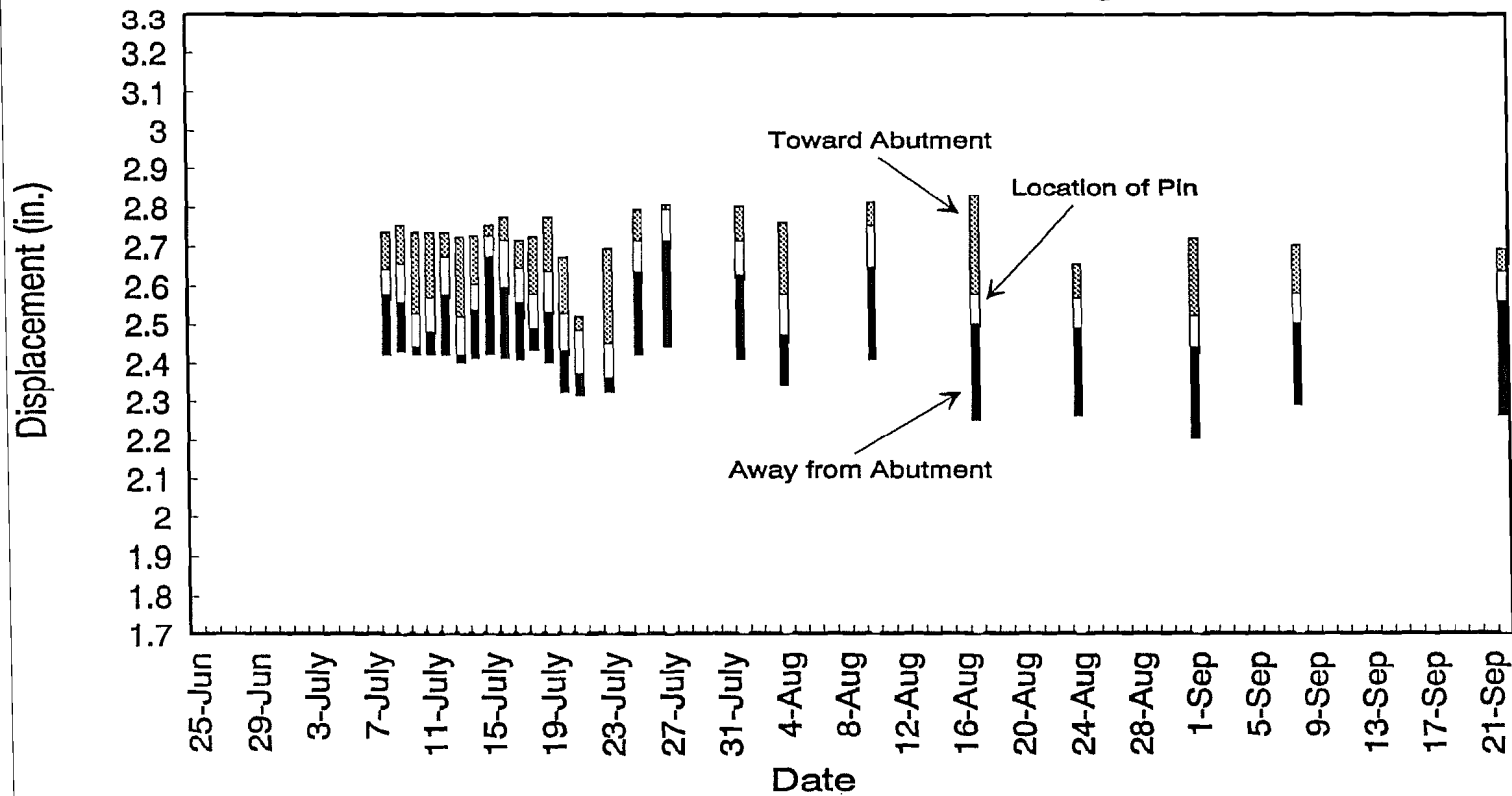
Note: 1 inch = 25.4 mm

Elastomeric Bearing Project
 University of Texas at Austin
 Slaughter Creek Bridge

Bridge Lift II

DAILY BEAM END MOVEMENT

South End Web Gage

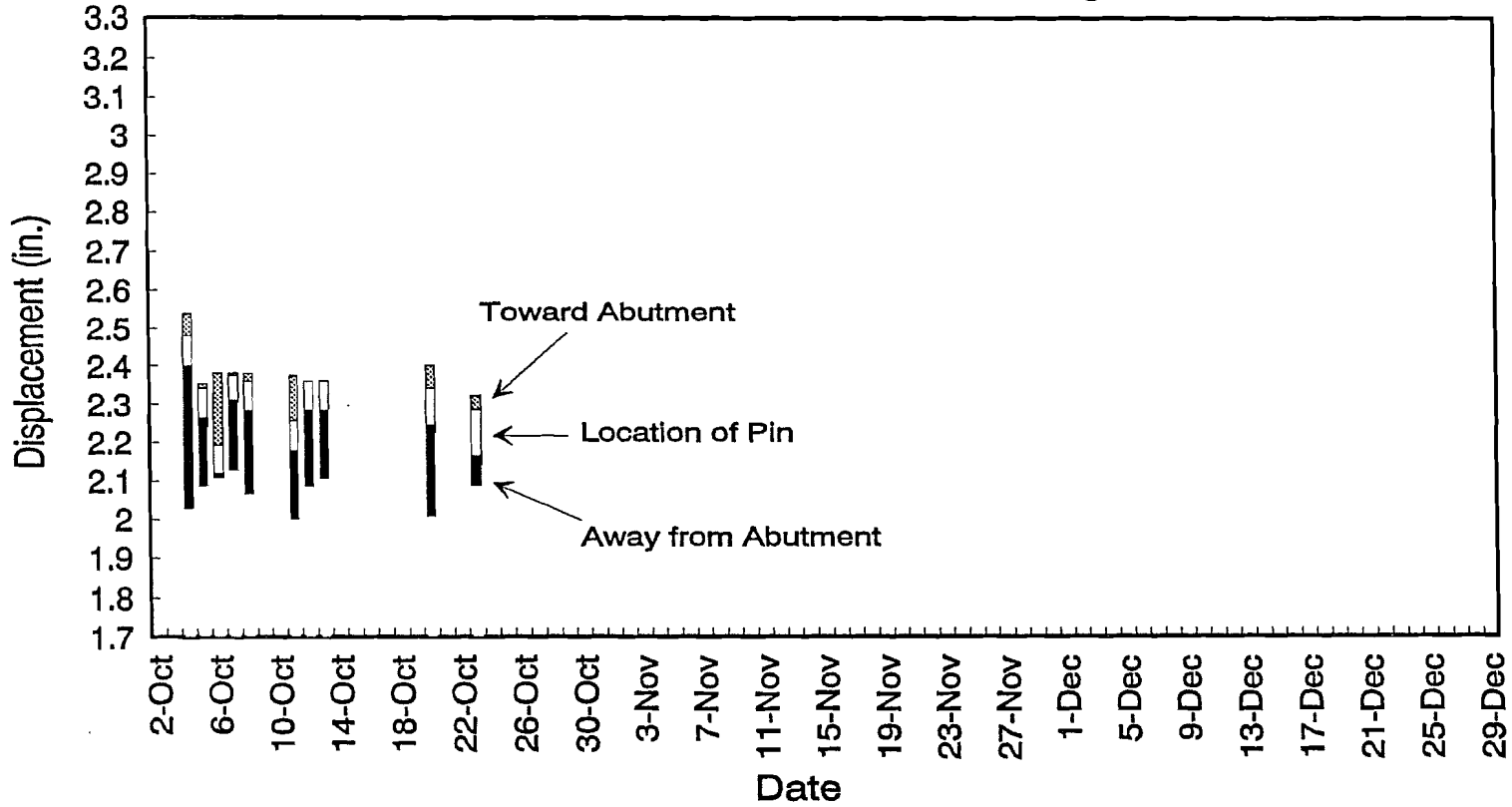


Note: 1 inch = 25.4 mm

Bridge Lift III

DAILY BEAM END MOVEMENT

South End Web Gage



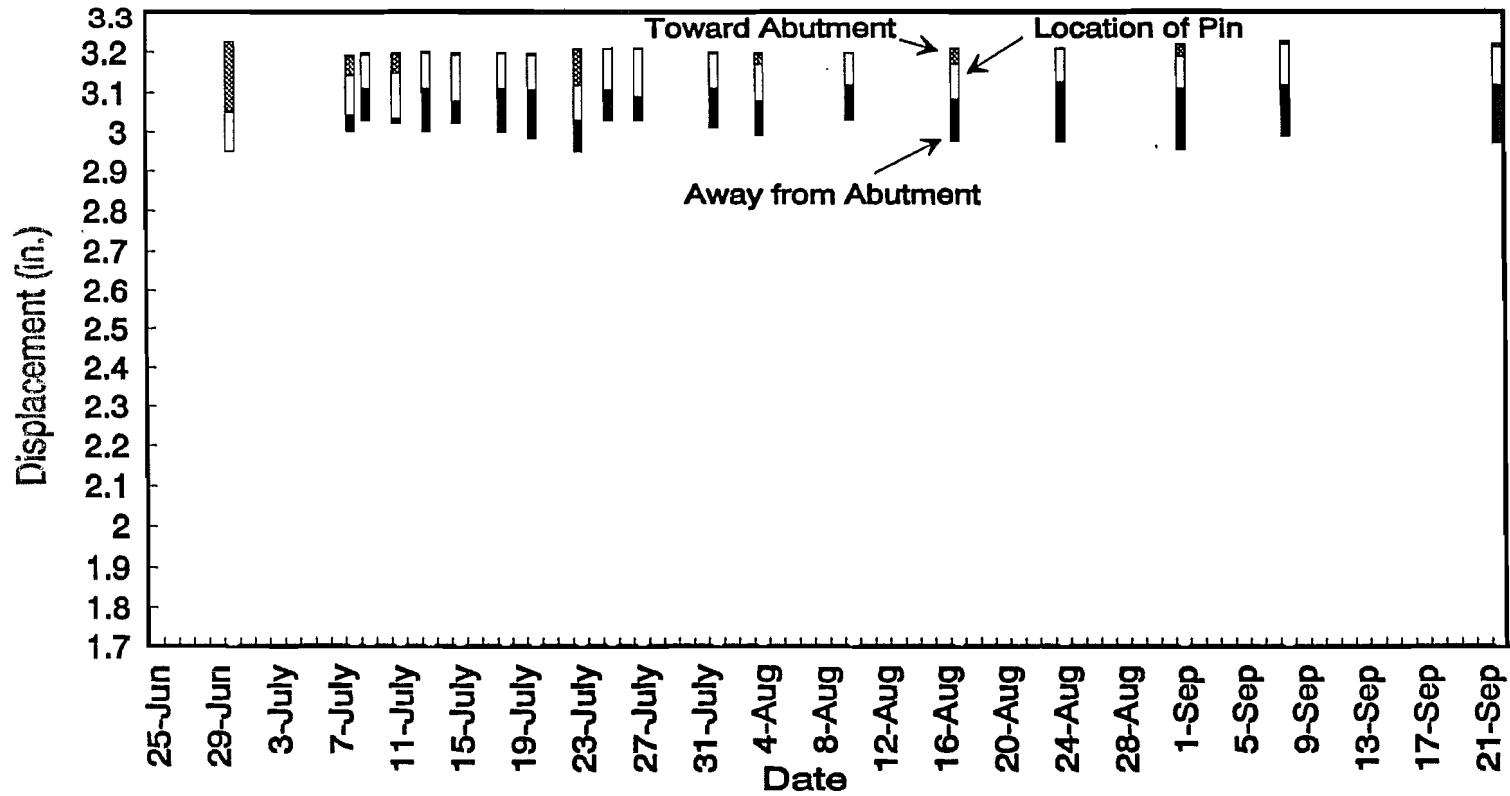
Note: 1 inch = 25.4 mm

Elastomeric Bearing Project
 University of Texas at Austin
 Slaughter Creek Bridge

Bridge Lift II

DAILY BEAM END MOVEMENT

North End Upper Flange Gage

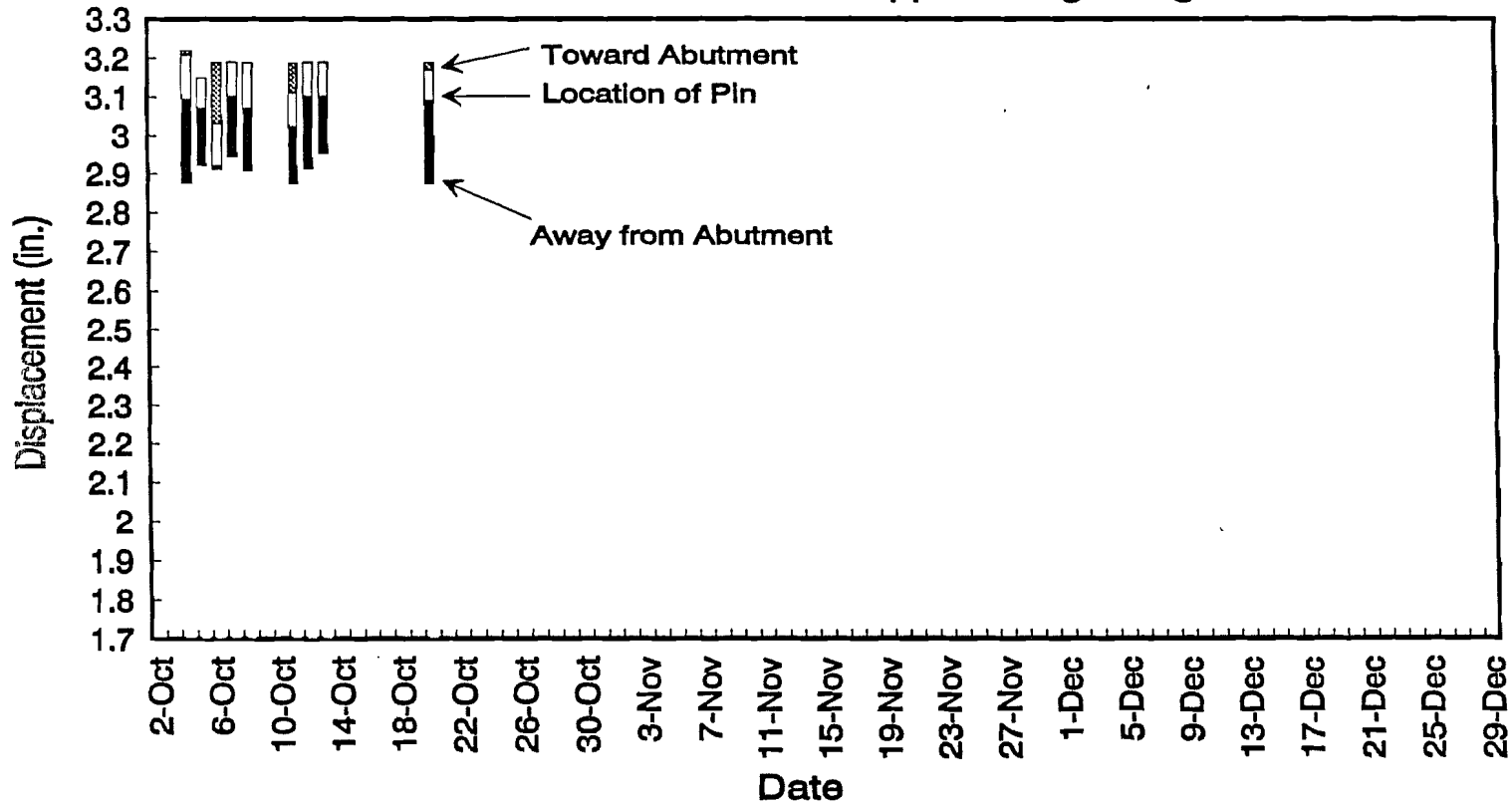


Note: 1 inch = 25.4 mm

Bridge Lift III

DAILY BEAM END MOVEMENT

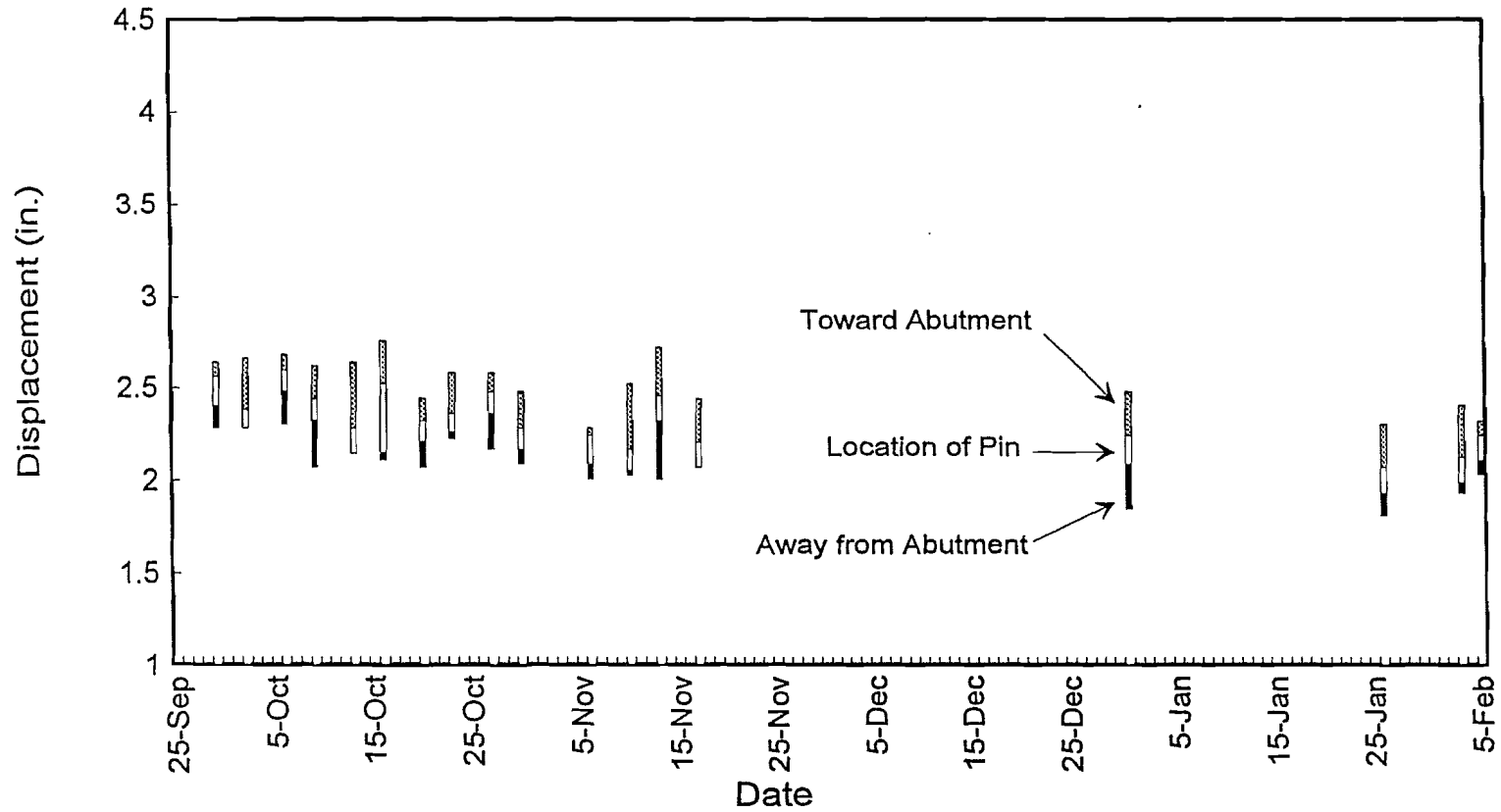
North End Upper Flange Gage



Note: 1 inch = 25.4 mm

A.2 - Alanreed Girder Movement

DAILY BEAM END MOVEMENT
Girder 1 Lower Flange Gage
South End

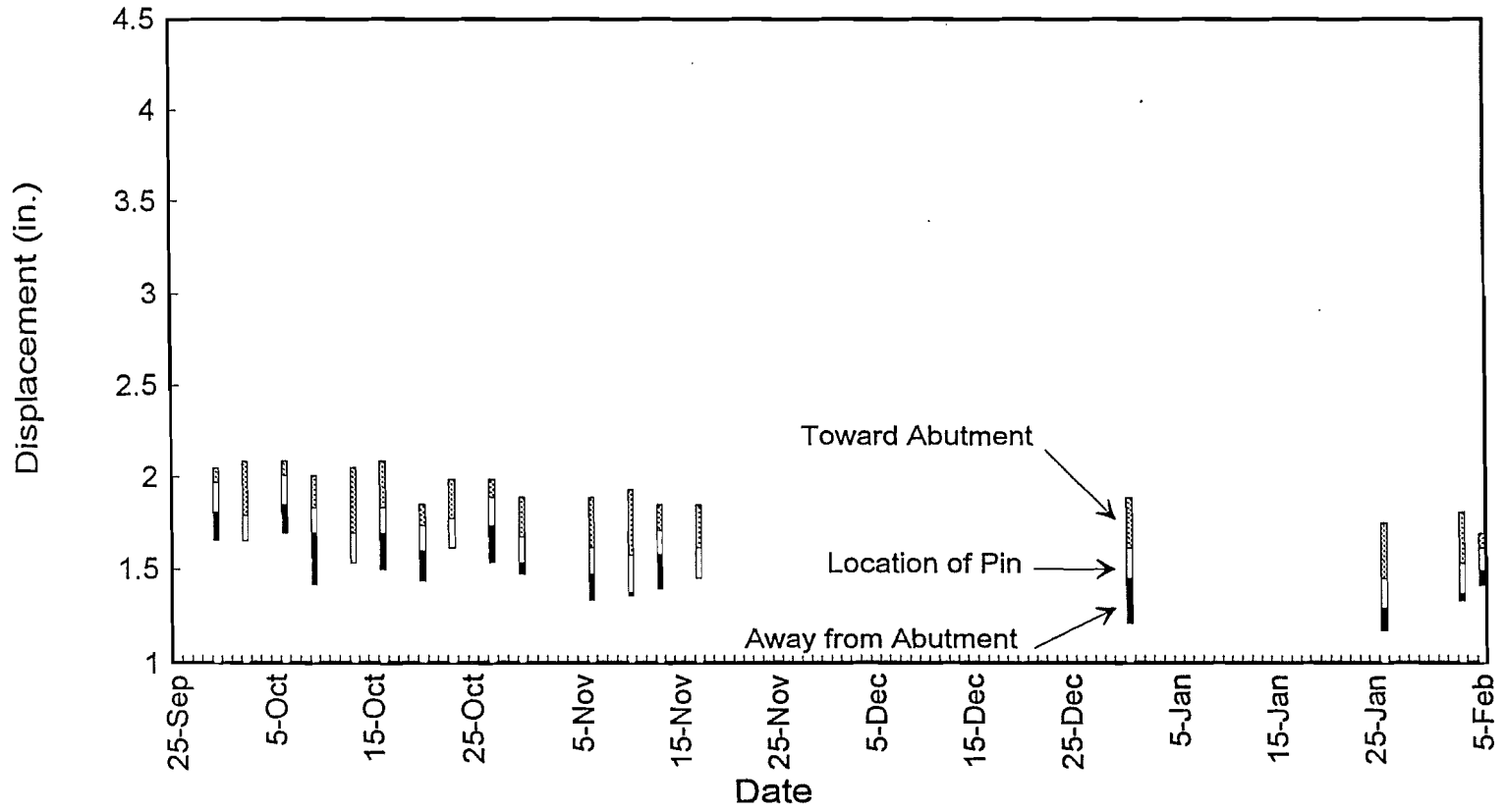


Note: 1 inch = 25.4 mm

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University of Texas at Austin
Amarillo Bridge

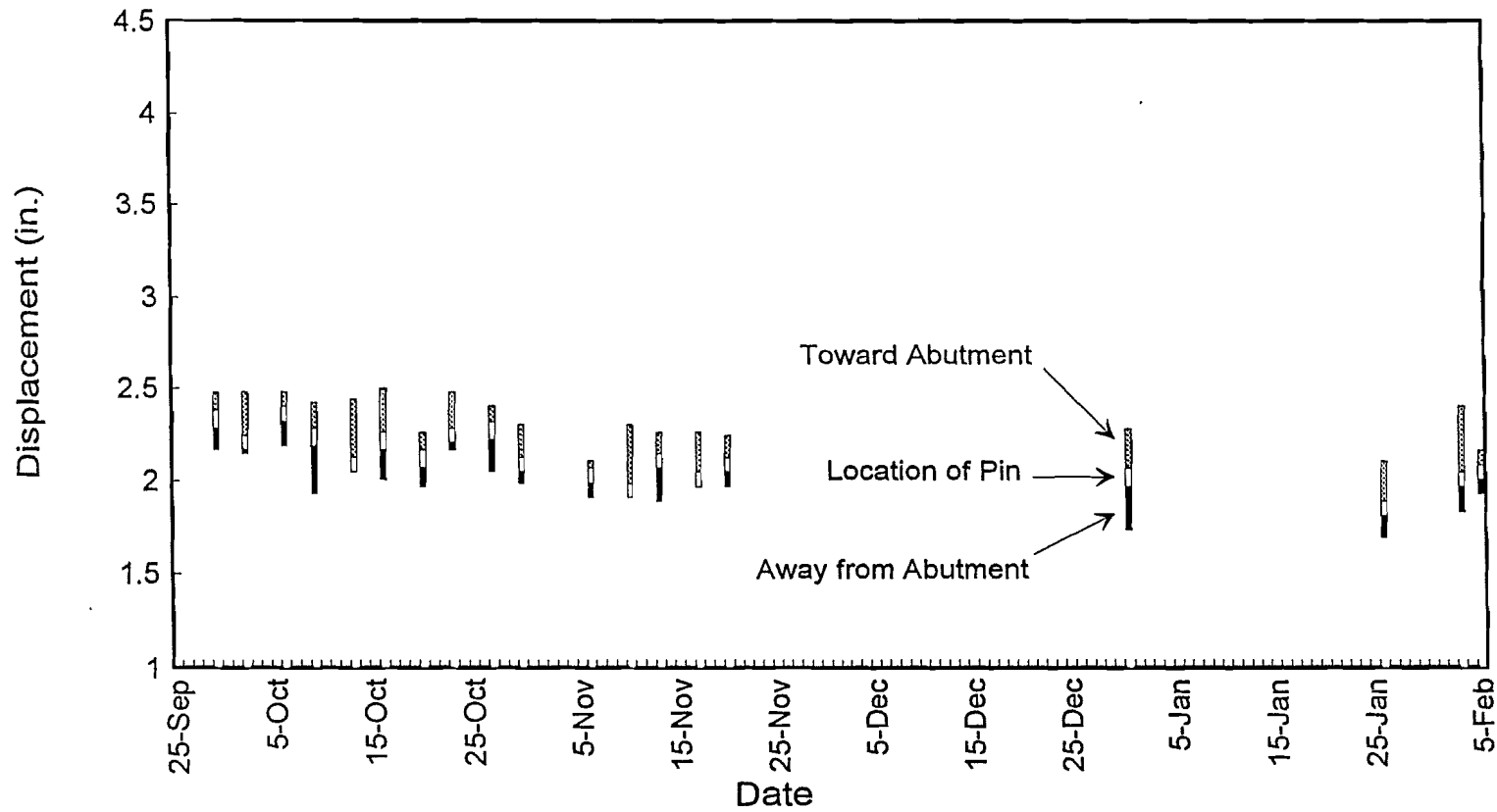
DAILY BEAM END MOVEMENT

Girder 1 Web Gage
South End



Note: 1 inch = 25.4 mm

DAILY BEAM END MOVEMENT
Girder 2 Lower Flange Gage
South End

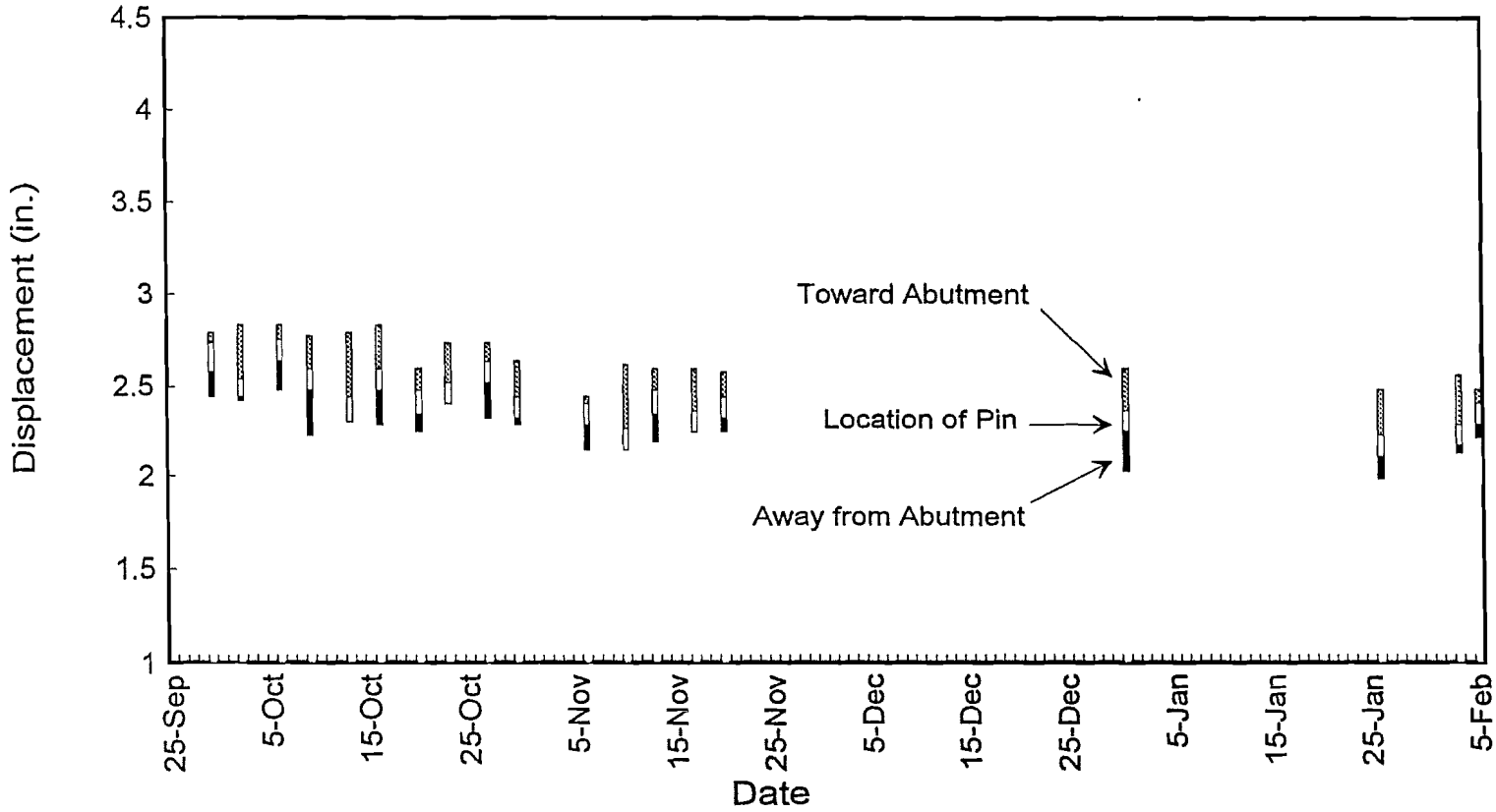


Note: 1 inch = 25.4 mm

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Amarillo Bridge

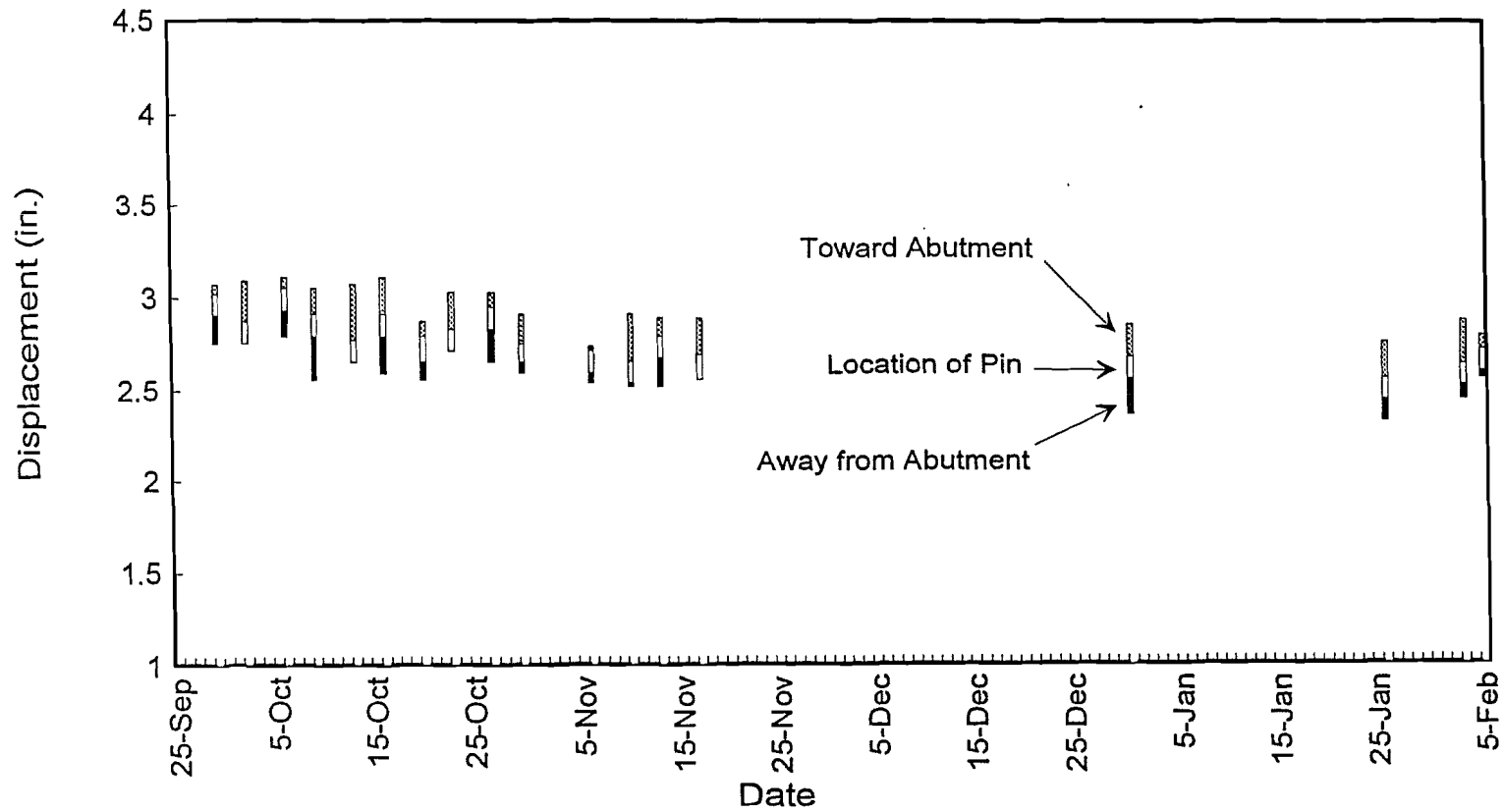
DAILY BEAM END MOVEMENT

Girder 2 Web Gage
South End



Note: 1 inch = 25.4 mm

DAILY BEAM END MOVEMENT Girder 3 Lower Flange Gage South End

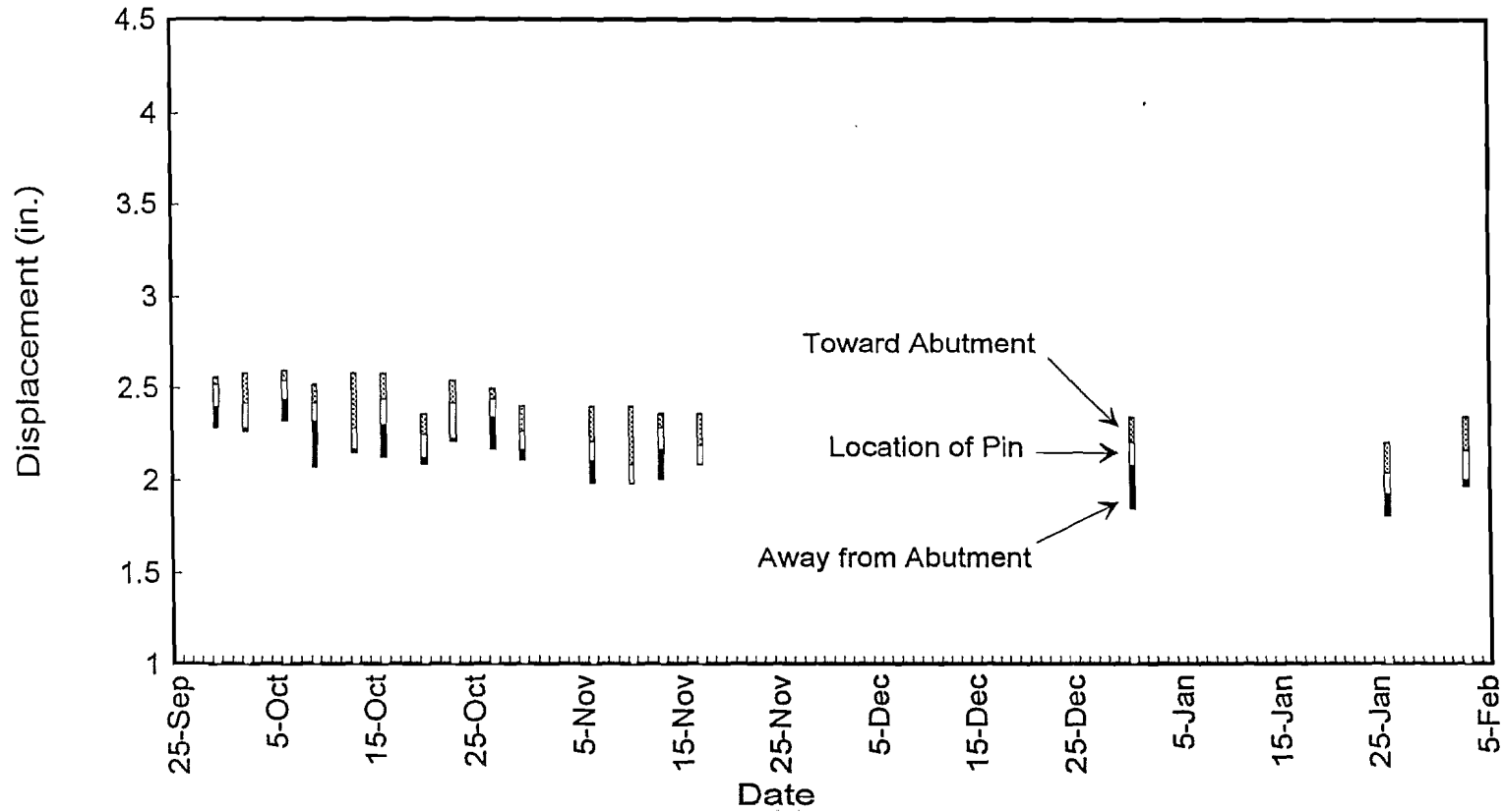


Note: 1 inch = 25.4 mm

Elastomeric Bearing Project
University of Texas at Austin
Amarillo Bridge

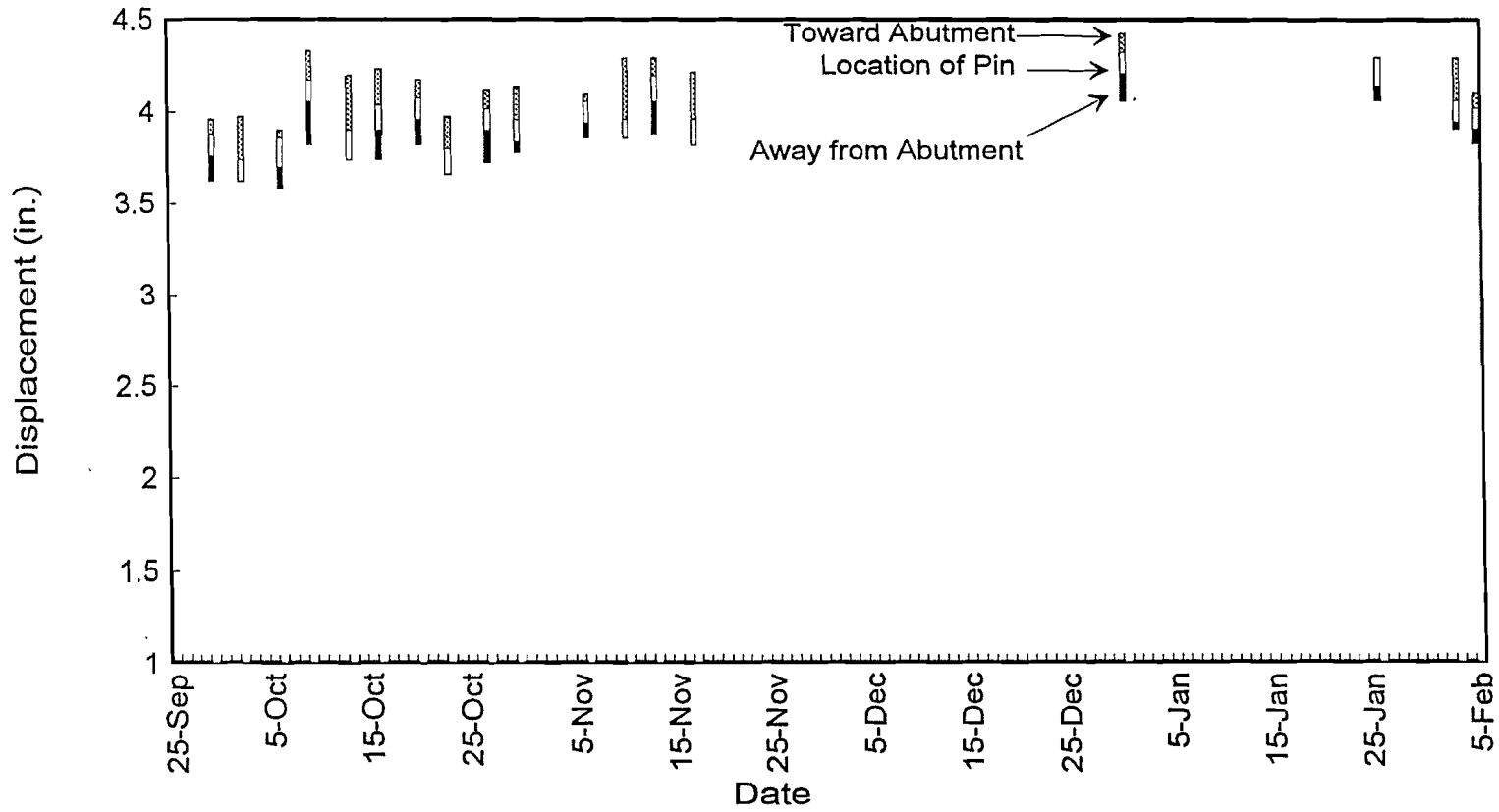
DAILY BEAM END MOVEMENT

Girder 3 Web Gage
South End



Note: 1 inch = 25.4 mm

DAILY BEAM END MOVEMENT Girder 4 Lower Flange Gage North End

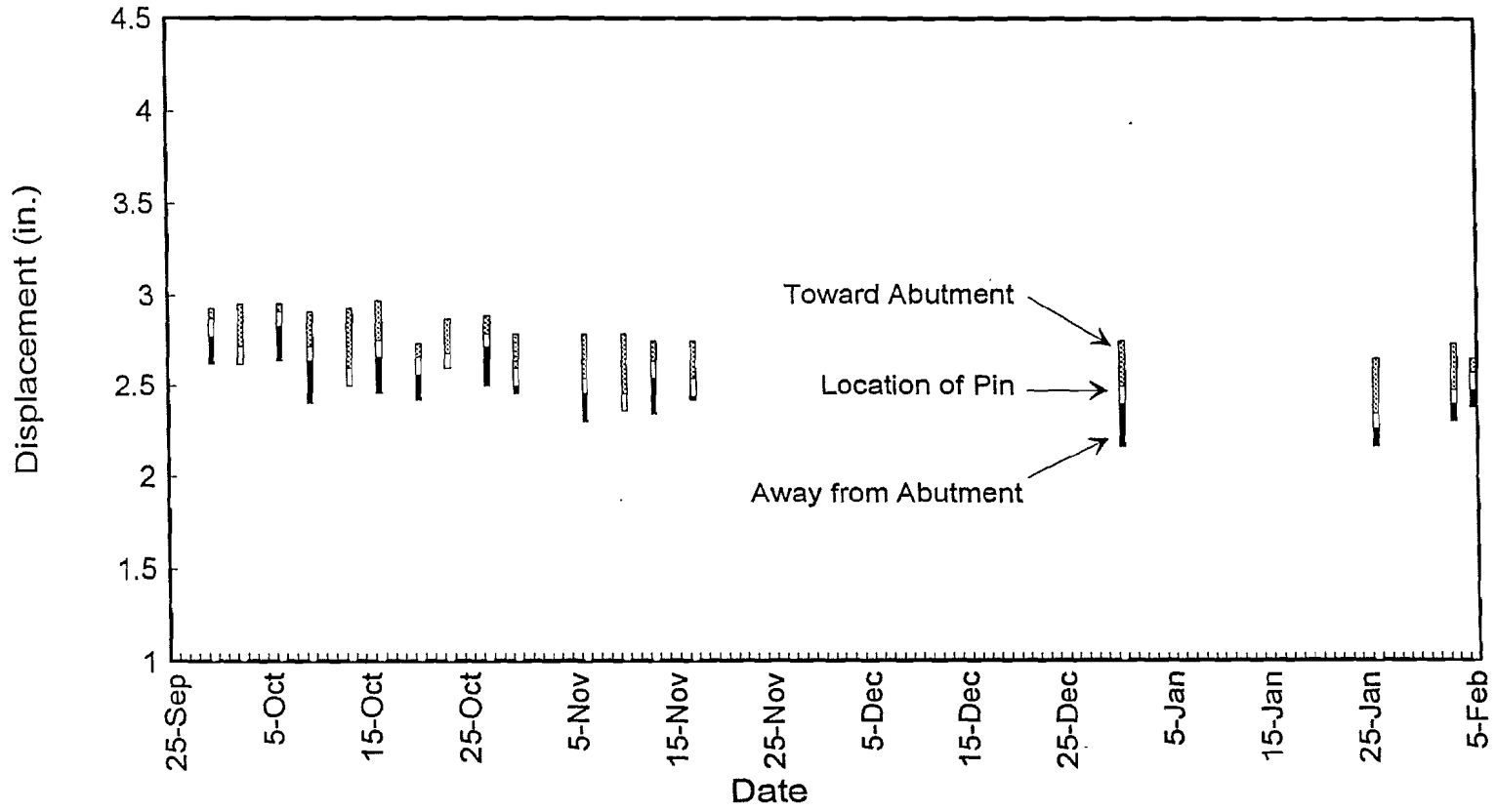


Note: 1 inch = 25.4 mm

Elastomeric Bearing Project
University of Texas at Austin
Amarillo Bridge

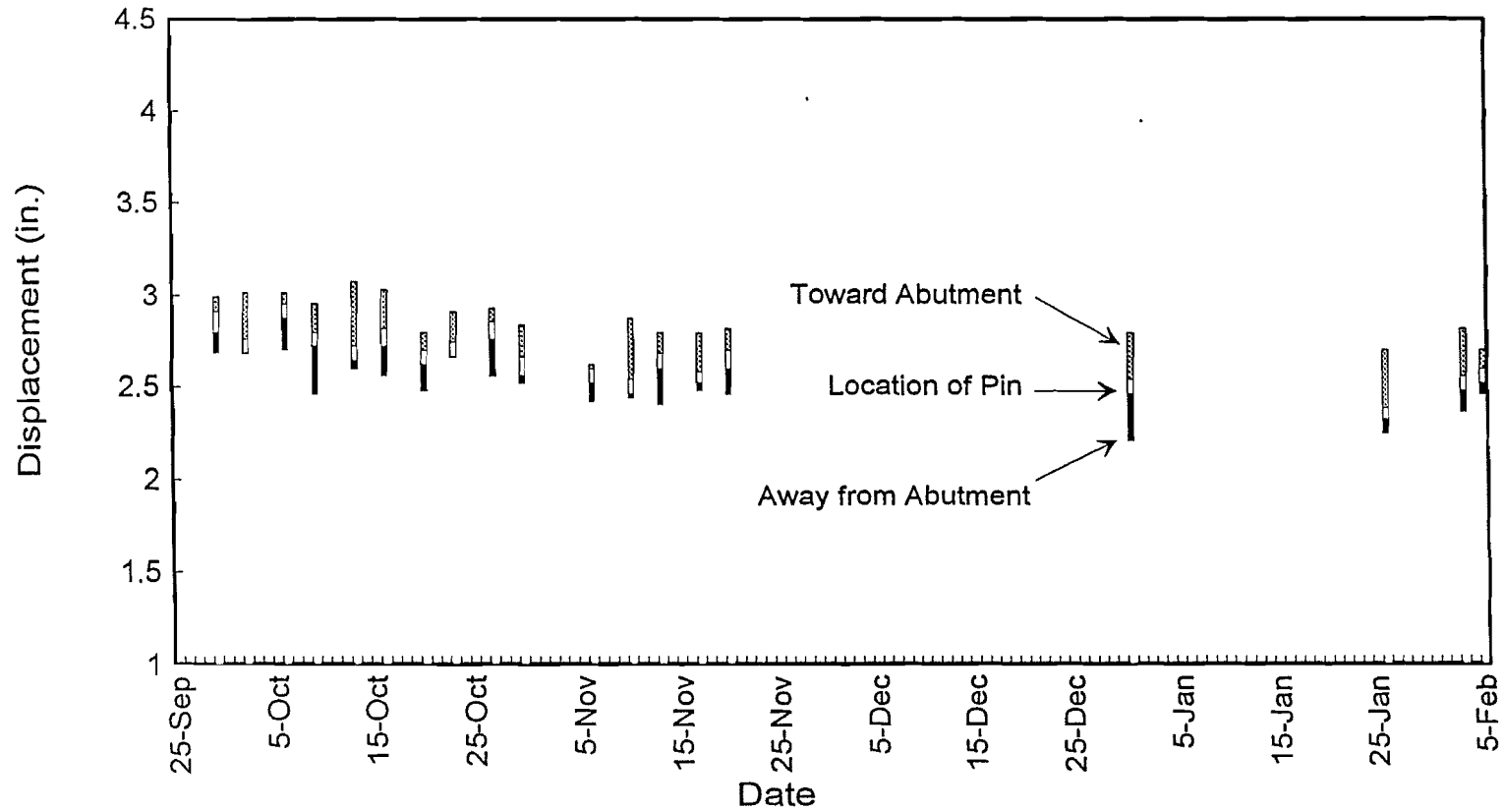
DAILY BEAM END MOVEMENT

Girder 4 Web Gage
North End



Note: 1 inch = 25.4 mm

DAILY BEAM END MOVEMENT Girder 5 Lower Flange Gage North End

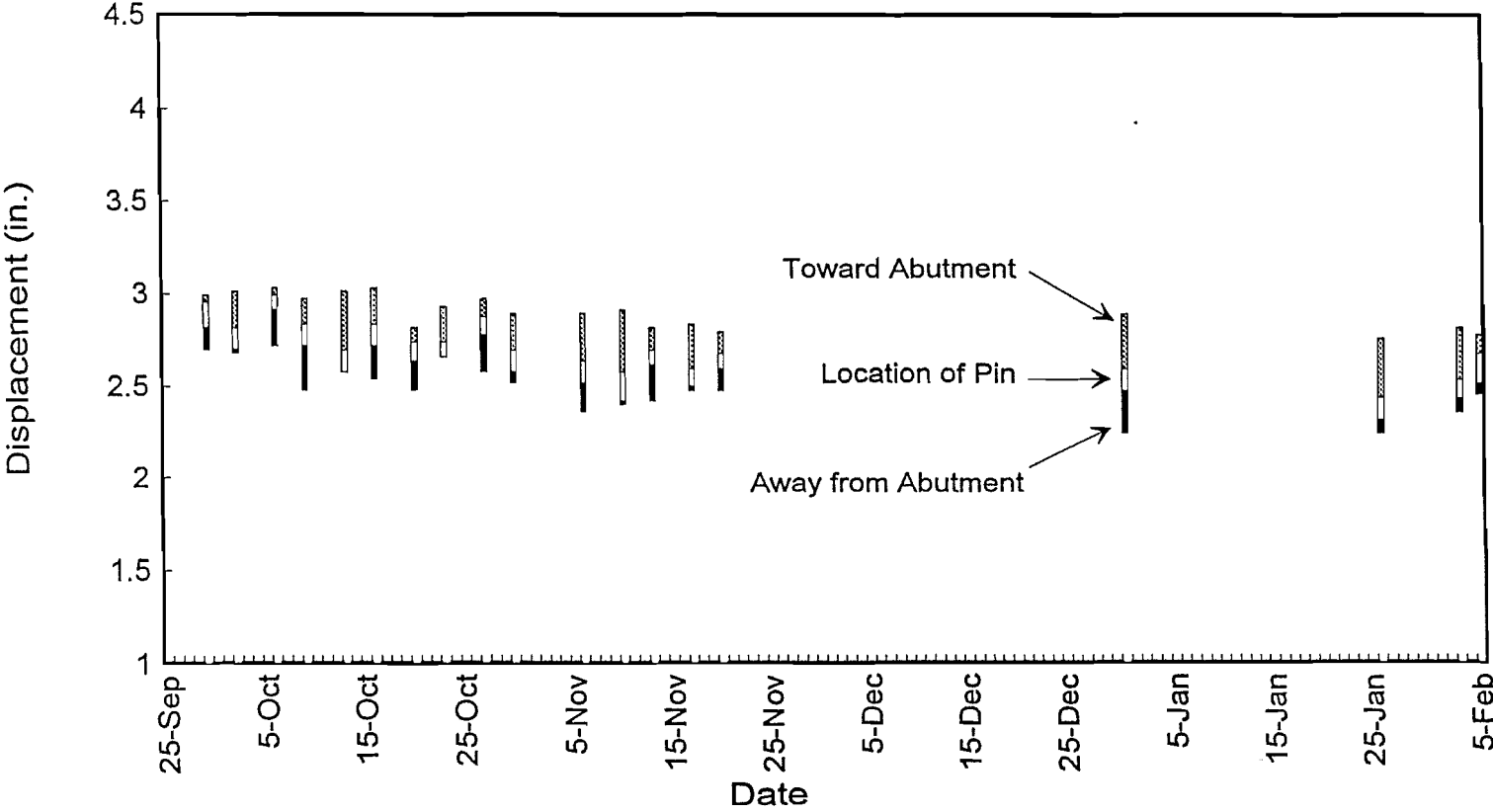


Note: 1 inch = 25.4 mm

Elastomeric Bearing Project
University of Texas at Austin
Amarillo Bridge

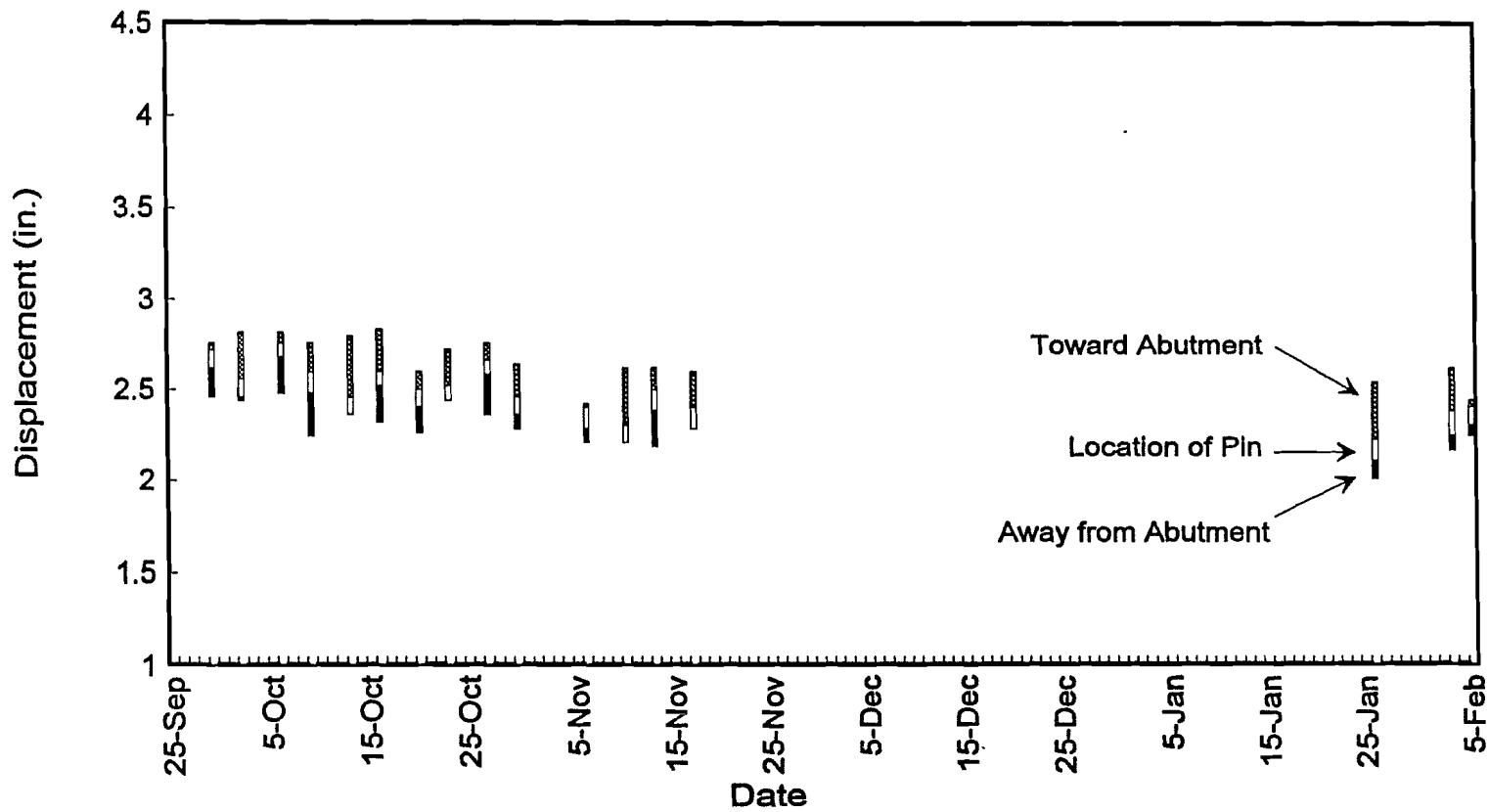
DAILY BEAM END MOVEMENT

Girder 5 Web Gage
North End



Note: 1 inch = 25.4 mm

DAILY BEAM END MOVEMENT Girder 6 Lower Flange Gage North End

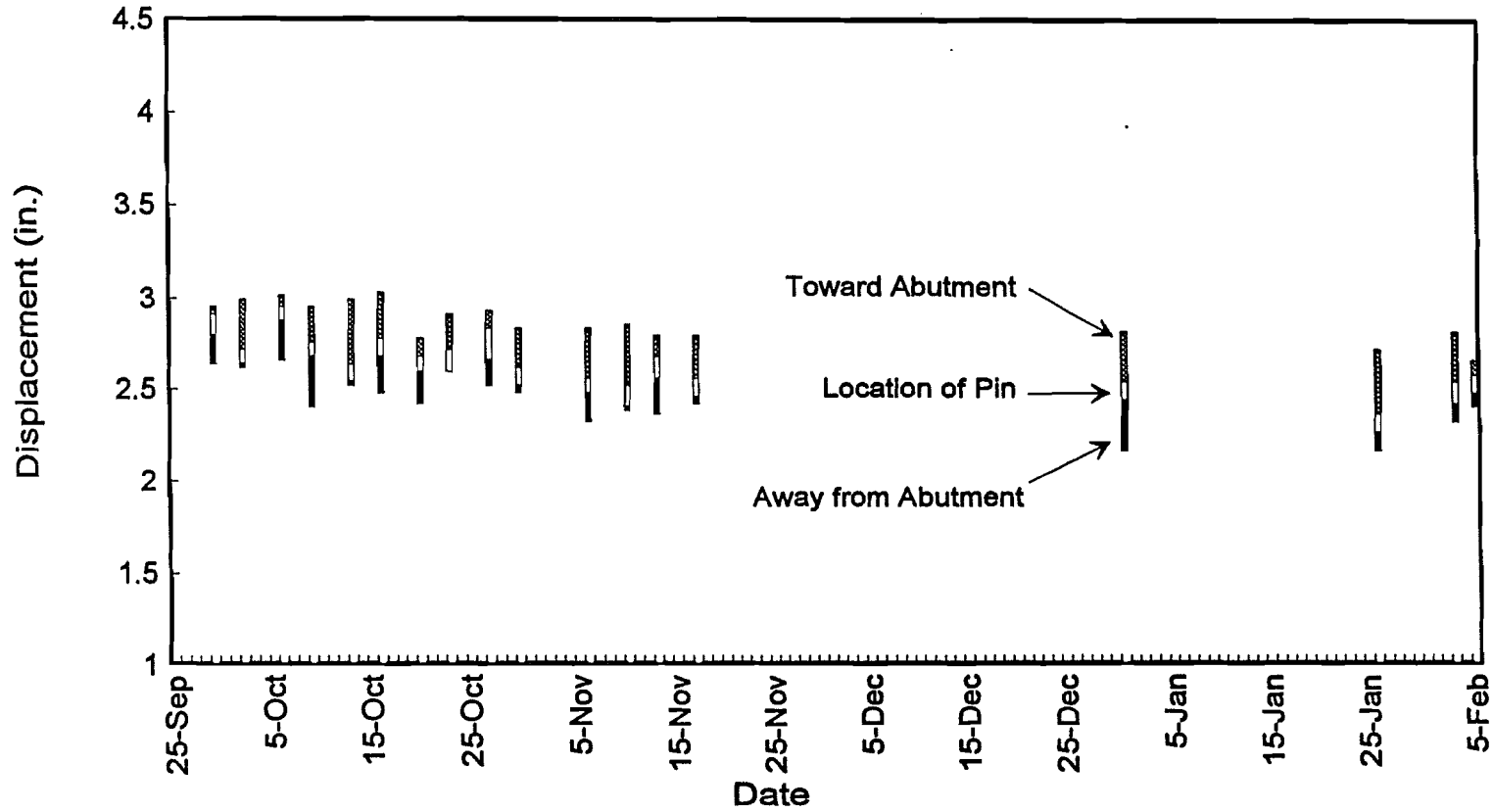


Note: 1 inch = 25.4 mm

Elastomeric Bearing Project
University of Texas at Austin
Amarillo Bridge

DAILY BEAM END MOVEMENT

Girder 6 Web Gage
North End



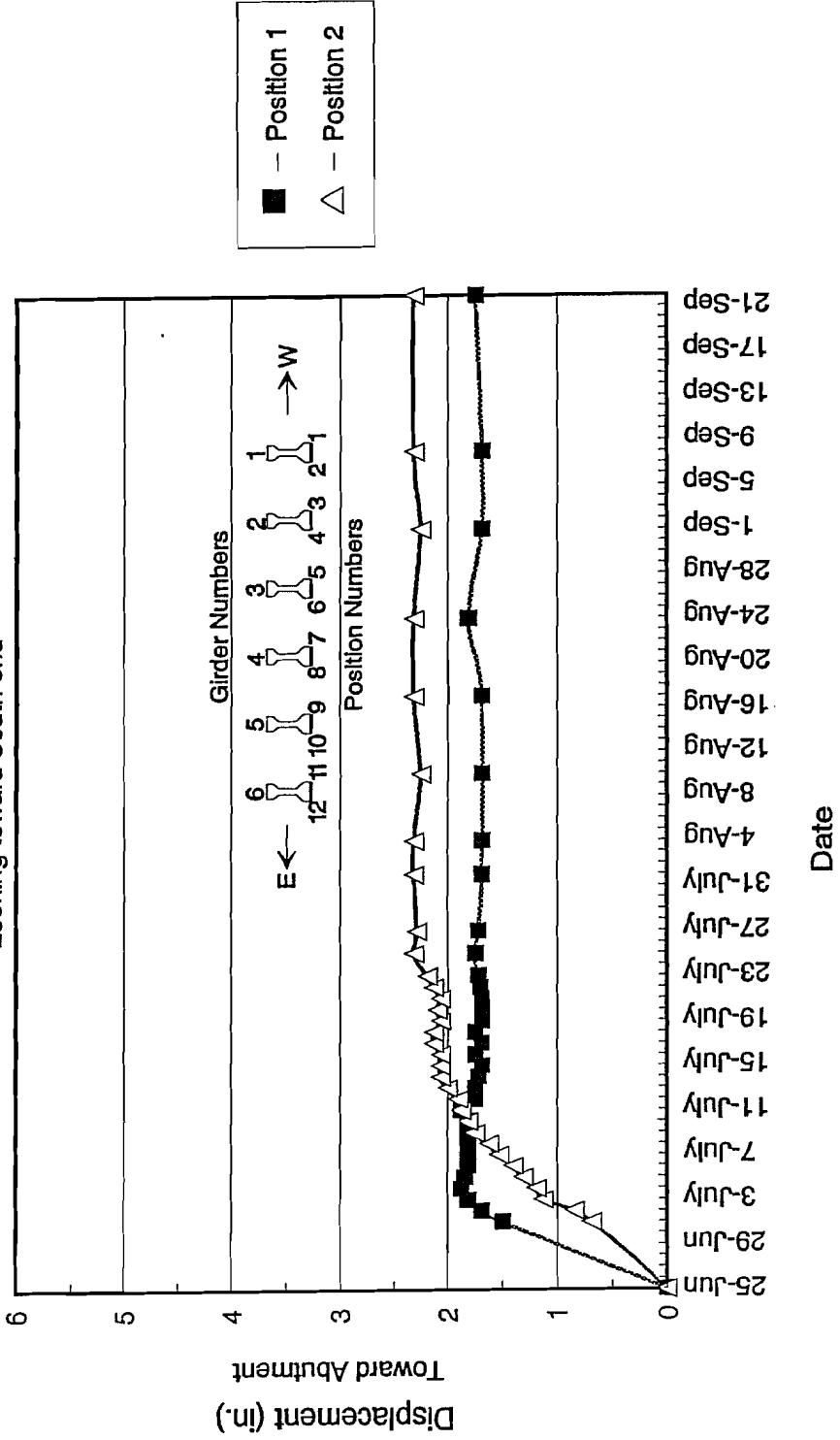
Note: 1 inch = 25.4 mm

APPENDIX B - BEARING MOVEMENT FOR IN-DEPTH FIELD STUDIES

B.1 - Slaughter Creek Bearing Movement

Elastomeric Bearing Project
 University of Texas at Austin
 Slaughter Creek Bridge

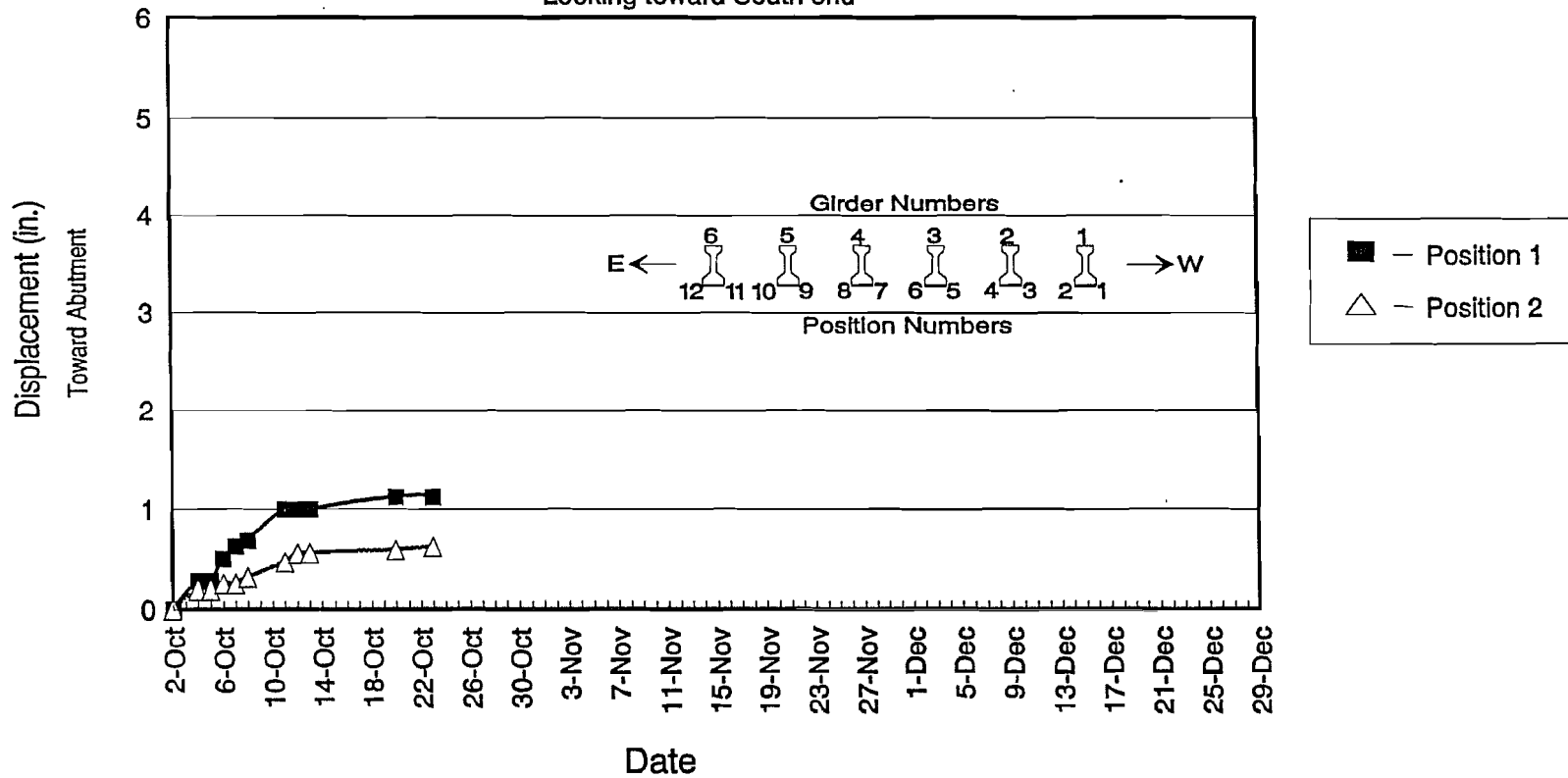
Bridge Lift II
GIRDER 1
 Bearing Movement
 Looking toward South end



Note: 1 inch = 25.4 mm

Elastomeric Bearing Project
 University of Texas at Austin
 Slaughter Creek Bridge

Bridge Lift III
GIRDER 1
 Bearing Movement
 Looking toward South end

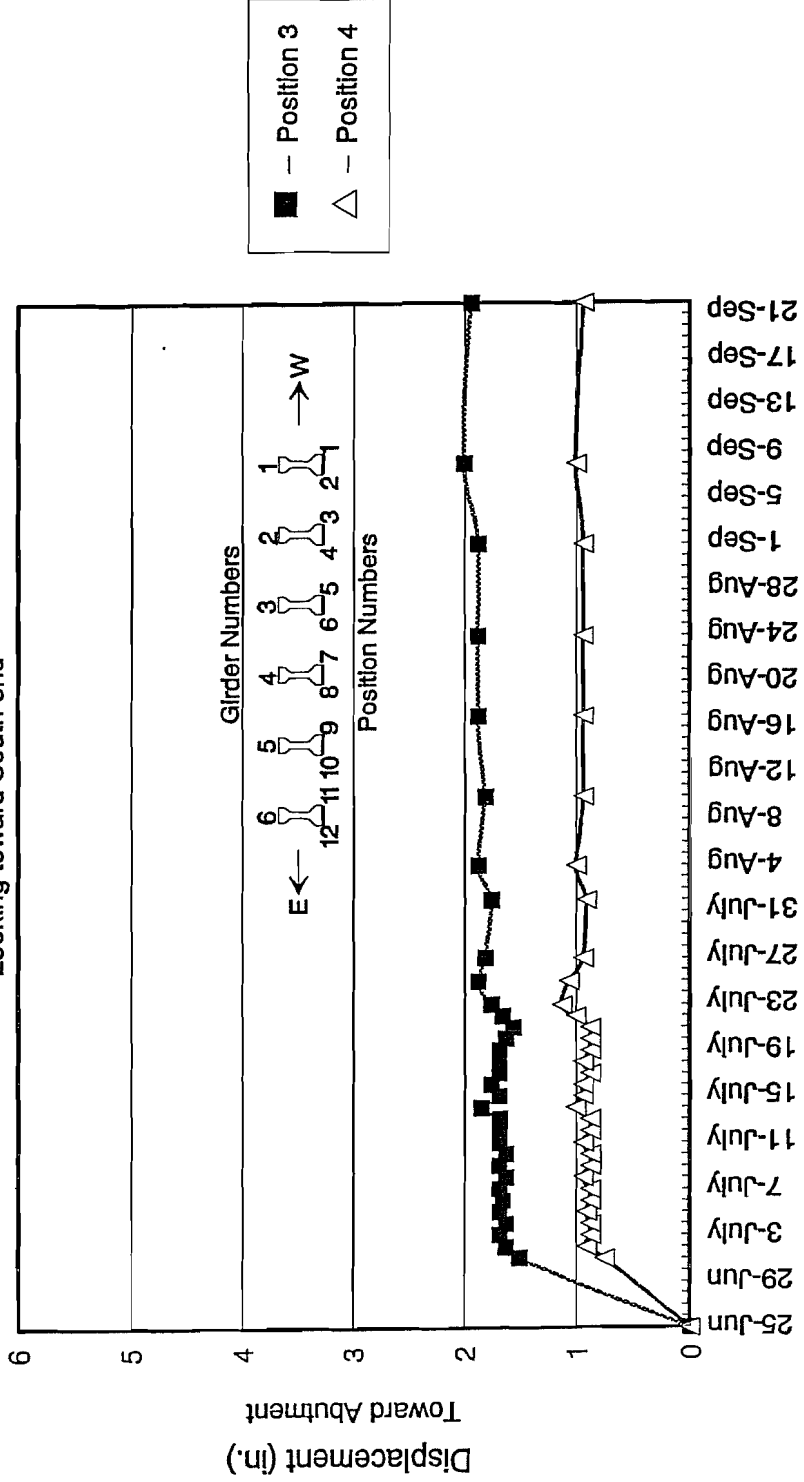


* Bearing under girder 1 has been rotated 180 degrees from its previous position during bridge lift II.

Note: 1 inch = 25.4

Elastomeric Bearing Project
 University of Texas at Austin
 Slaughter Creek Bridge

Bridge Lift II
GIRDER 2
 Bearing Movement
 Looking toward South end

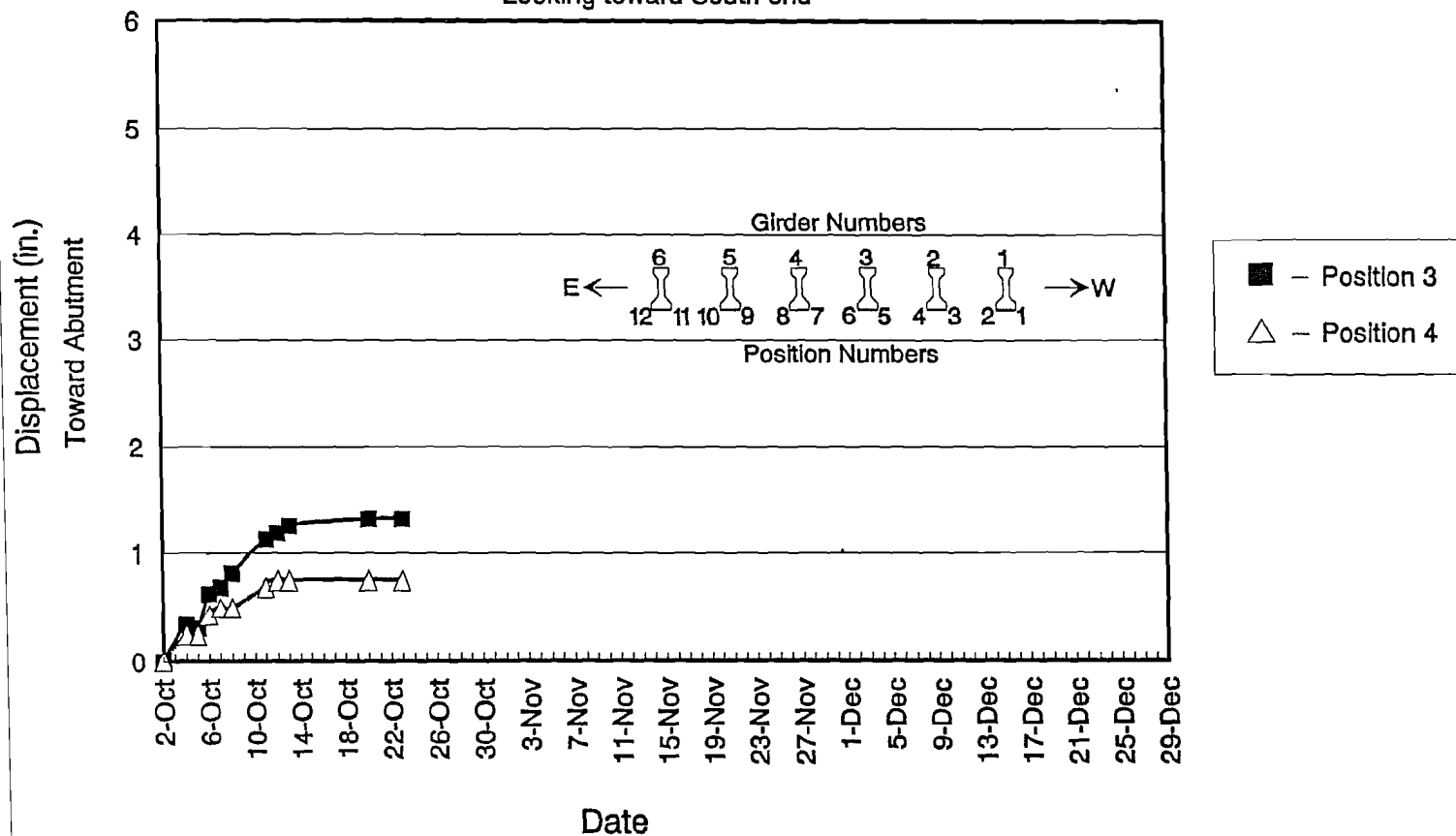


Date

Note: 1 inch = 25.4 mm

Elastomeric Bearing Project
 University of Texas at Austin
 Slaughter Creek Bridge

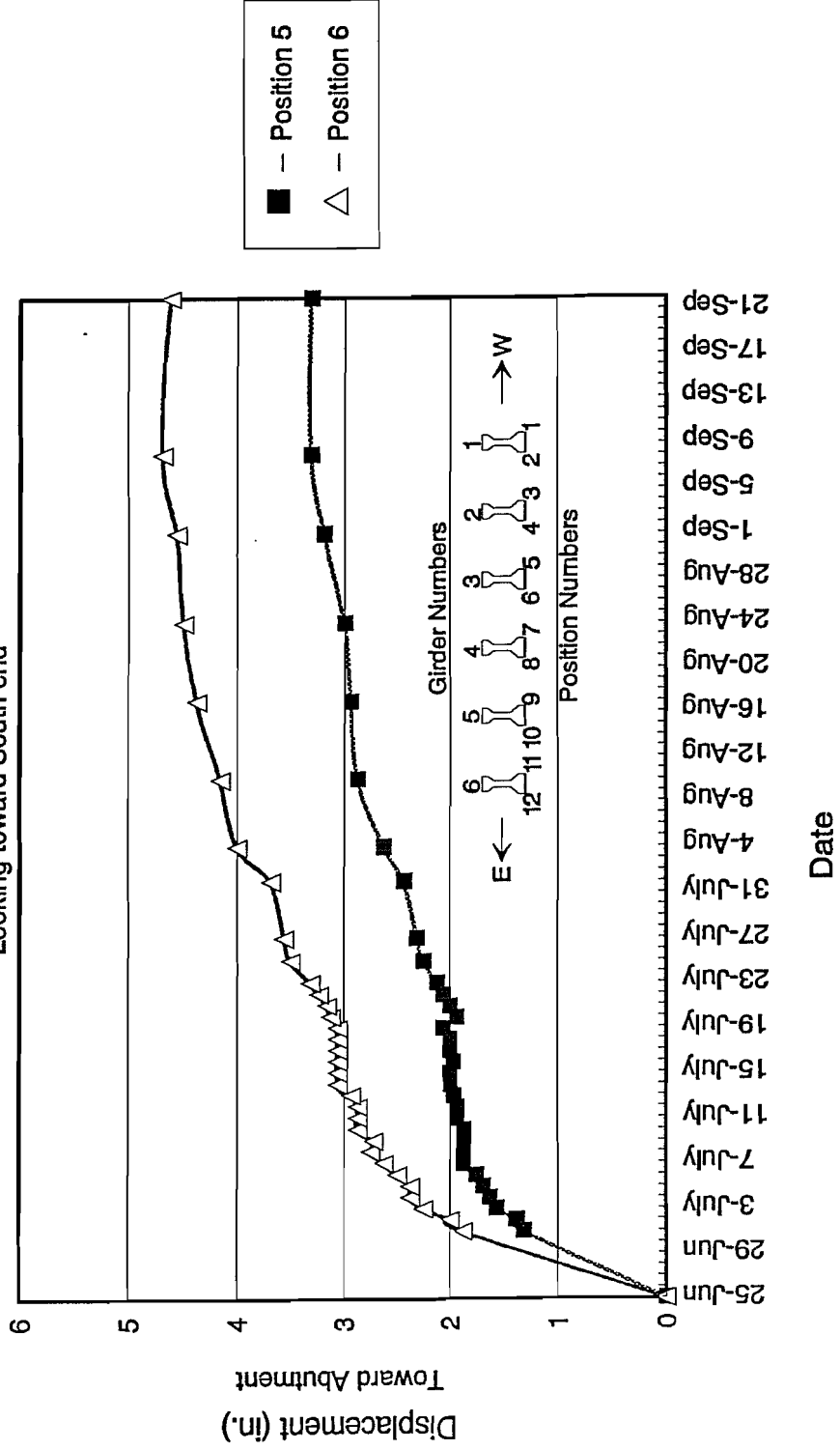
Bridge Lift III
GIRDER 2
 Bearing Movement
 Looking toward South end



Note: 1 inch = 25.4 mm

Elastomeric Bearing Project
 University of Texas at Austin
 Slaughter Creek Bridge

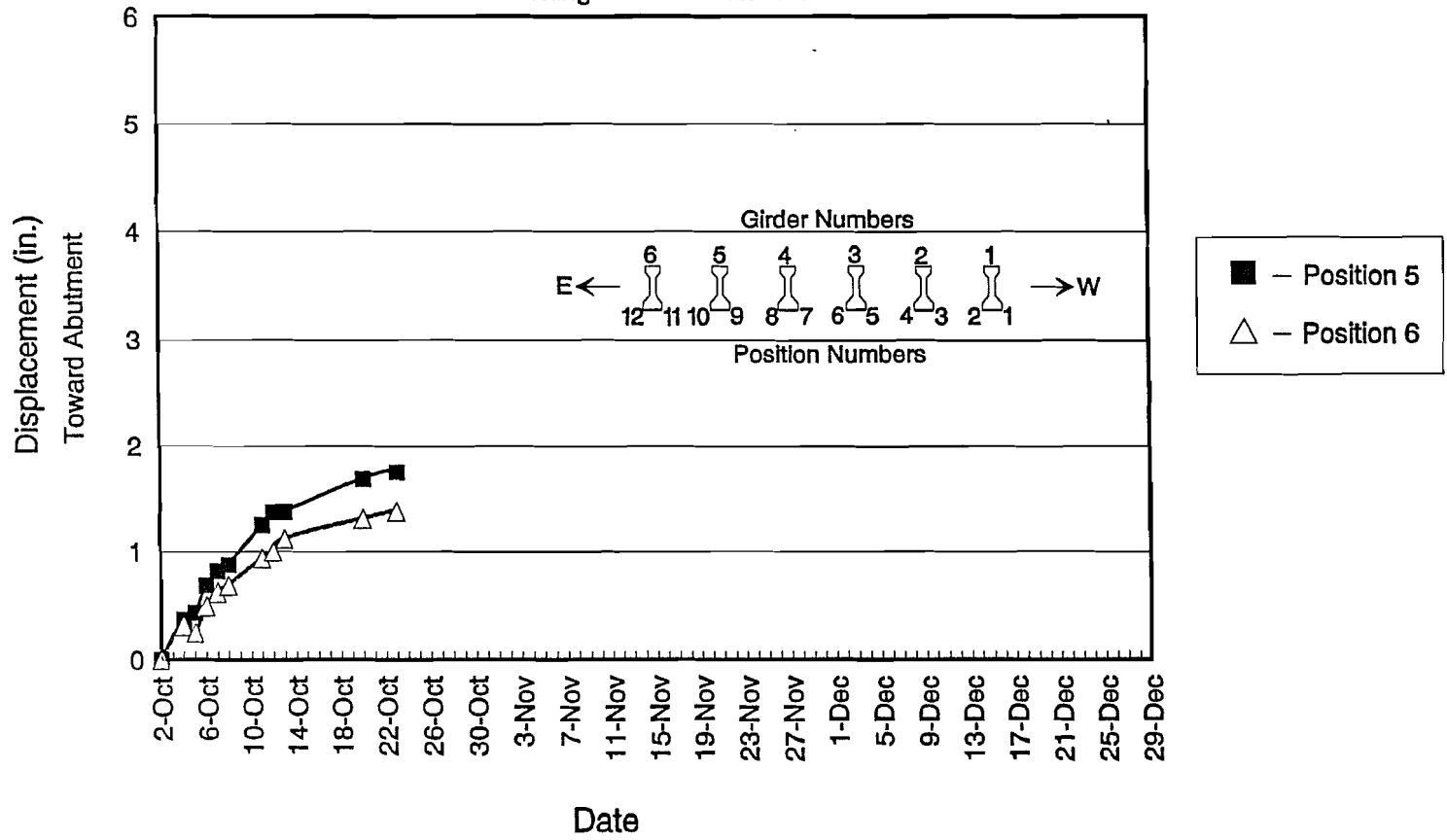
Bridge Lift II
GIRDER 3
 Bearing Movement
 Looking toward South end



Note: 1 inch = 25.4 mm

Elastomeric Bearing Project
 University of Texas at Austin
 Slaughter Creek Bridge

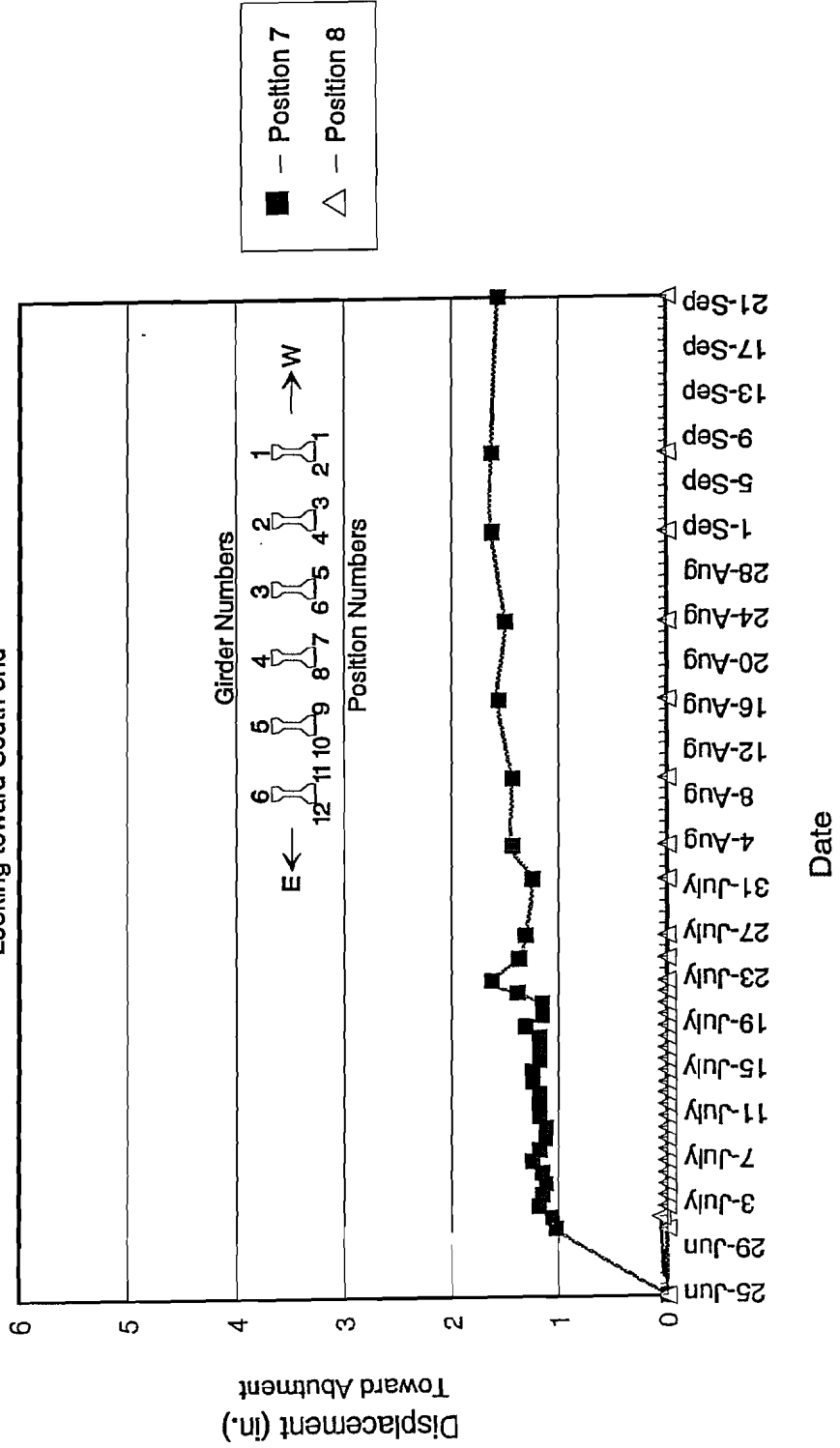
Bridge Lift III
GIRDER 3
 Bearing Movement
 Looking toward South end



Note: 1 inch = 25.4 mm

Elastomeric Bearing Project
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 Slaughter Creek Bridge

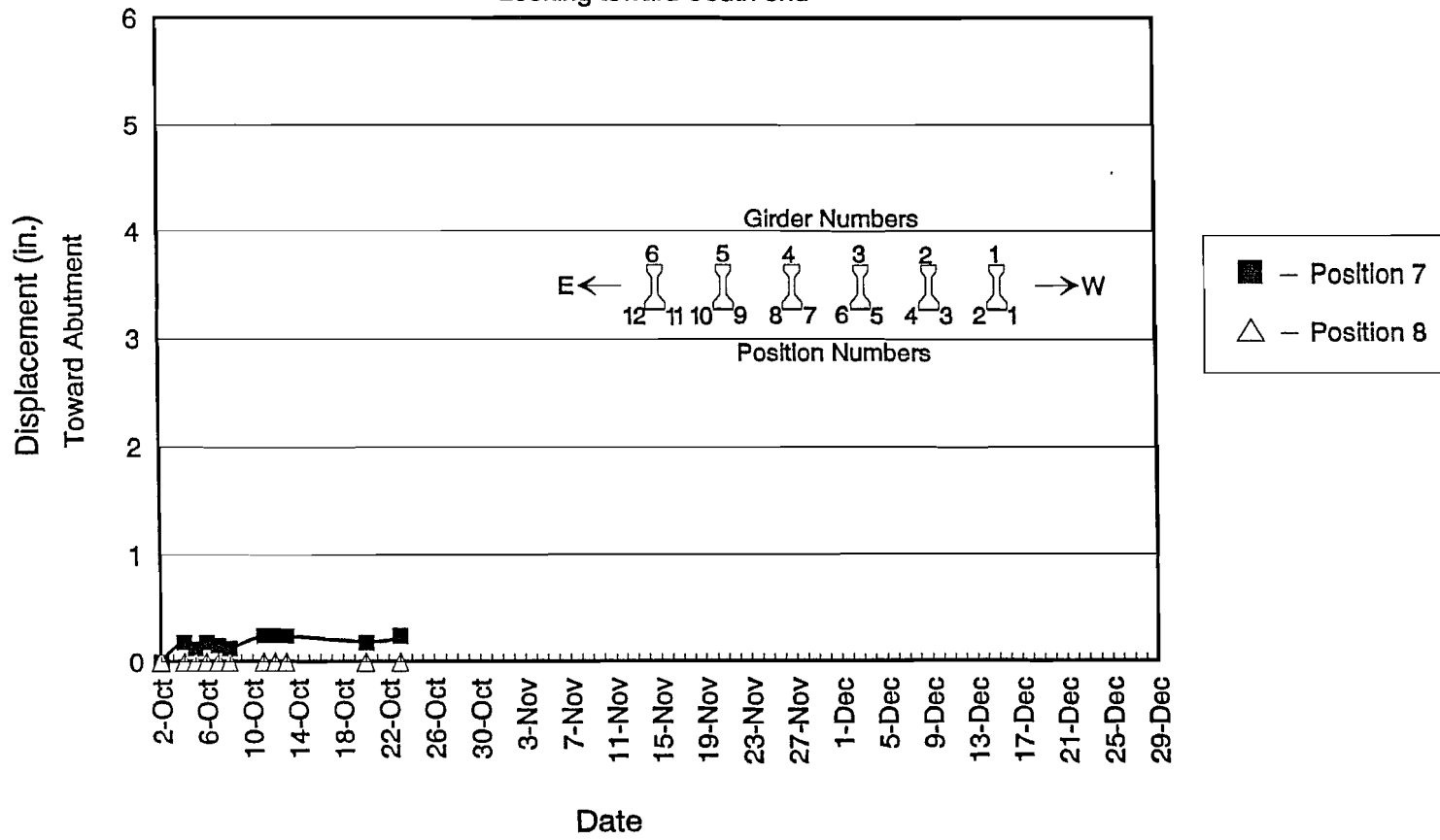
Bridge Lift II
GIRDER 4
 Bearing Movement
 Looking toward South end



Note: 1 inch = 25.4 mm

Elastomeric Bearing Project
 University of Texas at Austin
 Slaughter Creek Bridge

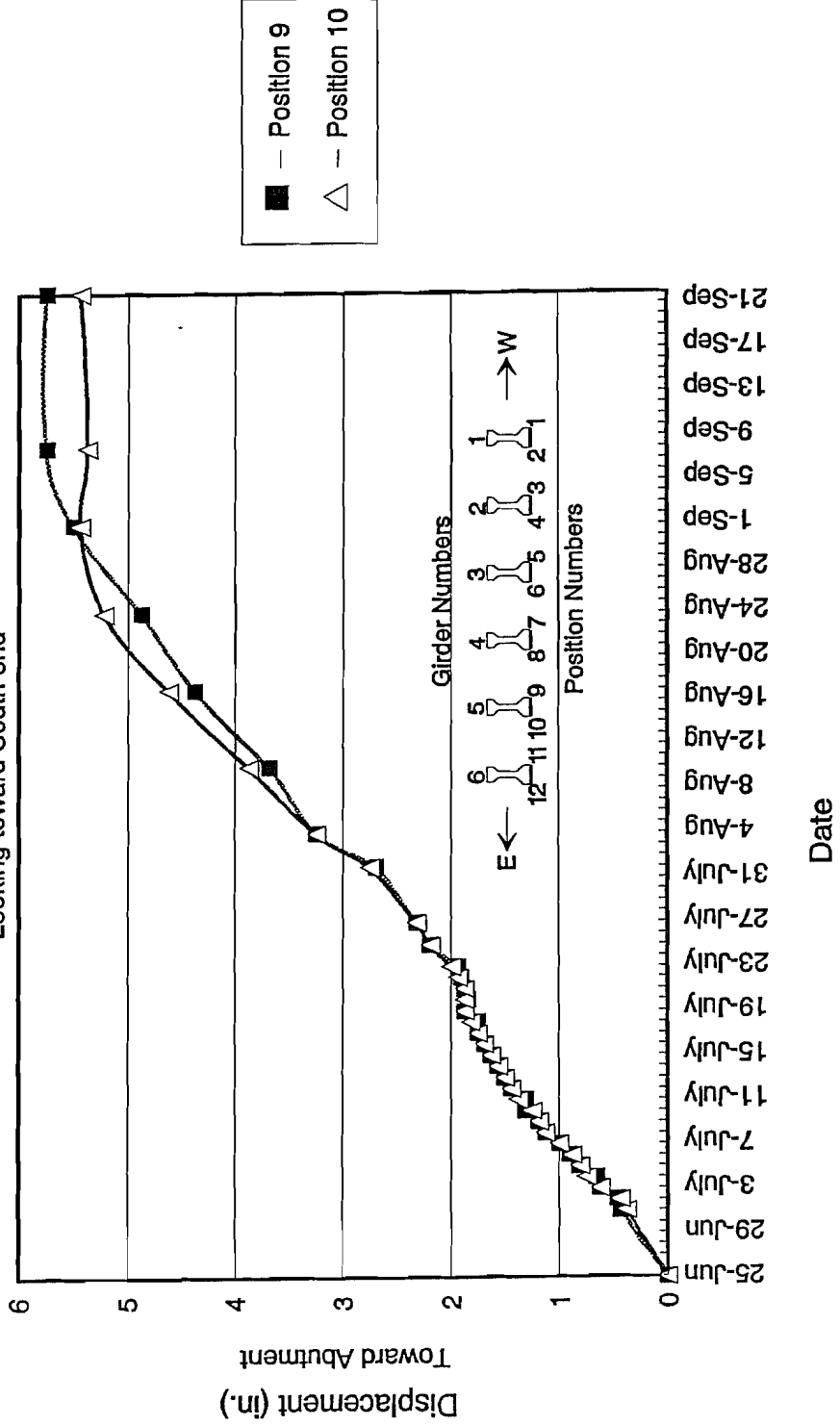
Bridge Lift III
GIRDER 4
 Bearing Movement
 Looking toward South end



Note: 1 inch = 25.4 mm

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 University of Texas at Austin
 Slaughter Creek Bridge

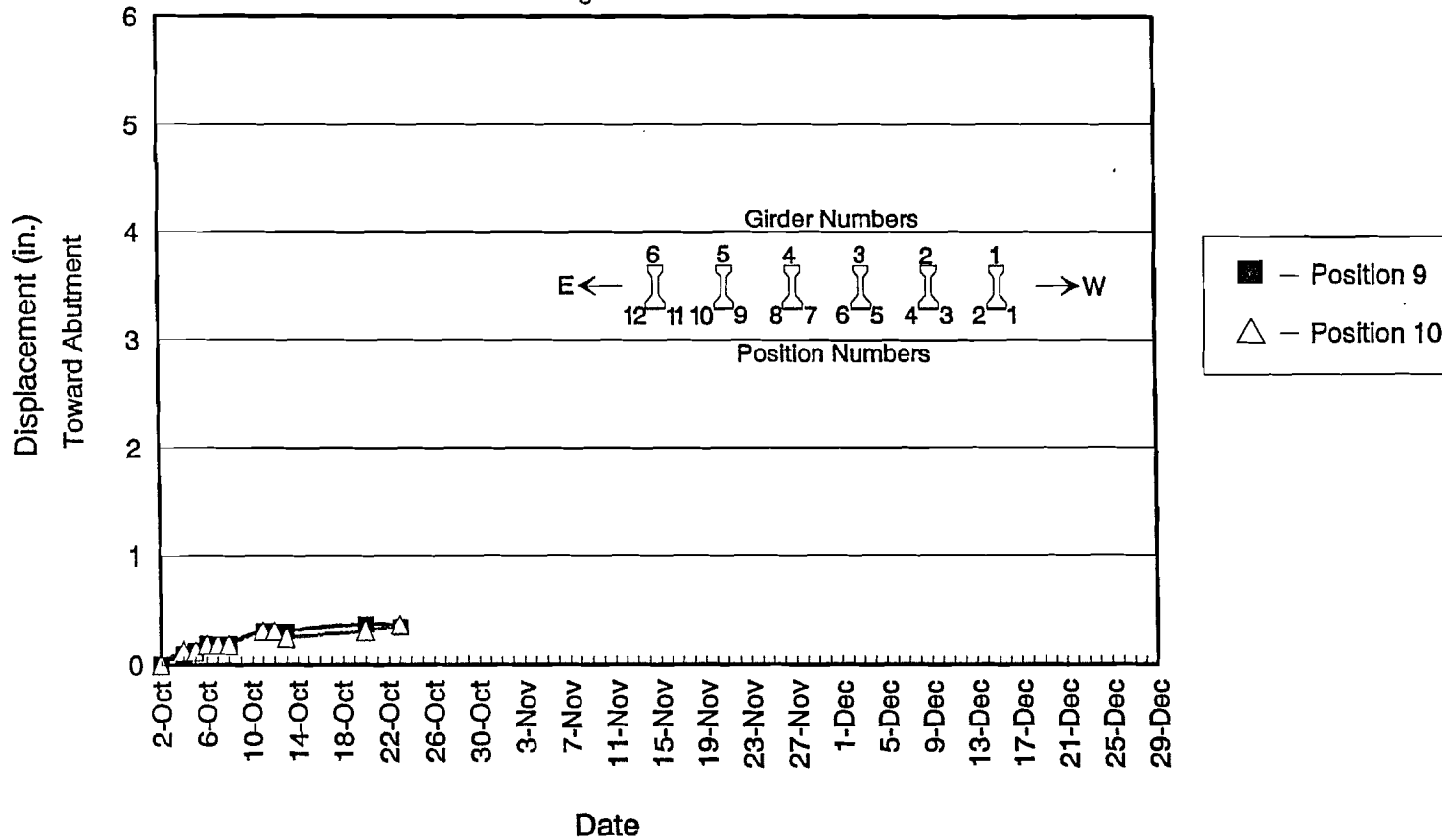
Bridge Lift II
GIRDER 5
 Bearing Movement
 Looking toward South end



Note: 1 inch = 25.4 mm

Elastomeric Bearing Project
 University of Texas at Austin
 Slaughter Creek Bridge

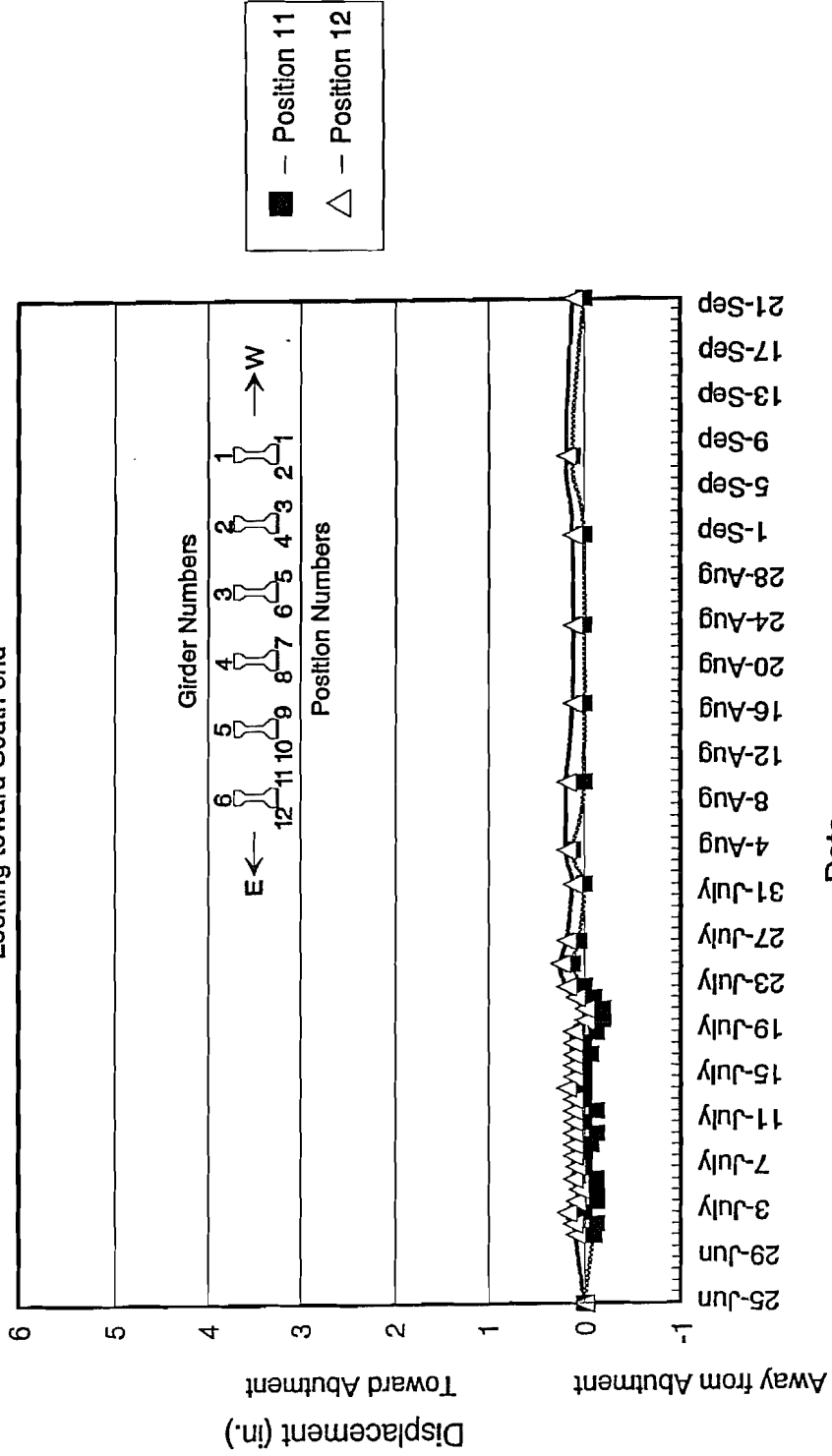
Bridge Lift III
GIRDER 5
 Bearing Movement
 Looking toward South end



Note: 1 inch = 25.4 mm

Elastomeric Bearing Project
 University of Texas at Austin
 Slaughter Creek Bridge

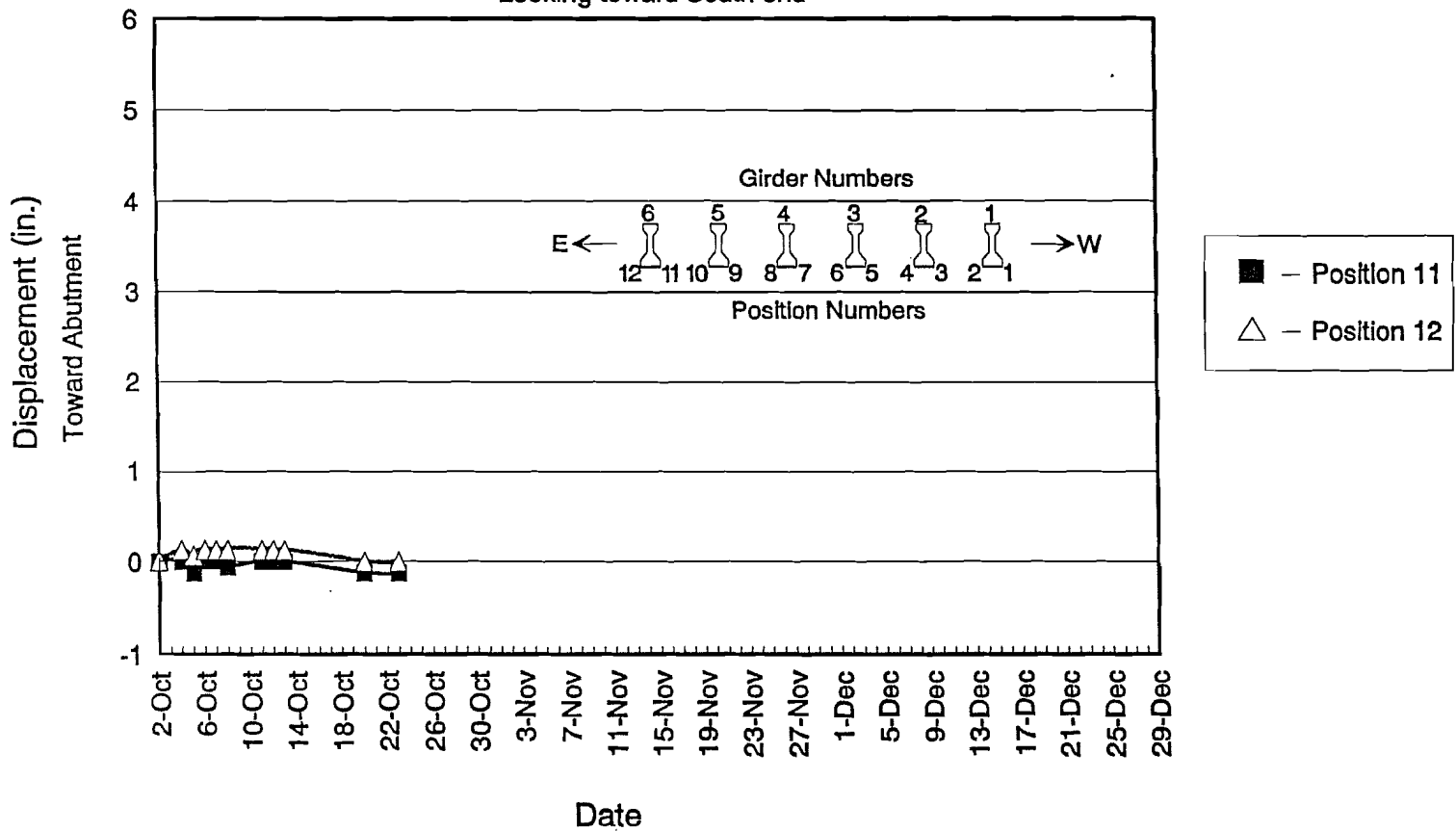
Bridge Lift II
GIRDER 6
 Bearing Movement
 Looking toward South end



Note: 1 inch = 25.4 mm

Elastomeric Bearing Project
 University of Texas at Austin
 Slaughter Creek Bridge

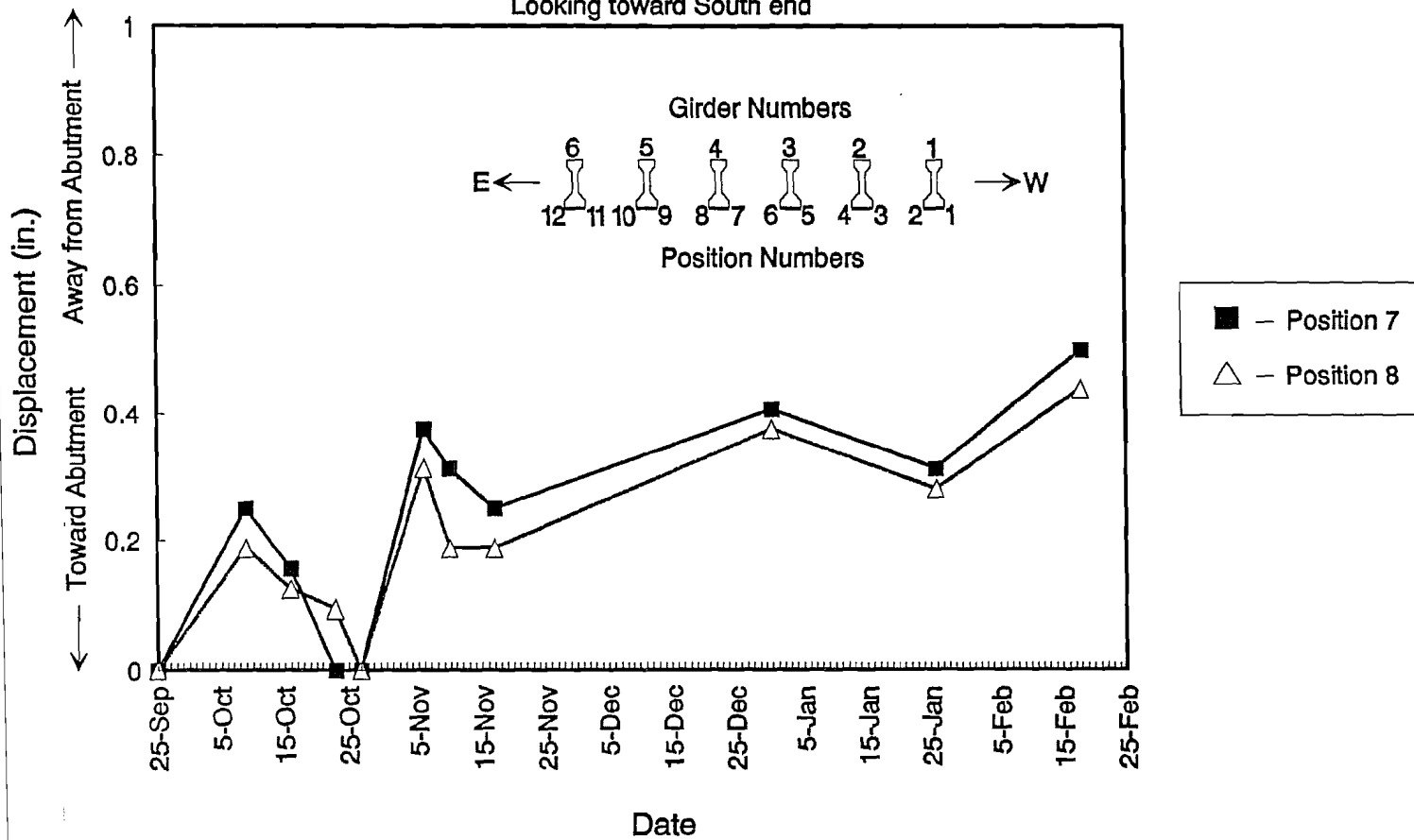
Bridge Lift III
GIRDER 6
 Bearing Movement
 Looking toward South end



Note: 1 inch = 25.4 mm

B.2 - Alanreed Bearing Movement

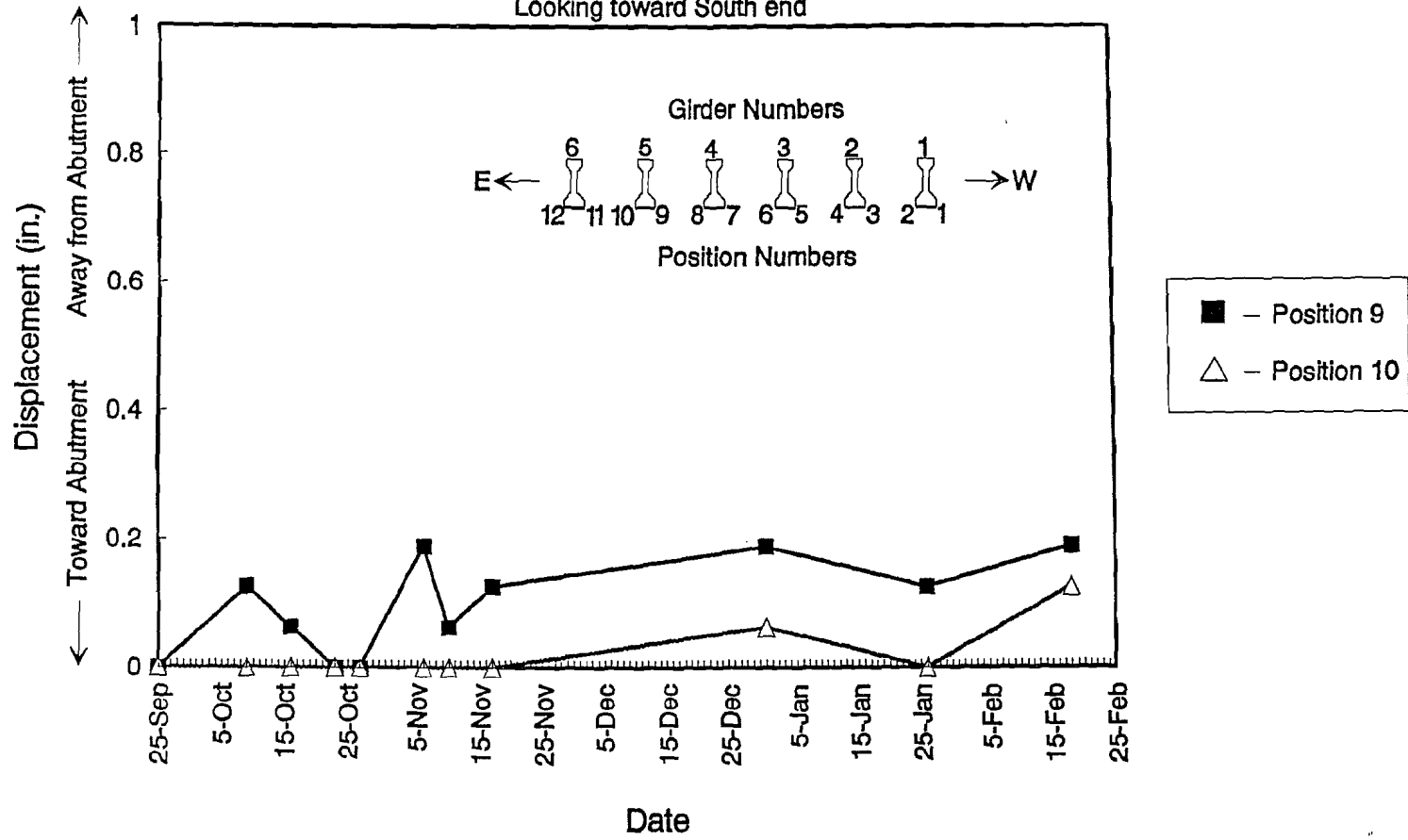
GIRDER 4
 Bearing Movement
 Looking toward South end



Note: 1 inch = 25.4 mm

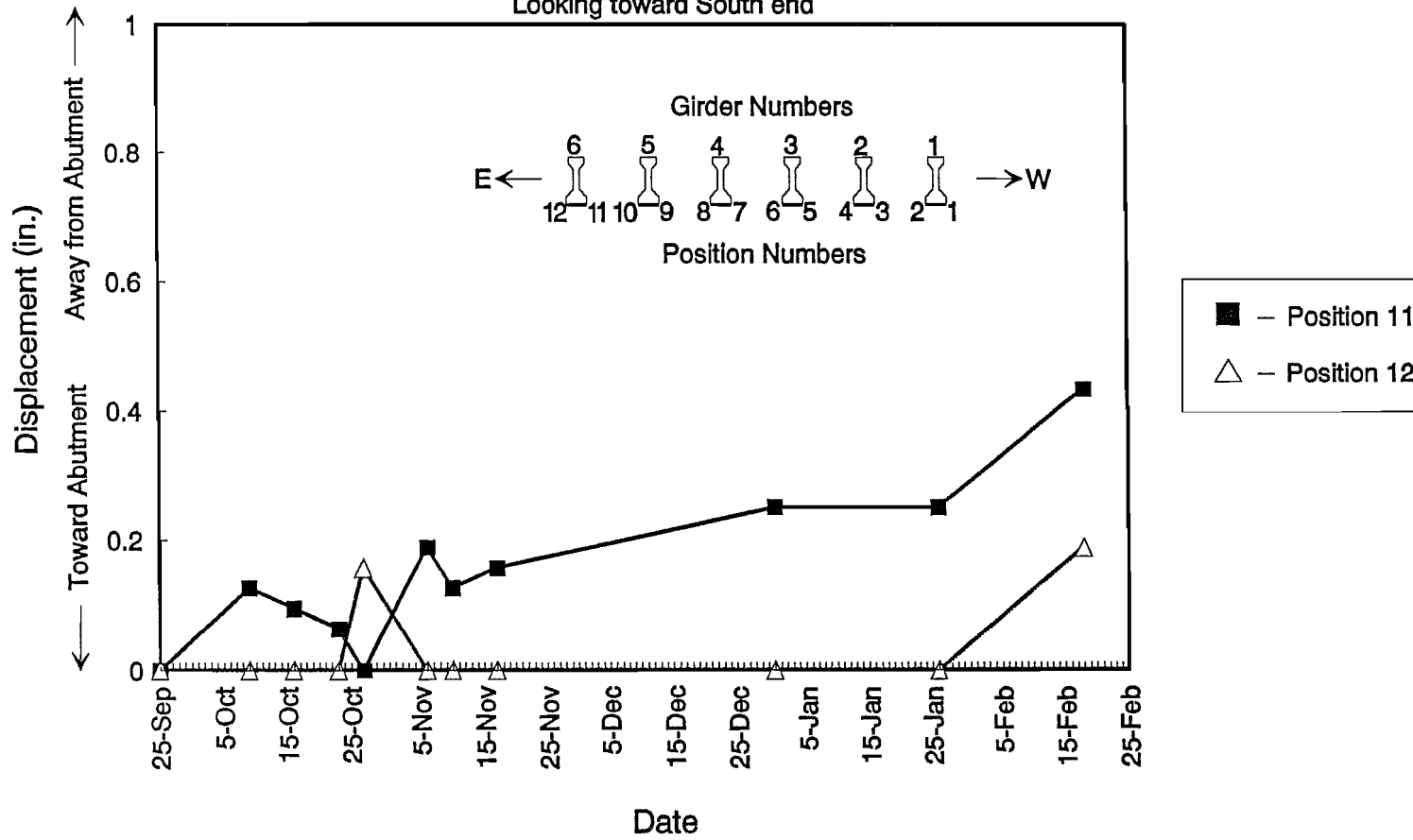
Elastomeric Bearing Project
University of Texas at Austin
Amarillo Bridge

GIRDER 5 Bearing Movement Looking toward South end



Note: 1 inch = 25.4 mm

GIRDER 6
 Bearing Movement
 Looking toward South end



Note: 1 inch = 25.4 mm

APPENDIX C
PREDICTION OF GIRDER THERMAL MOVEMENT USING HAND CALCULATIONS

PREDICATION OF GIRDER THERMAL MOVEMENT

In the hand calculations of this Appendix, the change in bridge length is computed as due entirely to uniaxial thermal expansion. As illustrated in Figure C-1, the change in length is computed as:

$$\Delta L = \alpha L \Delta T$$

where:

ΔL	=	Change in Length of the Bridge
α	=	Coefficient of Thermal Expansion
L	=	Length of the Bridge
ΔT	=	Change in Effective Bridge Temperature

The effective bridge temperature includes the effects of the thermal gradient through the bridge structure,

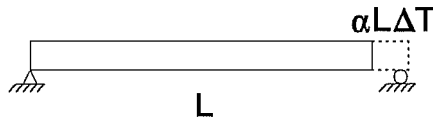


Figure C-1: Change in Length

thermal mass of the structure, and the heat absorption characteristics of the structure.

Sample Problem:

Determine the total thermal movement of the bridge at Slaughter Creek (Fig. 4.1). The girders and deck are concrete.

Solution:

- Step 1: Determine the normal daily maximum temperature for the month of July at the given location from Figure C-2.

$$\text{Maximum Temperature} = 98^{\circ}\text{F} (36.63^{\circ}\text{C})$$

- Step 2: Determine the normal daily minimum temperature for the month of January at the given location from Figure C-3.

$$\text{Minimum Temperature} = 41^{\circ}\text{F} (5.0^{\circ}\text{C})$$

Step 3: Determine the maximum effective bridge temperature from Table C-1.

$$\text{Maximum Effective Bridge Temperature} = 97^{\circ}\text{F} (36.11^{\circ}\text{C})$$

Step 4: Determine the minimum effective bridge temperature from Table C-2.

$$\text{Minimum Effective Bridge Temperature} = 38^{\circ}\text{F} (3.33^{\circ}\text{C})$$

Step 5: Calculate the total thermal movement

$$\begin{aligned}\Delta L &= L\alpha\Delta T \\ &= (304 \text{ ft})(6.0 \times 10^{-6} \text{ ft/ft/}^{\circ}\text{F})(97^{\circ}\text{F} - 38^{\circ}\text{F}) \\ &\quad (1 \text{ foot} = .3048 \text{ m}) \\ &= 0.11 \text{ ft} (0.034 \text{ m}) = 1.32 \text{ in.} (33.53 \text{ mm})\end{aligned}$$

Table C-1: Maximum effective bridge temperature as a function of normal daily maximum temperature [19].

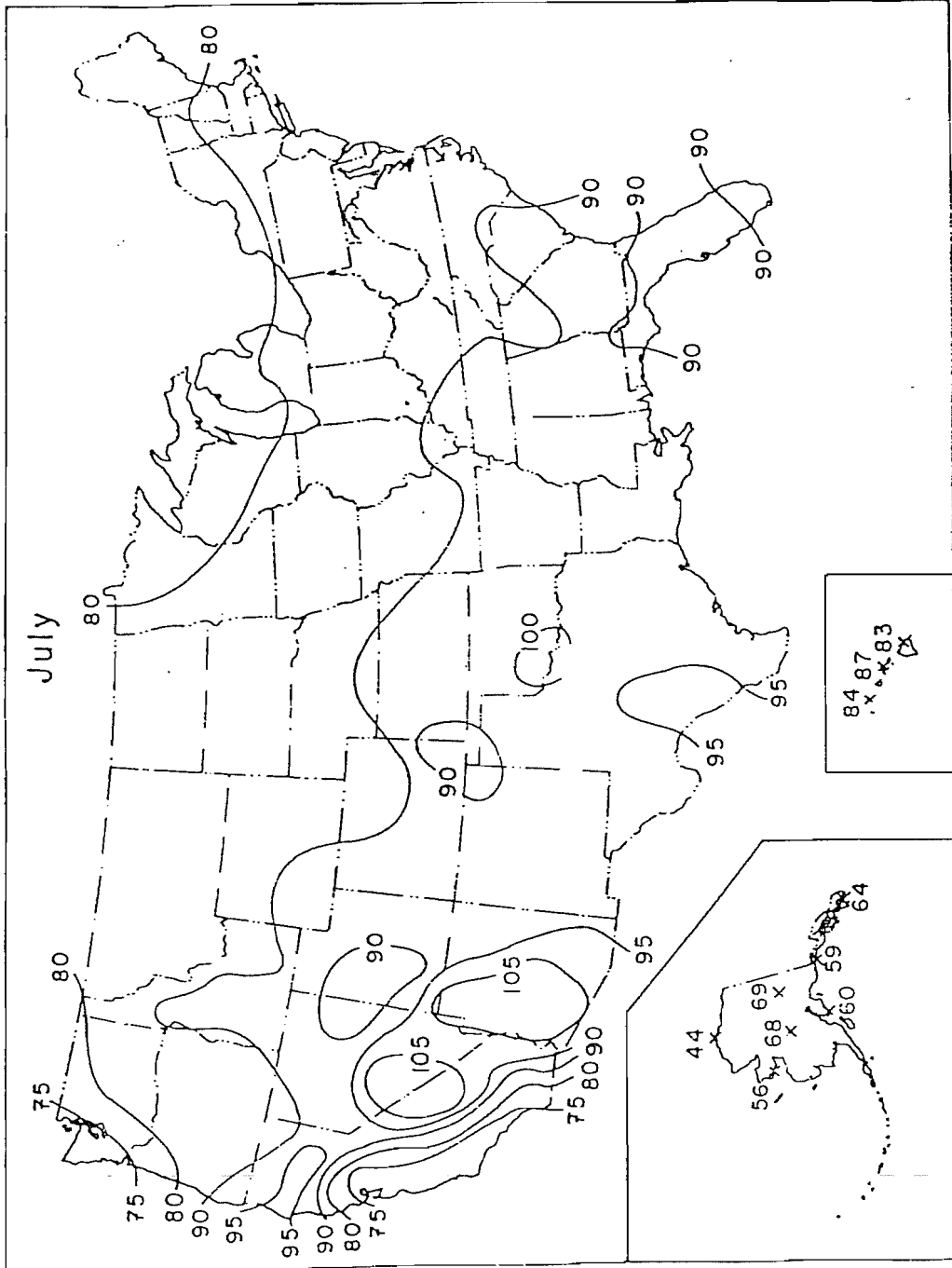
Normal Daily Maximum Temperature °F*	Maximum Effective Bridge Temperature - Type of Superstructure		
	Concrete, °F	Composite, °F	Steel Only, °F
55	66	70	91
60	69	74	94
65	73	79	97
70	77	83	101
75	80	88	104
80	84	93	107
85	88	96	110
90	92	99	112
95	95	102	115
100	98	104	116

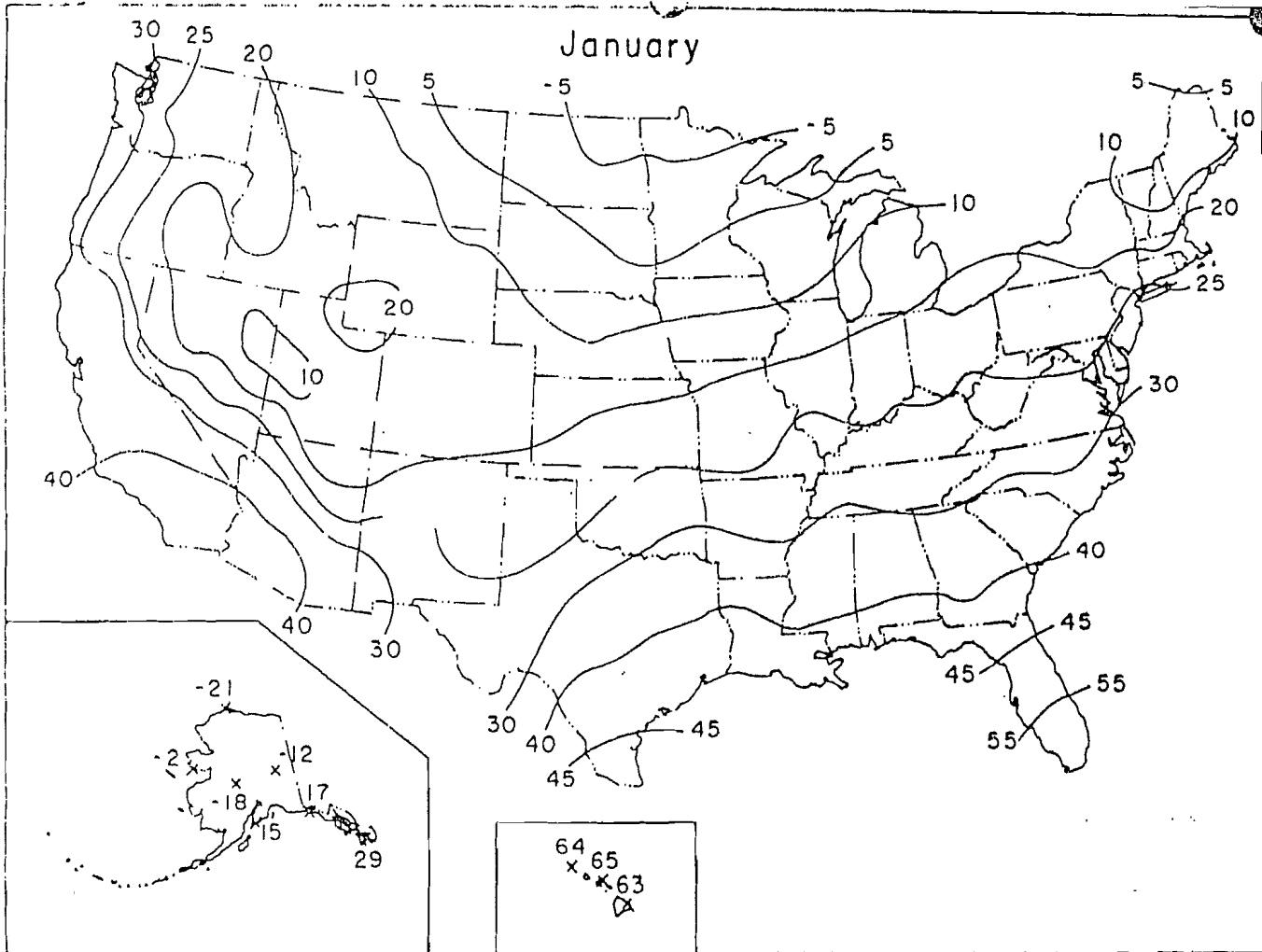
*Note: °C = (°F - 32) / 1.8

Table C-2: Minimum effective bridge temperature as a function of normal daily minimum temperature [19].

Normal Daily Minimum Temperature °F*	Minimum Effective Bridge Temperature - Type of Superstructure		
	Concrete, °F	Composite, °F	Steel Only, °F
-30	-3	-12	-43
-25	0	-9	-36
-20	3	-7	-30
-15	5	-4	-24
-10	8	-1	-17
-5	11	2	-10
0	13	4	-5
5	16	9	0
10	19	14	5
15	22	17	11
20	25	22	16
25	29	26	22
30	32	31	27
35	35	36	33
40	38	40	38

Note: $^{\circ}\text{C} = (^{\circ}\text{F} - 32) / 1.8$





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