

TFE Expansion Bearings for Highway Bridges

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16. Abstract This report covers the experimental work done to investigate the potential use of TFE as a sliding surface for highway bridge bearings. The research includes a comparison of TFE bearings with the bronze bearings which are currently used on prestressed concrete bridges. Samples supplied by various manufacturers were tested to determine the characteristics of TFE surfaces containing different amounts of glass fiber filler and to evaluate the effect of different types of backing material on the performance of the bearings. Both laboratory and comparative field tests were conducted to measure the relative behavior of the various bearing configurations. This report includes a description of the test procedures, an analysis of the data obtained, and a discussion of observations made during the testing program. The results of the research indicate that TFE bearings are suitable for use in highway bridges. From the conclusions derived from the study, design specifications are presented and recommendations are made for achieving the optimum TFE bearing configuration.			
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State of Illinois
DEPARTMENT OF TRANSPORTATION
Bureau of Materials and Physical Research

TFE EXPANSION BEARINGS FOR HIGHWAY BRIDGES

By

Floyd K. Jacobsen

Final Report
IHD-7

An Investigation of Elastomeric Expansion
Bearings for Highway Bridges

A Research Project Conducted by
Illinois Department of Transportation
in cooperation with
U. S. Department of Transportation
Federal Highway Administration

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

April 1977

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SUMMARY

The use of TFE (tetrafluoroethylene) as a sliding surface for expansion bearings is of interest to highway engineers who are searching for ways to improve existing bearing designs. The properties of TFE which make it potentially suitable for use as a bridge bearing include an anti-stick surface, a low coefficient of friction, and chemical inertness. This project was conducted to evaluate the performance of TFE surfaces in conjunction with various backing materials and to obtain information for use in future bearing design.

Many combinations of TFE surfaces and backing materials are commercially available, and the selection of the optimum bearing for a specific application is complicated by this variety of products. The bearings tested during the research consisted of samples obtained from several manufacturers. The test results illustrate the differences in the performance of specimens obtained from the several manufacturers as well as differences in the performance of specimens obtained from the same manufacturer. This variation complicated the analysis of the experimental results, especially for the TFE specimens containing a mineral filler.

Parameters investigated during this research include the coefficient of friction of TFE surfaces containing varying amounts of glass fiber filler, hardness and shape factor of elastomeric backing materials, fatigue life of the bearing assemblies, and effects of contamination. Although the limited number of samples tested for investigating some parameters reduced the degree of confidence for the recorded data, certain trends relating to the performance of the specimens could be established. By studying the trends of the parameters, both individually and collectively, the combination of materials resulting in the most effective bearing was determined.

Conclusions based on the test results are as follows:

1. Pure unfilled TFE material appears to be more suitable for highway bridge bearings than TFE material reinforced with glass fiber filler. The use of 15 to 25 percent glass filler resulted in a 35 to 50 percent increase in the values for the coefficient of friction under applied normal loads between 200 and 800 psi (1.38 and 5.52 MPa).
2. Excessive horizontal strains exceeding 50 percent of the rubber thickness occurred under normal loads when using soft 50-durometer rubber. An interior restraining device should be provided to restrict the horizontal shear when the anticipated movement exceeds 50 percent of the total rubber thickness.
3. Fabric backing materials are suitable only when used in conjunction with unfilled TFE. Several fabric-backed specimens with filled TFE surfaces failed by delamination of the fabric pad.
4. The performance of fabric backing materials in conjunction with filled TFE surfaces could be substantially improved by increasing the thickness of the fabric to a minimum of 1 1/2 inches (38,1 mm).
5. The TFE backed with plain or laminated rubber should be supported with a steel laminate. The use of a thin vulcanized layer of hard rubber for bonding the TFE to the steel is most effective in reducing surface irregularities of the TFE sheet. A steel laminate is also beneficial when used in conjunction with the rubber-impregnated fabric backing.
6. The loosely woven surface of pure TFE fibers absorbed contaminating particles more effectively than the solid TFE surfaces.
7. The unfilled TFE-surfaced bearings consistently performed better than the currently used bronze bearings.

Based on the above tentative conclusions, TFE expansion bearings of a suitable design can be used for highway bridges. In particular, the TFE bearings should be used in lieu of the graphite-impregnated self-lubricating bronze bearings currently used on highway bridges. Other TFE bearing configurations may provide adequate performance; however, for optimum durability and economy, designs based on the above guidelines are recommended.

APPENDIX C

ILLINOIS STANDARD SPECIFICATIONS FOR ELASTOMERIC
AND TFE-ELASTOMERIC BRIDGE BEARINGS

SPECIFICATIONS FOR ELASTOMERIC AND
TFE-ELASTOMERIC BEARINGS

718.20 Elastomeric Bearings. Elastomeric Bearings shall consist of laminated elastomeric pads or assemblies of laminated elastomeric pads with externally bonded structural steel bearing plates, structural steel top bearing plate and required stainless steel and TFE sheets, as shown on the plans and as specified.

All material used in the manufacture of the bearing assemblies shall be new and unused with no reclaimed material incorporated into the finished assembly. All bonding of components shall be done under heat and pressure during the vulcanizing process. The bond shall be continuous throughout the plan area with no voids or air spaces greater than 0.010 inch within the bonding material. The bearing assemblies shall be furnished as a complete unit from one manufacturing source.

The materials for the elastomeric bearings and assemblies shall comply with the following requirements:

- (a) Elastomeric Materials. The Elastomeric Materials of the compounds shall be either 100% virgin polyisoprene (natural rubber) - Table A, or 100% virgin polychloroprene rubber - Table B. The properties of the elastomeric compounds shall be determined from test specimens conforming to Part B or ASTM D15. A variation of $\pm 20\%$ in tensile strength and ultimate elongation under "physical properties" will be permitted when test specimens are cut from the finished product.

TABLE A

Polyisoprene - Natural Rubber

Rubber shall meet the requirement of ASTM D2000, Line Call-Outs, 2AA, 525 A13, F17, Z1, Z2, Z3, Z4, Z5, and 2AA, 915 K11, Z1, Z2, Z3.

ASTM Standard	Physical Properties	55 Duro	90 Duro
----	Hardness, ASTM D2240	55 \pm (Z1)	90 \pm 5
	Tensile Strength, Min., psi, ASTM D412	2500	1500
	Ultimate elongation, Min. %	400	100 (Z1)
D573	<u>Heat Resistance</u>		
70 Hrs. @ 158°F	Change in durometer hardness max. points	± 15	
	Change in tensile strength, Max. %	± 30	
	Change in ultimate elongation, Max. %	-50	
D395	<u>Compression Set</u>		
Method B 22 Hrs. @ 158°F Max.		25 (Z2)	

TABLE A (continued)

Polyisoprene - Natural Rubber

ASTM Standard	Physical Properties	55 Duro	90 Duro
D1149, 25 pphm in air by volume, 20% strain 100 hrs at 40°C. (Test specimen D518, Procedure A)	Ozone	No Cracks (Z3)	
	<u>Adhesion to Steel</u>		
D429, A	Bond made during vulcanization	80% R (Z4)	80% R (Z2)
D429, B	Bond Strength	-	200 psi
	Peel Strength	40 lbs/in.	
	<u>Adhesion to TFE</u>		
D429, B	Bond made during vulcanization	-	80% R (Z3)
	Peel Strength		25 lbs/in.
	<u>Low Temperature Test</u>		
	Bearing or sample preparation 96 hrs @ -20°F, +2°F. The specimen shall have a 24-hr conditioning period at room temperature prior to low-temperature exposure. The durometer test shall be made on an unbuffed surface. Durometer hardness increase Max. per ASTM D2240, 30 second reading. Durometer to be placed in freezer with test specimen.	+15 (Z5)	
D746	Brittleness temperature, 3 min. at -40°F. No cracks.	No Cracks	

TABLE B

Polychloroprene - Synthetic Rubber

Rubber shall meet the requirements of ASTM D2000, Line Call-Outs - 2BC, 525, A14, B14, C12, K21, Z1, Z2; and 2BC, 915, K11, Z1, Z2, Z3.

ASTM Standard	Physical Properties	55 Duro	90 Duro
-----	Hardness, ASTM D2240	55 ± 5	90 ± 5
	Tensile Strength, min. psi ASTM D412	2500	1500
	Ultimate elongation, Min. %	425	75 (Z1)
	<u>Heat Resistance</u>		
D573, 70 Hrs @ 212°F.	Change in durometer hardness, Max. points	+15	
	Change in tensile strength, Max. %	-15	
	Change in ultimate elongation, Max. %	-40	
D395, Method B	<u>Compression Set</u> 22 hrs @ 212°F, Max. %	35	
D1149	<u>Ozone</u> 100 pphm ozone in air by volume 20% strain, 100°F, ± 2°F, 100 hrs. mounting procedure D518, Procedure A.	No Cracks	
	<u>Adhesion to Steel</u>		
D429, A	Bond made during vulcanization	80% R (Z1)	80% R (Z2)
D429, B	Bond Strength Peel Strength	40 lbs/in.	200 psi
	<u>Adhesion to TFE</u>		
D429, B	Bond made during vulcanization Peel Strength		80% R (Z3) 25 lbs/in.
	<u>Low Temperature Test - Durometer Change</u>		
	Bearing or sample to be exposed for 96 hrs @ -20°F, +2°F. (The specimen shall have a 24-hr conditioning period at room temperature prior to low-temperature exposure). The durometer test shall be made at -20°F. on an unbuffered surface. Durometer hardness increase, Max. ASTM D2240, 30 second reading. Durometer to be placed in freezer with test specimen.		
D746	Brittleness temp., 3 min., at -40°F		No Cracks

TABLE B (continued)

Polychloroprene - Synthetic Rubber

ASTM Standard	Physical Properties	55 Duro	90 Duro
(b)	TFE Material. The TFE resin shall be 100 percent virgin material, premium grade, meeting the requirements of ASTM D1457. The TFE sheet (polytetrafluoroethylene sheet, premium grade) shall consist of pure TFE resin, compression molded, and skived into sheets of the required thickness. The finished sheet shall conform to the following physical properties:		
D638	Tensile strength, psi		2800 min.
D638	Elongation		200 min.
D792	Specific Gravity		2.15-2.20
D2240	Hardness, Durometer D		50-65
D621	Deformation Under Load		
	73°F/1000 psi/24 hrs, %		2-3
	122°F/1200 psi/24 hrs, %		4-8
	73°F/2000 psi/24 hrs, %		15 max.
D570	Water Absorption, %		.01 max.
	Static Coef. of Friction		
	@ 500 psi bearing pressure on stainless steel		.07 max.

(c) Stainless Steel Sheets. The stainless steel sheets shall be of the thickness specified and shall conform to ASTM A240. The sliding surface shall have a Type 2B finish or smoother as per the American Society of Metals.

(d) Structural Steel.

- 1) Structural Steel Bearing Plates. The structural steel bearing plates shall conform to the requirements of AASHTO M183.
- 2) Internal Steel Laminates. The internal steel laminates for the laminated elastomeric bearings shall be rolled mild steel sheets conforming to SAE 1020 or AASHTO M183.
- 3) Shear Restrictor Pin. The shear restrictor pin, when required, shall be press fit into the bearing plate and shall be alloy steel, quenched and tempered to a minimum yield strength 210,000 psi (or R_c hardness of 50 to 55).

Laminated elastomeric bearings shall be individually molded to the required size. Corners and edges may be rounded with a radius at the corners not exceeding 3/8 inch and a radius at the edges not exceeding 1/4 inch. All edges of the steel laminations shall be covered with not less than 1/8 inch and not more than 1/4 inch of elastomer. No rubber flash will be permitted on the edges of TFE bearing surfaces. All burrs or raised edges along the perimeter of the TFE surface shall

be removed before shipment. The dimensions of the elastomeric bearings shall be within the following listed tolerances:

Overall vertical dimension.

Average total rubber thickness 1 1/4" or less	-0, + 1/8"
Average total rubber thickness over 1 1/4"	-0, + 1/4"

Overall Horizontal Rubber Dimension.

36" or less	0, + 1/8"
more than 36"	0, + 3/16"

Thickness of individual layers of elastomer (55 Durometer Only)	± 20%
--	-------

Thickness of each 90-Durometer elastomer layer	+0 of rubber ply thickness -1/16"
--	--------------------------------------

Variation from a plane parallel to the theoretical surface.	1/16" per foot, Tops 1/4" Sides
---	------------------------------------

Position of exposed connection members	± 1/8"
--	--------

Edge cover of embedded metallic laminate (except at Laminate Restraining Devices and around holes and slots).	1/8" min. 1/4" max.
---	------------------------

Location of holes or slots	±1/8"
----------------------------	-------

The rubber laminates shall be uniform integral units, capable of being separated by mechanical means into separate, well-defined elastomeric layers. The ultimate breakdown limit of the elastomeric bearing under compressive loading shall be not less than 2,000 psi. In addition to the requirements of Table A or B, the stress-strain relationship of the finished elastomeric bearings at room temperature shall not exceed the following limitations:

	<u>Compression</u>	
Stress	500 psi	800 psi
Strain*	5 %	7 %

*Percent of total thickness of all elastomer laminations.

In addition, shear resistance of the bearing shall not exceed 30 psi for 55 durometer, Table A compounds; nor 50 psi for 55 durometer, Table B compounds at 25% strain of the total effective rubber thickness after an extended four-day ambient temperature of -20°F.

Structural Steel bearing plates shall be fabricated in accordance with Article 507.04 (M). The exposed surfaces of these plates shall be zinc-phosphate coated to a density of 300-500 milligrams per square foot.

The contractor shall furnish the Engineer certified copies of the bearing manufacturer's test report on the physical properties of the elastomer for the bearings to be furnished and a certification by the bearing manufacturer that the bearings to be furnished conform to all the requirements shown on the plans and as stipulated herein.

METRIC CONVERSION

1 inch	=	25.4 mm
1 lbf	=	4.45 N
1 psi	=	6.89 kPa
1 lbf/inch	=	0.175 N/mm

APPENDIX A

BRIDGE BEARING FAILURES

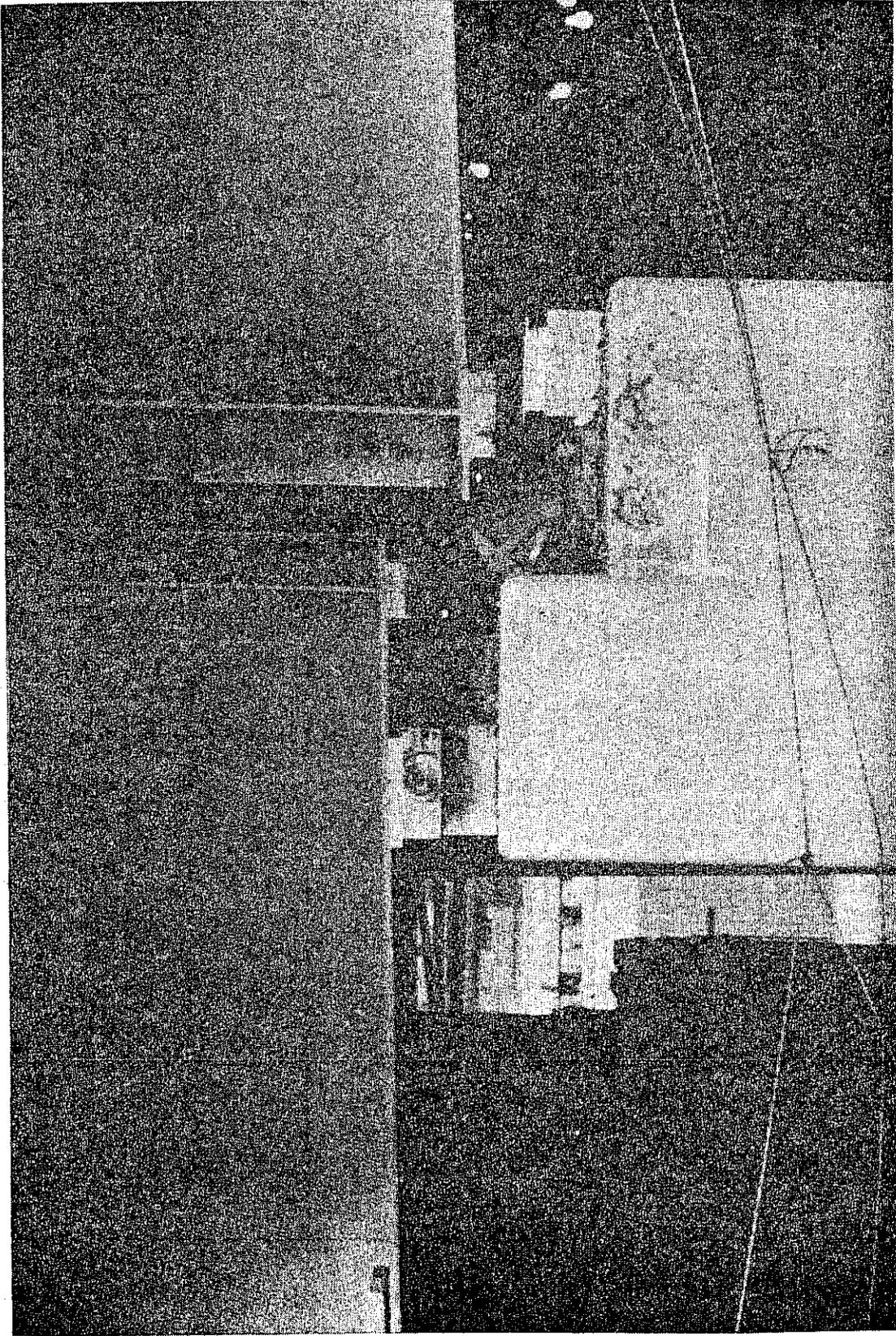


Figure 25. Failure of rocker type bearing on Dan Ryan Expressway in Chicago.

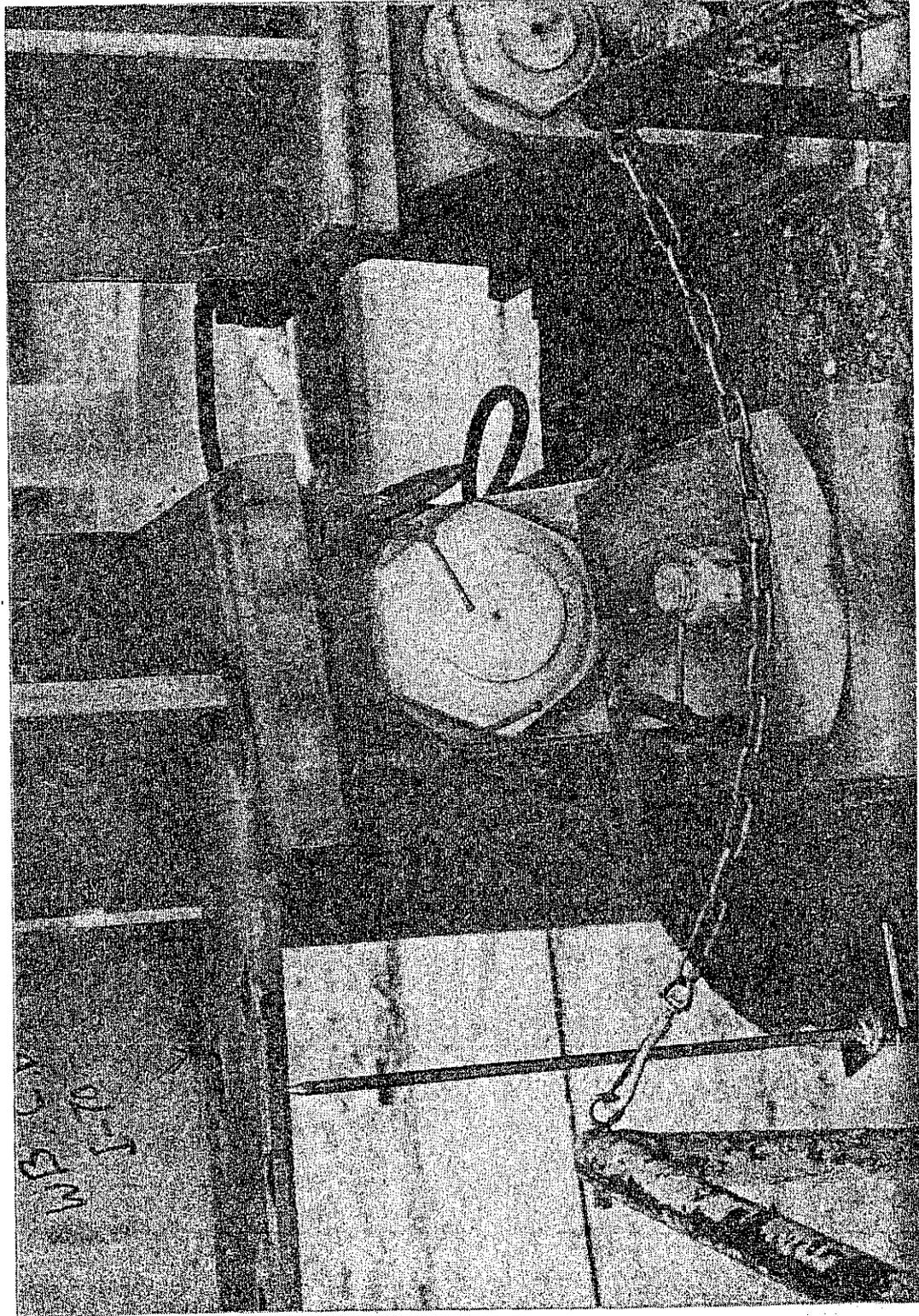


Figure 26. Failure of pin-connected type bearing on Poplar Street Complex in East St. Louis.

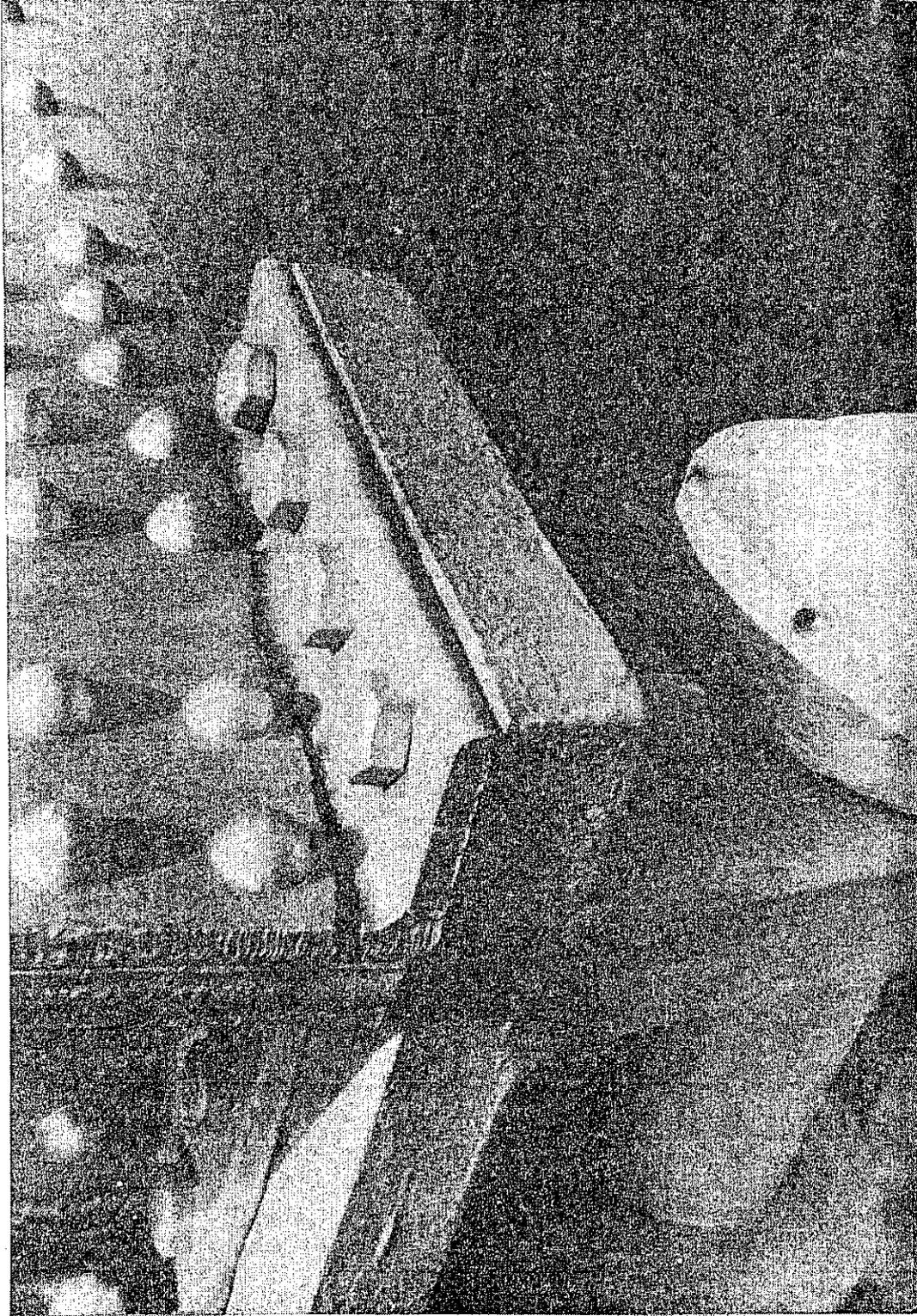


Figure 27. Failure of pin-connected type bearing on Illinois River Bridge near Lacon.

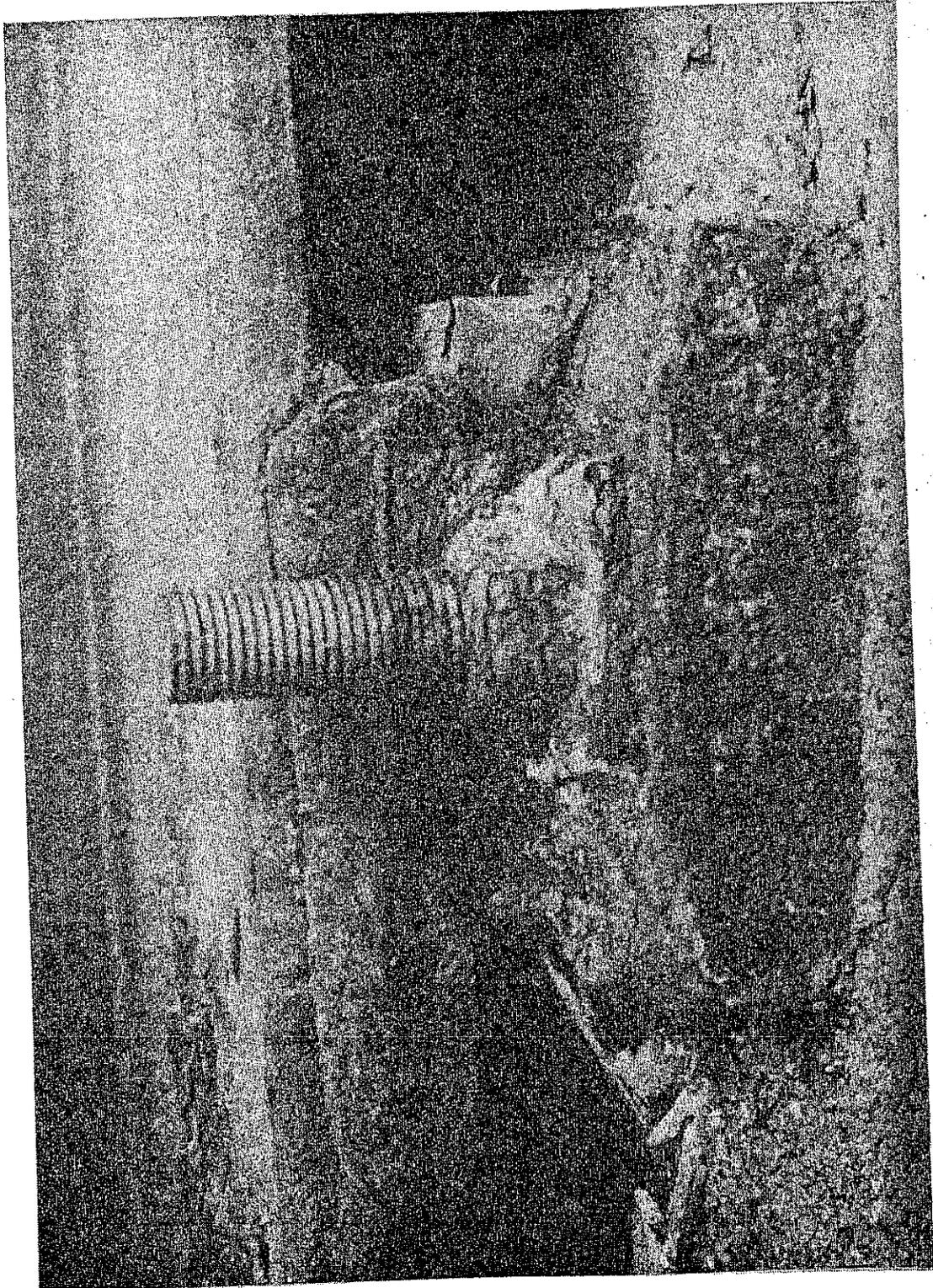


Figure 28. Failure of graphite impregnated bronze bearing on Lake Shore Drive in Chicago.

APPENDIX B

DESIGN CHARTS AND INSTRUCTIONS FOR ELASTOMERIC
AND TFE-ELASTOMERIC BRIDGE BEARINGS.

ELASTOMERIC AND TFE- ELASTOMERIC BRIDGE BEARINGS

General Discussion

The following instructions are provided as a guide for designing elastomeric bearings for highway bridges. A series of design standards based on the principles of a laminated rubber as a structural material have been developed for both expansion- and fixed-bearing conditions. Design charts and tables are included in these instructions for selecting a standard bearing that will satisfy most conditions for expansion or contraction, and provide rotational freedom for non-parallel load surfaces.

The instructions which follow are divided into two parts: Part I covers the design of expansion bearings and Part II covers the design of fixed bearings.

PART I - ELASTOMERIC EXPANSION BEARING

Three different types of standard expansion bearings have been developed to satisfy most requirements for highway bridges (Plate III/5.25).

Type I

The expansion bearing designated as Type I is the conventional laminated bearing which has no provisions for slippage within the component. Thermal or longitudinal movement is taken by internal distortion within the rubber. The Type I bearing is used when the total thickness of the rubber laminates is not critical for the amount of expansion taking place. Horizontal movement or shear within the bearing is limited to 50 percent of the elastomer thickness and the width of the bearing should not be less than 3 times the elastomer thickness to maintain stability of the bearing. These limitations exclude the use of this type of bearing for expansion lengths over 75 feet (22.86 m) for a bearing 6 inches (152.4 mm) wide and 150 feet (45.72 m) for a bearing 12 inches (304.8 mm) wide.

Type II

The design of the Type II bearing incorporates a teflon sliding surface to provide initial slippage shortly after installing the bearing. The design takes into account the extreme ambient temperature that may occur during the installation of the bearing. The assembly is self adjusting regardless of the installation temperature and the design permits the bearing to align itself to a normal temperature. Once the bearing becomes aligned, the travel is taken by horizontal shear within the rubber. The design of the Type II bearing is limited to a maximum expansion length of 150 feet (45.72 m) for a bearing 6 inches (152.4 mm) wide and 300 feet (91.44 m) for a bearing 12 inches (304.8 mm) wide.

Type III

The Type III bearing is used to accommodate large thermal movements which exceed the limits of a Type II bearing. The design of the bearing provides an internal restrictor pin to avoid overstressing the rubber in shear. The assembly permits continual slippage at the TFE surface and has no limitation relative to expansion length. The required rubber thickness is based on the rotational requirements for non-parallel load surfaces.

Instructions

There are four basic parameters which govern the design of an elastomeric bearing. These parameters consist of the following:

- a. Dead-Load Reaction
- b. Dead-Load + Live-Load Reaction
 - (1) Impact not included
- c. Expansion Length
 - (1) Distance from fixed bearing to expansion bearing

d. Percent slope due to non-parallel surfaces

- (1) Dead-Load Rotation
- (2) Camber of prestress beams
- (3) Profile grade of beam

Knowing the above parameters, the following procedure is used for selecting an appropriate bearing:

Step 1 - Determine from Plate III/5.26 the minimum plan dimensions needed to satisfy the requirements for load capacity.

a. Design Limits

- (1) 200 psi (1.38 MPa) \leq DL \leq 500 psi (3.45 MPa)
- (2) 200 psi (1.38 MPa) \leq DL + LL \leq 800 psi (5.52 MPa)

The horizontal boundaries of the blocked areas in Plate III/5.26 define the maximum and minimum dead loads according to limits of (1) above, and the vertical boundaries define the maximum and minimum dead plus live loads according to the limits of (2) above.

The outer limits of the boundaries are based on the net area of the bearing, with no allowances for reduction in area due to internal holes or slots. These boundaries apply to the Type I and Type II bearings.

The shaded areas define the limits for a Type III bearing, which requires a slotted hole to accommodate a restrictor pin. An allowance has been made in the reduction of the plan area due to the slotted holes.

Step 2 - Determine from Plate III/5.27 the type of bearing needed to satisfy expansion requirements.

- a. Type I - Conventional Elastomeric Bearing
- b. Type II - TFE-Elastomeric
 - (1) Permits initial slip to compensate for installation temperature.
- c. Type III - TFE-Elastomeric with restrictor pin
 - (1) Permits slippage under all temperature ranges

Step 3 - Determine bearing thickness from Plates III/5.28 - III/5.32

The minimum bearing thickness for Types I and II bearings is based on the following two factors: (1) Sufficient rubber thickness should be provided to satisfy the minimum expansion requirements of the total horizontal movement not exceeding 50 percent of the rubber thickness (Plates III/5.28 and III/5.29).

(2) Consideration also should be given to providing sufficient rubber thickness to avoid a lift-off condition at the leading edges of the pad (Plates III/5.30 - III/5.32).

The minimum rubber thickness for a Type III bearing is not dependent on expansion length. However, the bearing should be designed to provide rotational freedom with no lift-off at the leading edges.

a. Type I

- (1) Plate III/5.28 - Determine minimum bearing thickness (Series a, b, c, etc.) needed to satisfy expansion requirements.
- (2) Plates III/5.30 - III/5.32 - Determine minimum bearing thickness (Series a, b, c, etc.) needed to satisfy slope requirements. If tapered plate is used, slope equals zero and slope limit charts do not apply.
- (3) Use the larger thickness determined in (1) and (2).

b. Type II

- (1) Plate III/5.29 - Determine minimum bearing thickness (Series a, b, c, etc.) needed to satisfy expansion requirements.
- (2) Plates III/5.30 - III/5.32 - Determine minimum bearing thickness (Series a, b, c, etc.) needed to satisfy slope requirements. If tapered plate is used, slope equals zero and slope limit charts do not apply.
- (3) Use the larger thickness determined in (1) and (2).

c. Type III

- (1) Plates III/5.30 - III/5.32 - Determine minimum bearing thickness (Series a, b, c, etc.) needed to satisfy slope requirements. If tapered plate is used, slope equals zero and slope limit charts do not apply. If tapered plate is required, use minimum thickness (series "a" bearing) within bearing series.

Design Details

The design formulas for determining slope limits as given in plates III/5.30, III/5.31, III/5.32, and III/5.40 are shown on plate III/5.33.

Plates III/5.34 - III/5.37 show details of the standard elastomeric expansion bearings for steel structures.

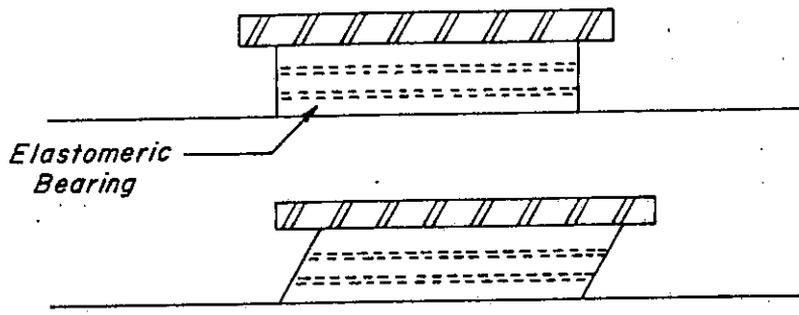
Dimensions for the standard bearings are given on plates III/5.40 - III.5.42.

Load capacity and slope factors for the standard bearings are given on plate III/5.39.

The bearing plate thicknesses and connecting welds are determined by the formulas given on plate III/5.38.

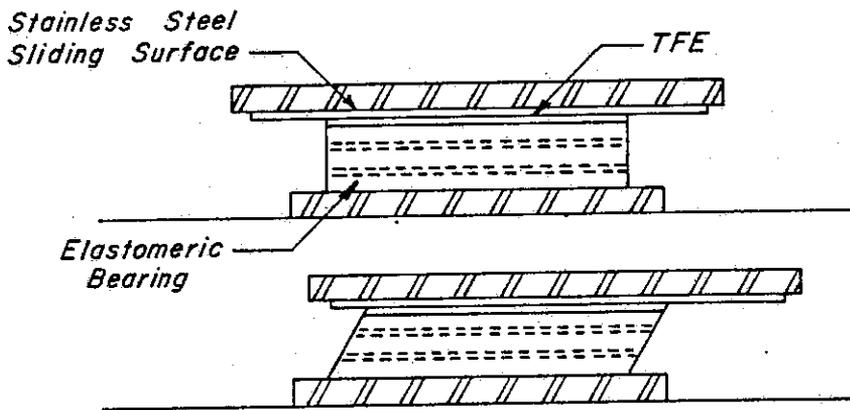
PART II - FIXED BEARING

The design of the fixed bearings shall be in accordance with the standard details as shown in Article III/5 Bearings of the IDOT Bridge Manual.



Elastomeric Bearing

TYPE I BEARING

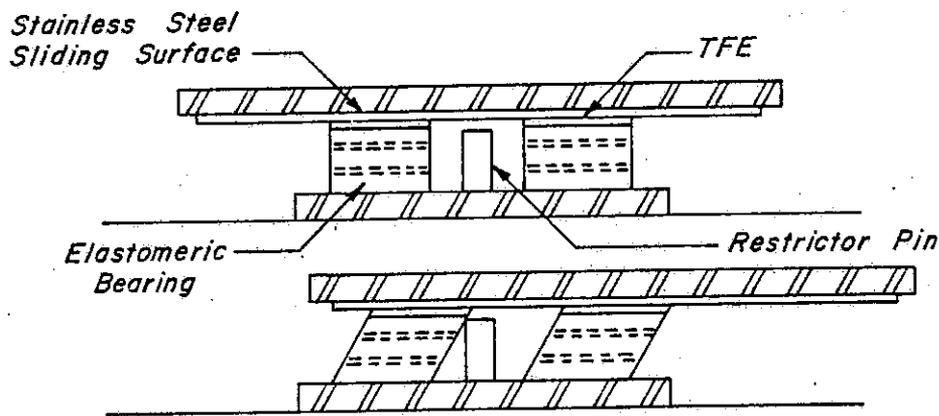


Stainless Steel Sliding Surface

TFE

Elastomeric Bearing

TYPE II BEARING



Stainless Steel Sliding Surface

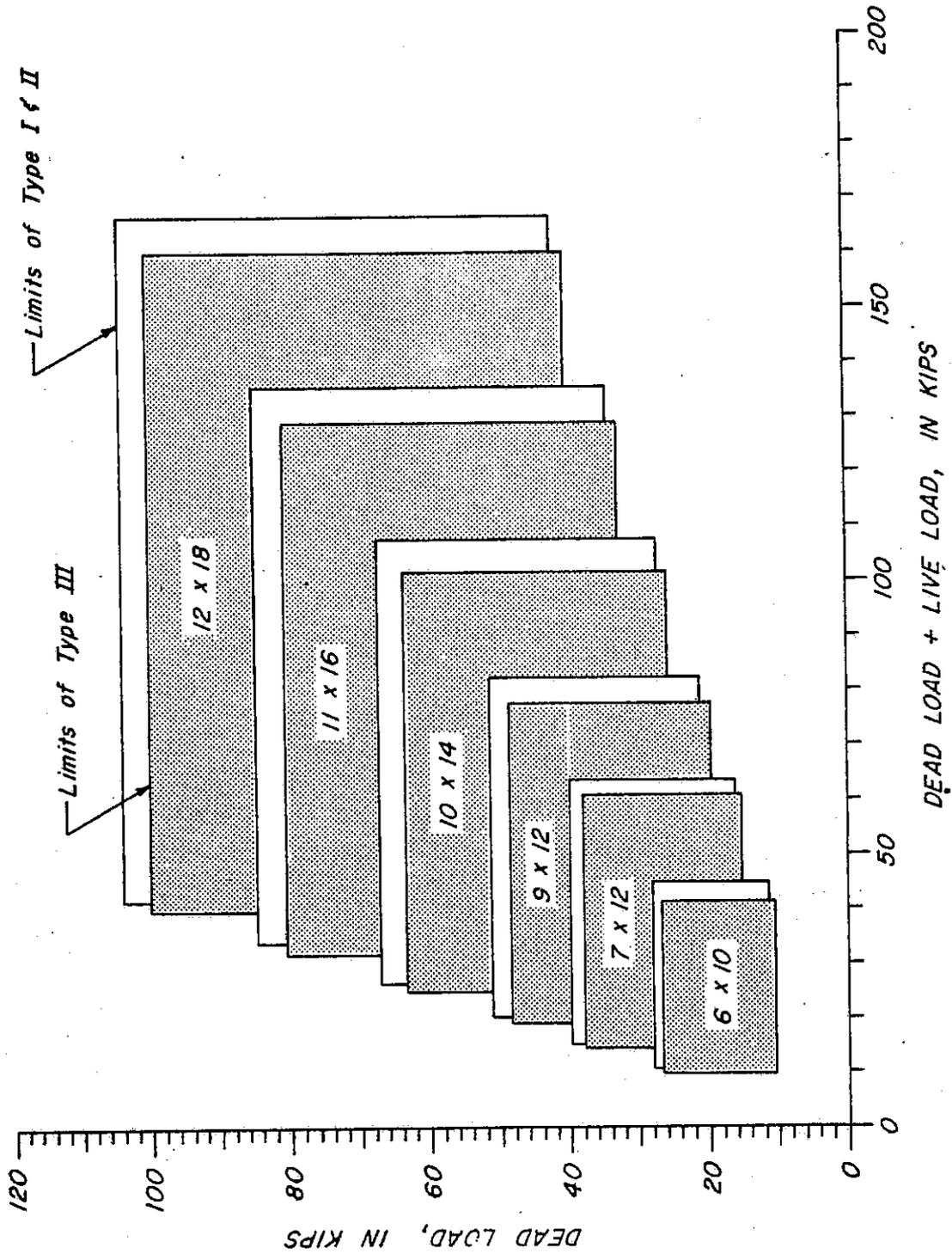
TFE

Elastomeric Bearing

Restrictor Pin

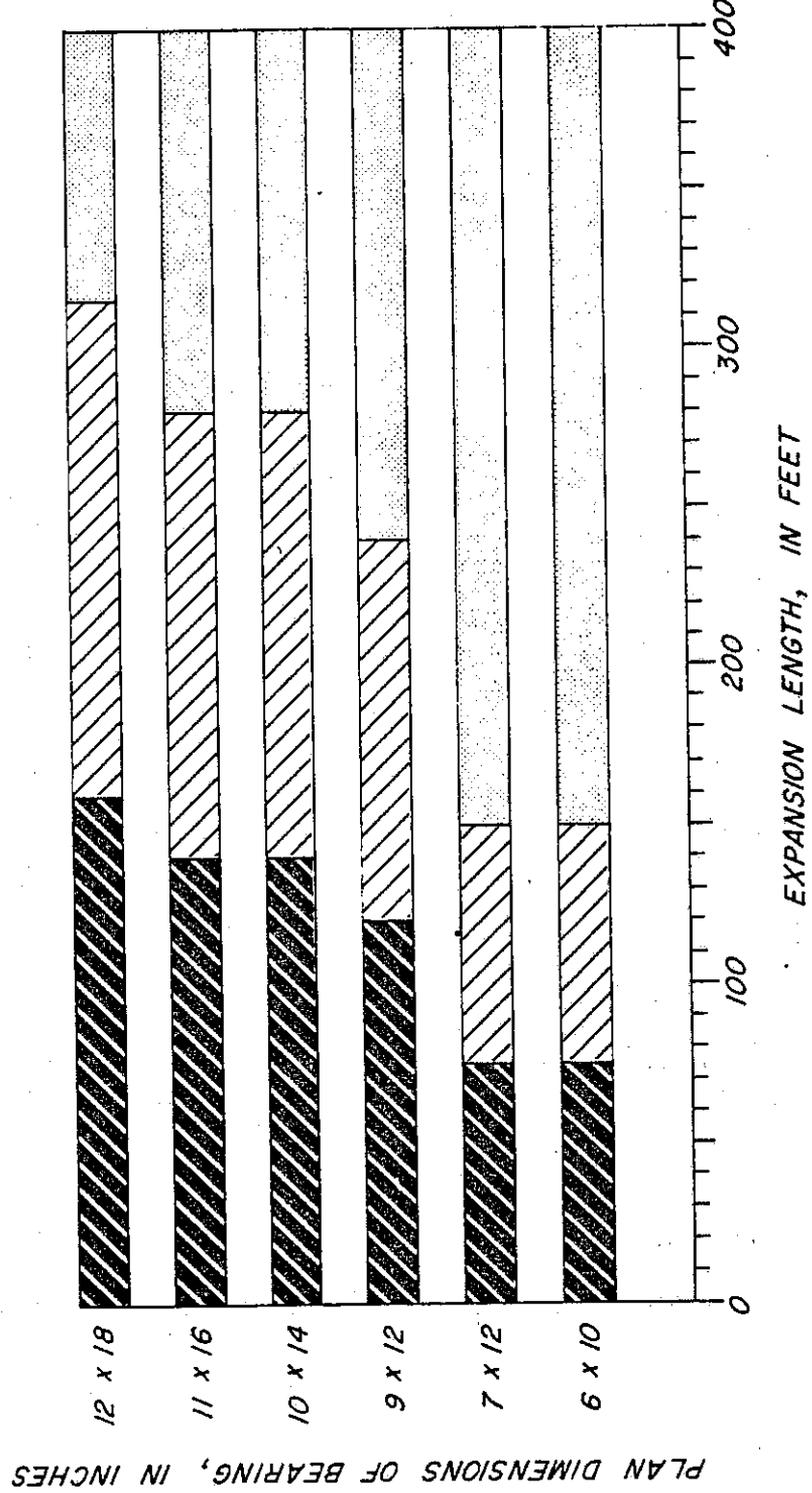
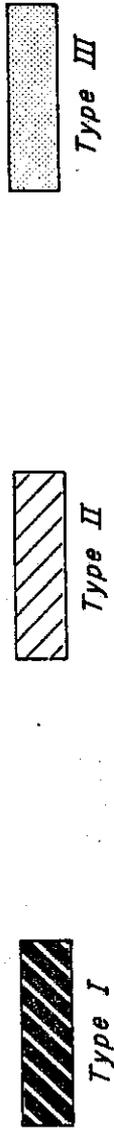
TYPE III BEARING

ELASTOMERIC AND
TFE ELASTOMERIC
EXPANSION BEARINGS



METRIC CONVERSION
1 kip = 4.45 kN

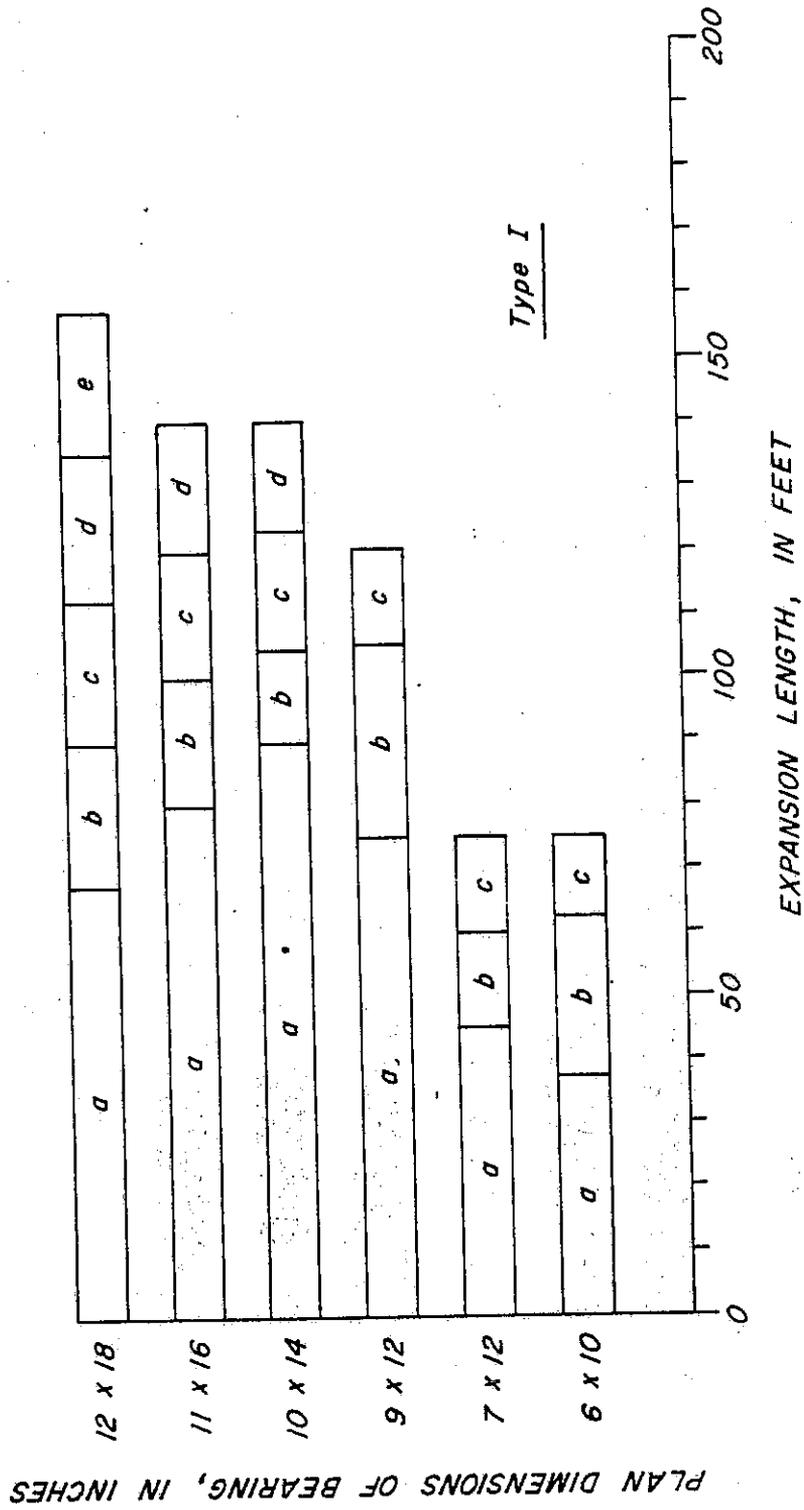
PLAN DIMENSIONS
VS. LOADING



METRIC CONVERSION

1 inch = 25.4 mm
1 foot = 0.305 m

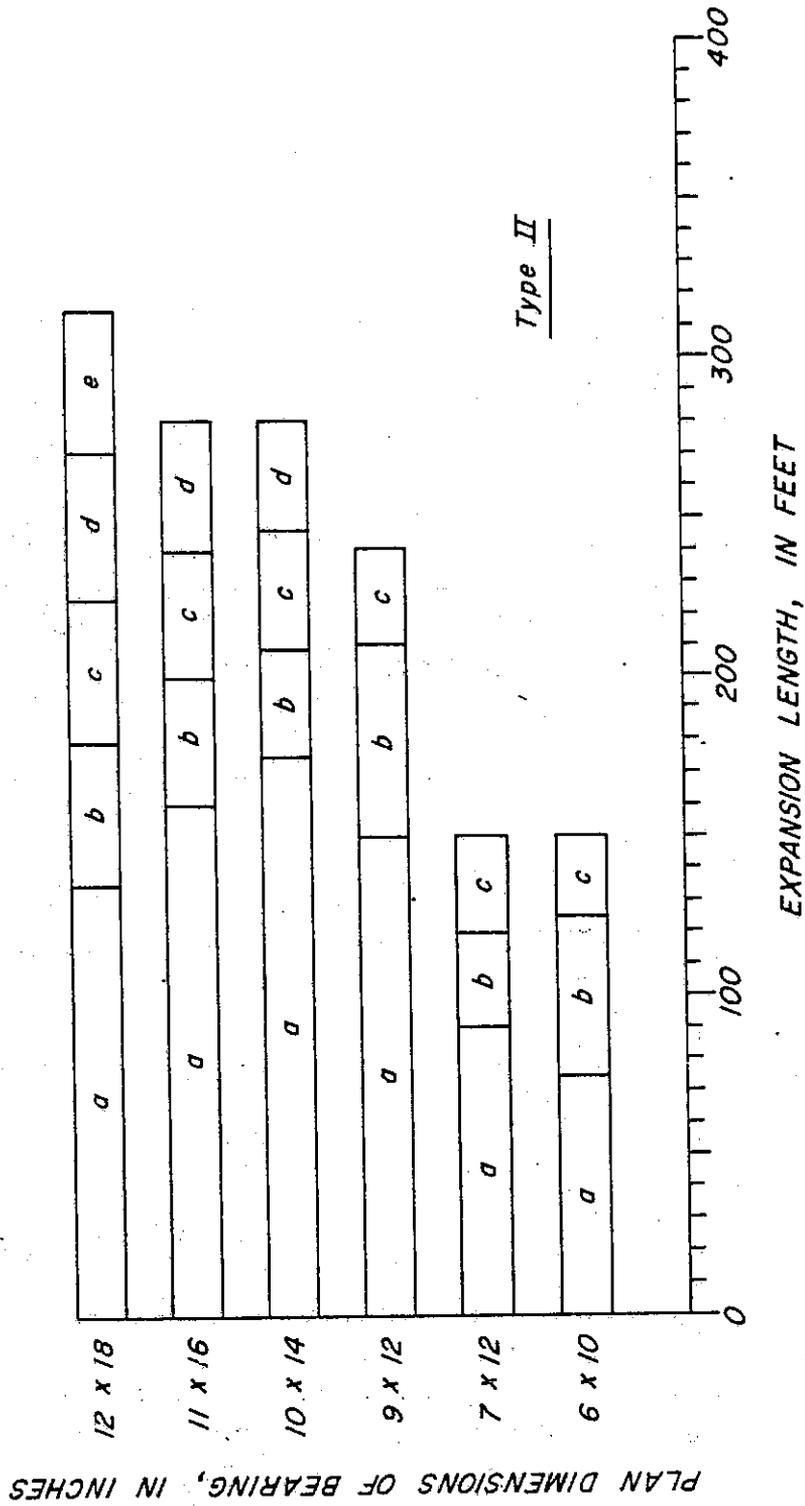
TYPE OF BEARING
VS. EXPANSION LENGTH



METRIC CONVERSION

1 inch = 25.4 mm
 1 foot = 0.305 m

TYPE I
MINIMUM BEARING THICKNESS
VS. EXPANSION LENGTH



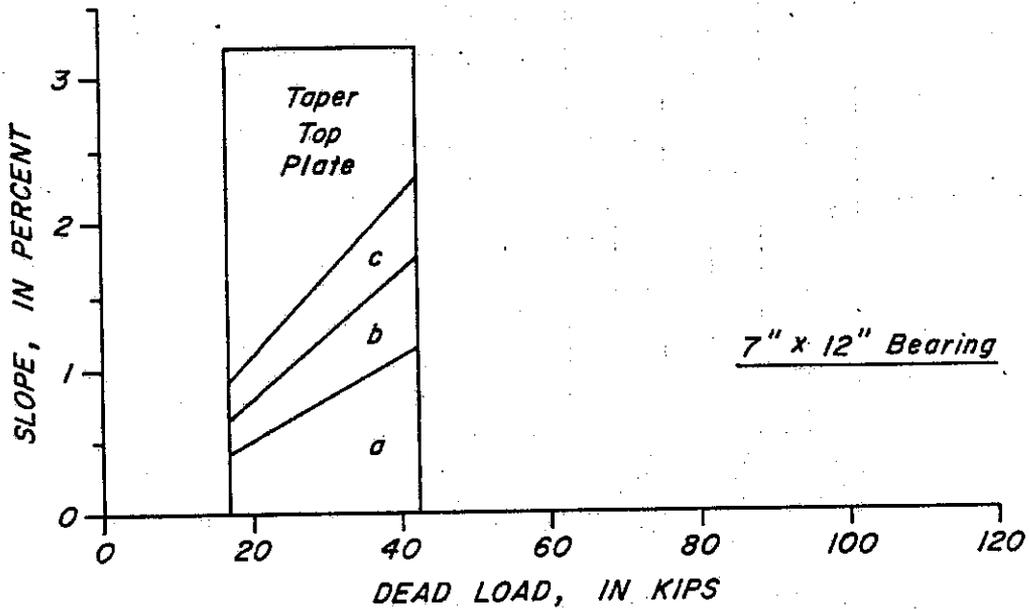
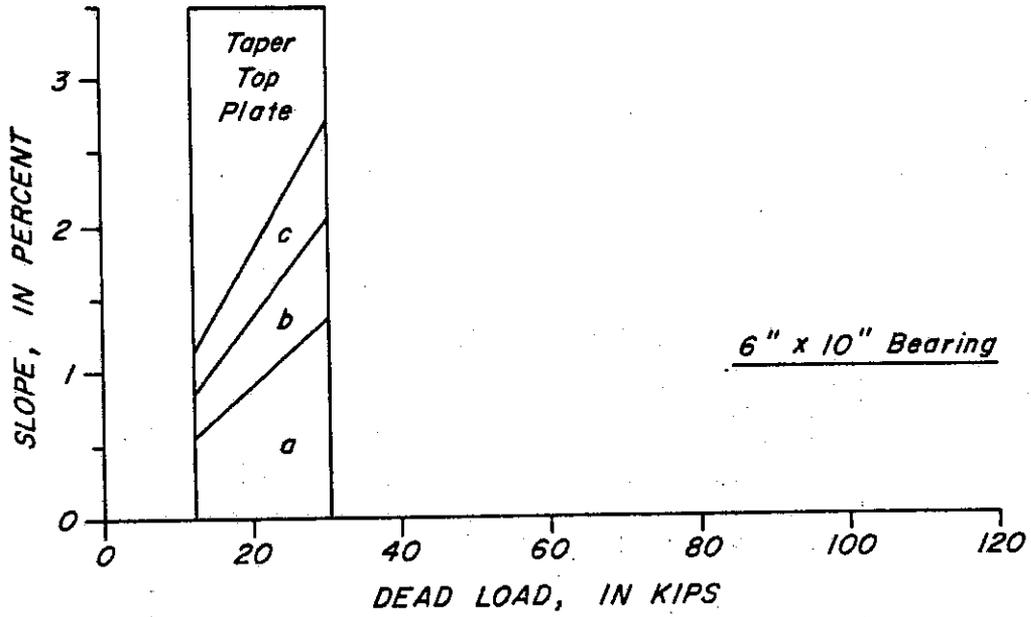
Type II

METRIC CONVERSION

1 inch = 25.4 mm

1 foot = 0.305 m

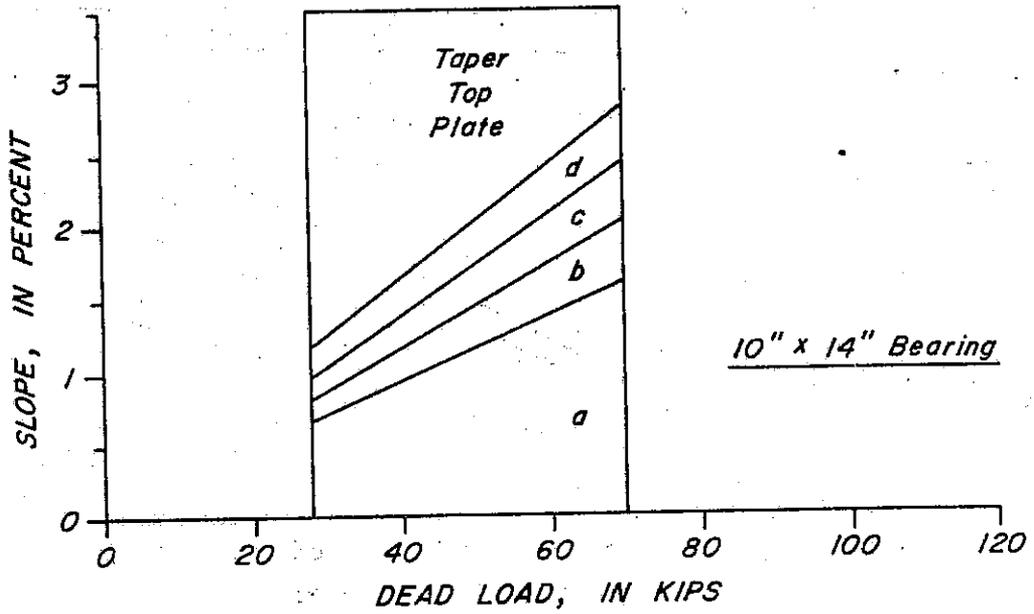
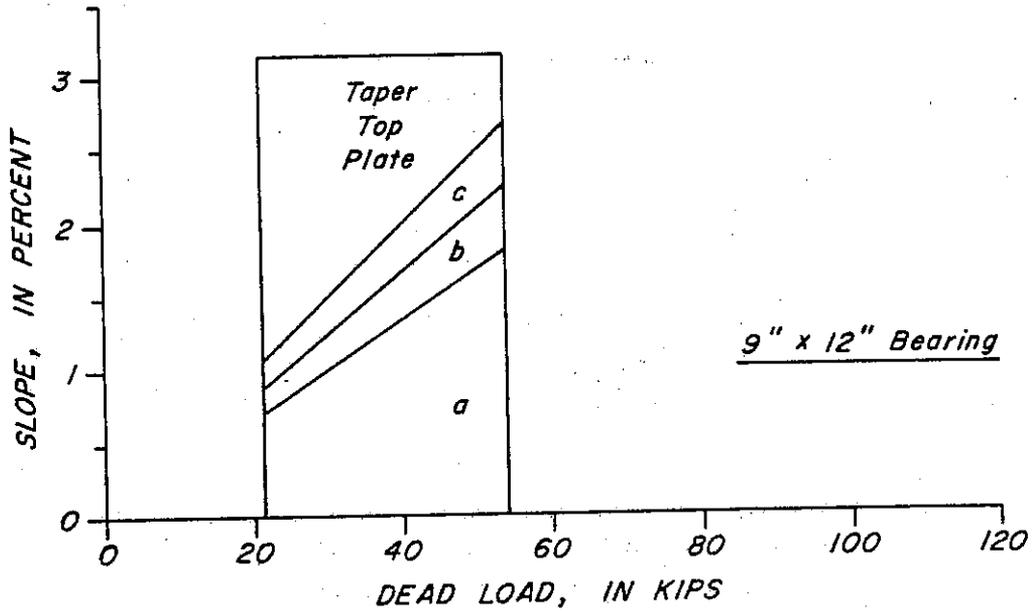
TYPE II
MINIMUM BEARING THICKNESS
VS. EXPANSION LENGTH



METRIC CONVERSION

1 kip = 4.45 kN
1 inch = 25.4 mm

MINIMUM BEARING THICKNESS
VS. SLOPE

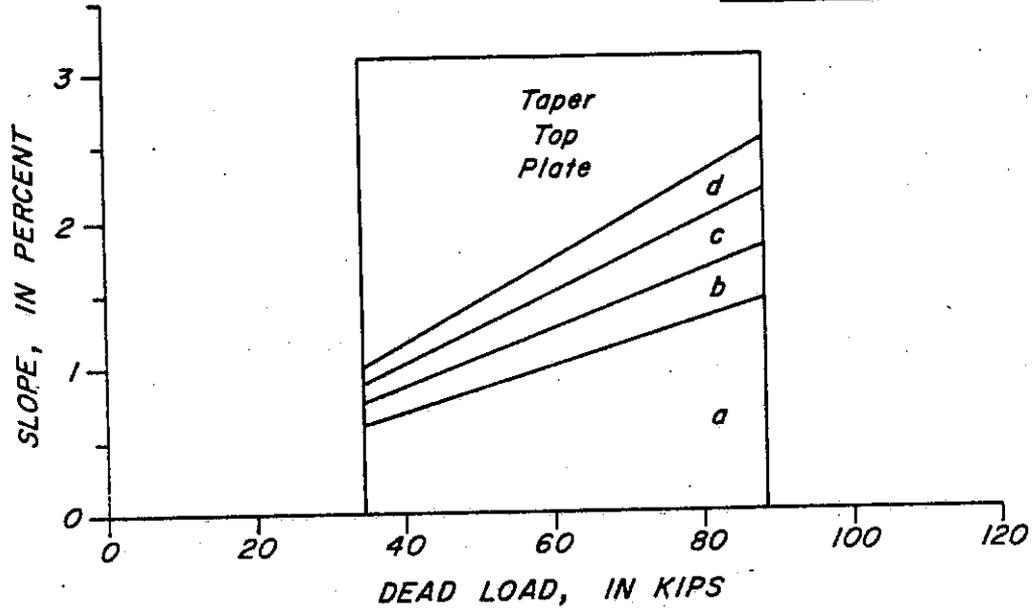


METRIC CONVERSION

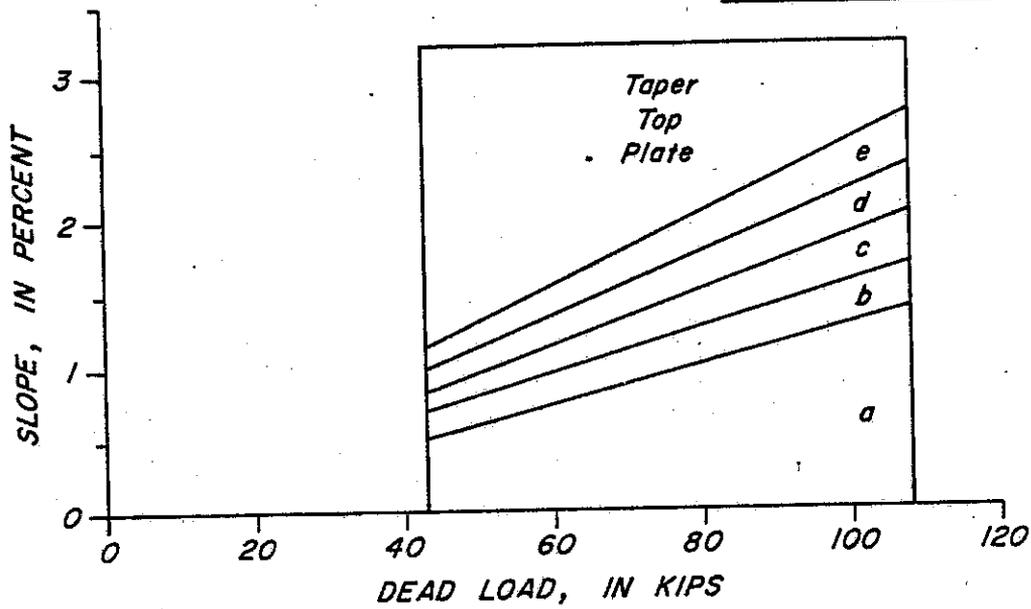
1 kip = 4.45 kN
1 inch = 25.4 mm

MINIMUM BEARING THICKNESS
VS. SLOPE

11" x 16" Bearing



12" x 18" Bearing



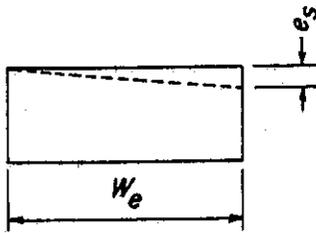
METRIC CONVERSION

1 kip = 4.45 kN
1 inch = 25.4 mm

MINIMUM BEARING THICKNESS
VS. SLOPE

TYPE I

(Maximum edge strain due to nonparallelism $\leq .06$ ERT)
 (as given in the table on plate III / 5.40)



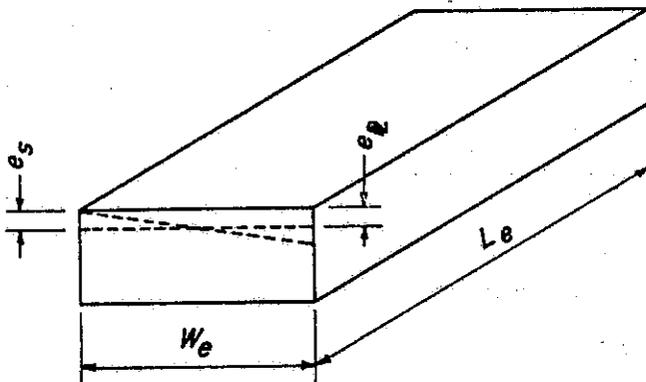
$$e_s = .06 \text{ ERT}$$

$$\text{Maximum \% Slope} = \frac{100 e_s}{W_e / 2}$$

$$\text{Maximum \% Slope} = \frac{12 (\text{ERT})}{W_e}$$

TYPE I, II, & III

(No lift-off permitted under dead load)
 (Recommended design as given in plates III / 5.30 - 5.32)



$$\% \text{ Slope} = \frac{100 e_s}{W_e / 2}$$

$$\text{Maximum \% Slope} = \frac{200 e_e}{W_e / 2}$$

$$e_e = \frac{R (\text{ERT})}{E_r W_e L_e}$$

$$\text{Maximum \% Slope} = \frac{200 R (\text{ERT})}{E_r W_e^2 L_e}$$

For $4.5 \leq \text{S.F.} \leq 5.5$,

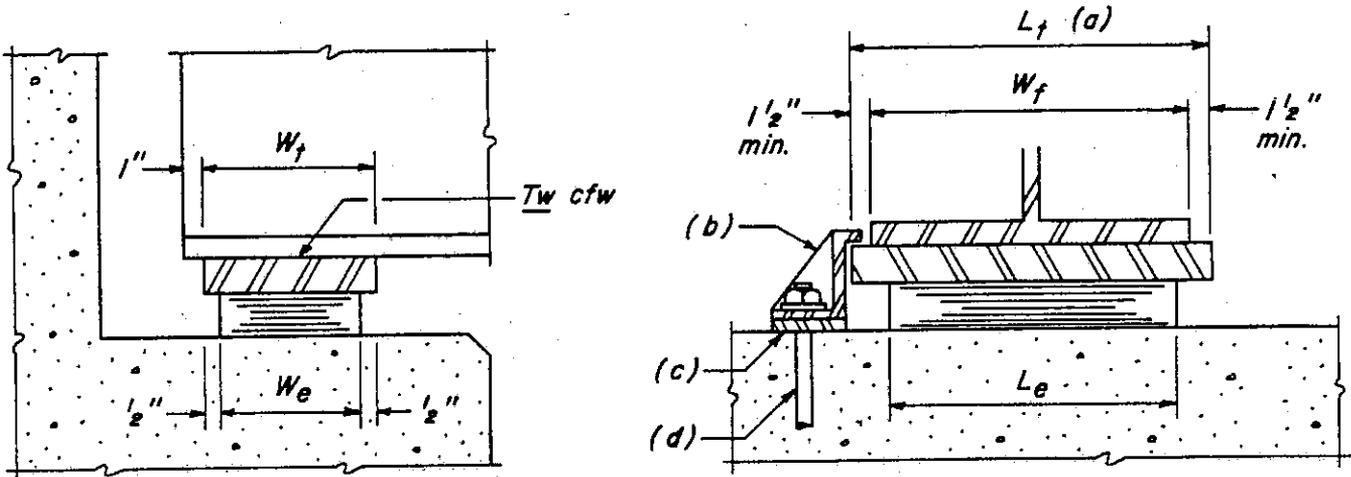
$$E_r = 1.2 \times 10^4 \frac{\text{psi}}{\text{in.} / (\text{ERT})}$$

$$\text{Maximum \% Slope} = \frac{R (\text{ERT})}{60 W_e^2 L_e}$$

METRIC CONVERSION

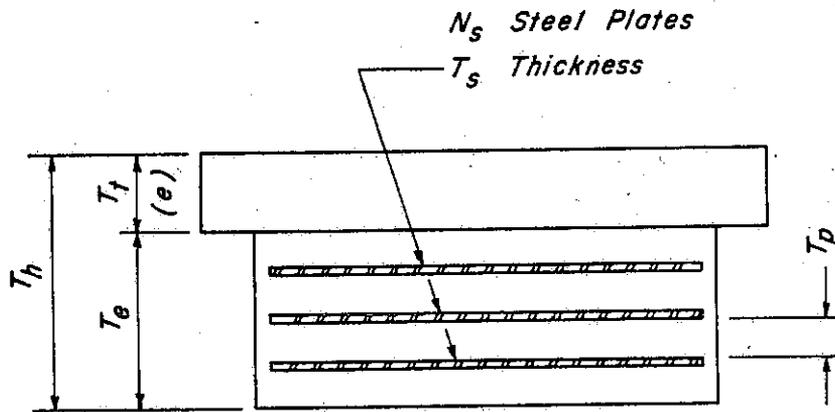
1 psi = 6.89 kPa

SLOPE LIMITATIONS
FOR ELASTOMERIC
EXPANSION BEARINGS



Note:

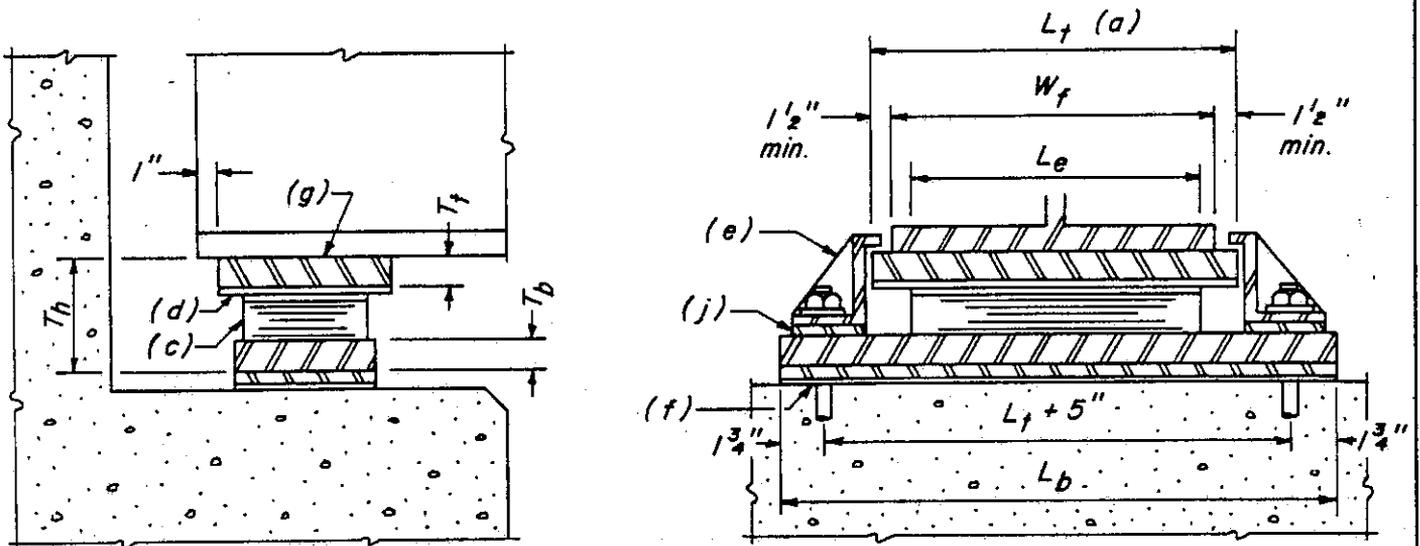
- a $L_f = W_f + 3''$ or $L_e + 2''$ whichever is greater.
- b Side retainer. (Place at inside face of exterior girders only)
- c Steel shim for retainer.
- d 1" ϕ x 12" anchor bolt.
- e Includes fill height for crown, 1 1/2" minimum thickness.



METRIC CONVERSION

1 inch = 25.4 mm

TYPE I
ELASTOMERIC
EXPANSION BEARING

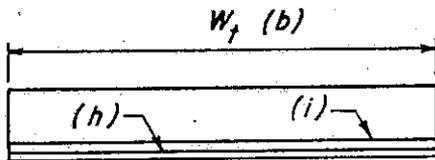


Note:

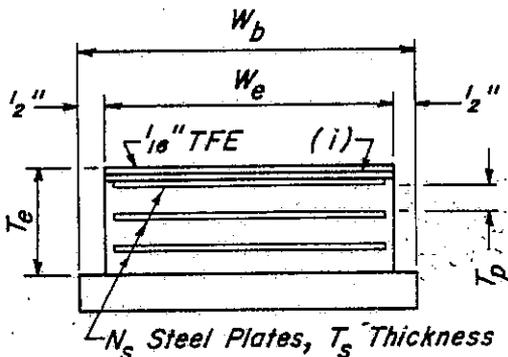
- a $L_1 = W_f + 3''$ or $L_e + 2''$ whichever is greater.
- b $W_f = W_e + 2E + 2''$, $E = \text{Expansion from } 50^\circ \text{ normal temperature.}$
- c TFE - Elastomeric bearing.
- d Stainless steel sliding plate.
- e Side retainer.
- f Fill plate for crown and $\frac{1}{8}''$ lead plate.
- g $\frac{5}{16}''$ continuous fillet weld 4 sides.
- h $\frac{1}{16}''$ stainless, A240, Type 304, 2B finish.
- i $\frac{1}{8}''$ - 90 Durometer Neoprene.
- j Steel shim for retainer.

METRIC CONVERSION

1 inch = 25.4 mm
 50°F = 10°C



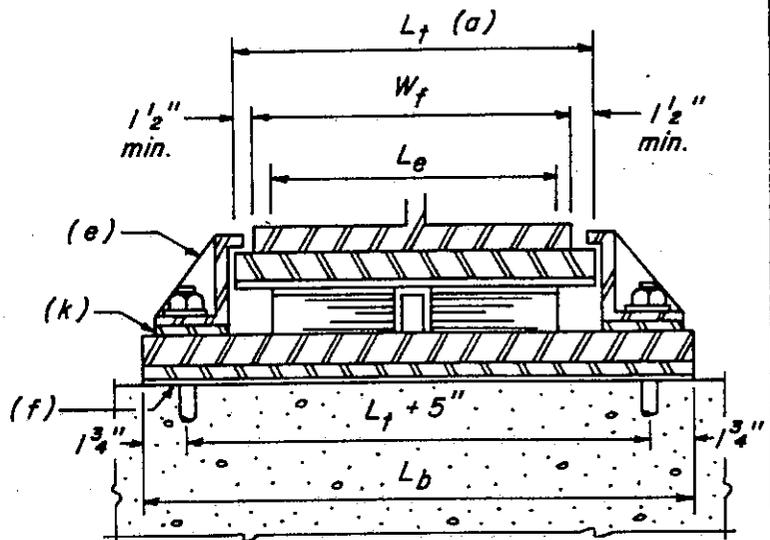
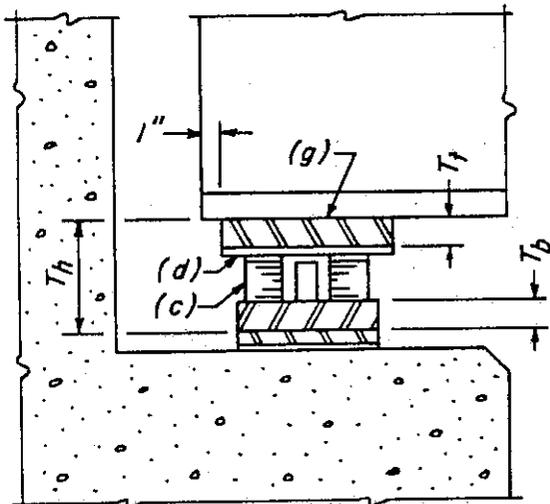
TOP BEARING ASSEMBLY



BOTTOM BEARING ASSEMBLY

Note: This design contains certain features for which patents have been granted or applied for. An acceptable alternate may be needed for competitive bidding.

TYPE II
TFE ELASTOMERIC
EXPANSION BEARING

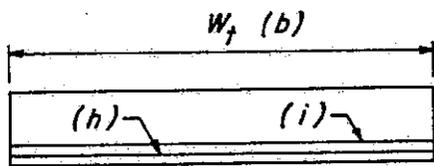


Note:

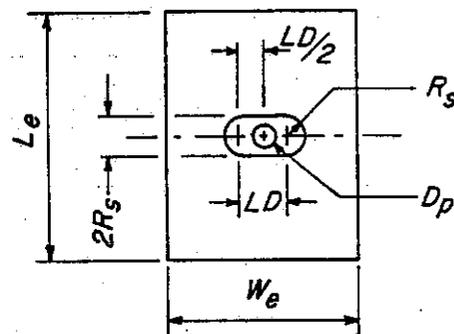
- a $L_f = W_f + 3$ or $L_e + 2$ whichever is greater.
- b $W_f = W_e + 2E + 2$, $E = \text{Expansion from } 50^\circ \text{ normal temperature.}$
- c TFE - Elastomeric bearing.
- d Stainless steel sliding plate.
- e Side retainer.
- f Fill plate for crown and $\frac{1}{8}$ inch lead plate.
- g $\frac{5}{16}$ inch continuous fillet weld 4 sides.
- h $\frac{1}{16}$ inch stainless, A240, Type 304, 2B finish.
- i $\frac{1}{8}$ inch - 90 Durometer Neoprene.
- j Restrictor pin, AISI 4340, quenched and tempered.
- k Steel shim for retainer.

METRIC CONVERSION

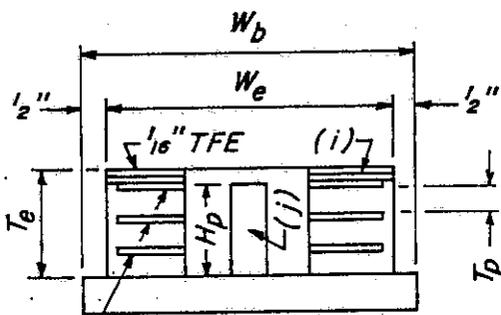
1 inch = 25.4 mm
 $50^\circ\text{F} = 10^\circ\text{C}$



TOP BEARING ASSEMBLY



SLOT DETAIL

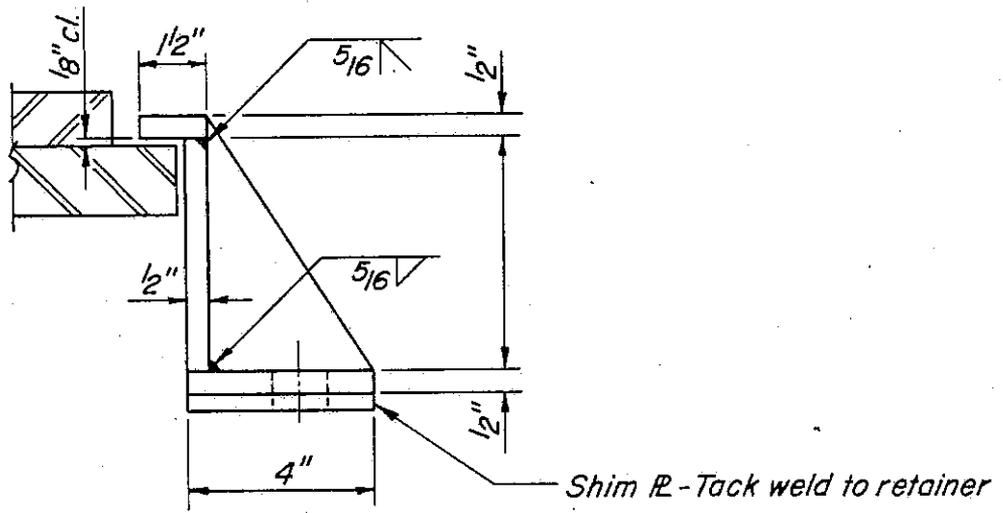
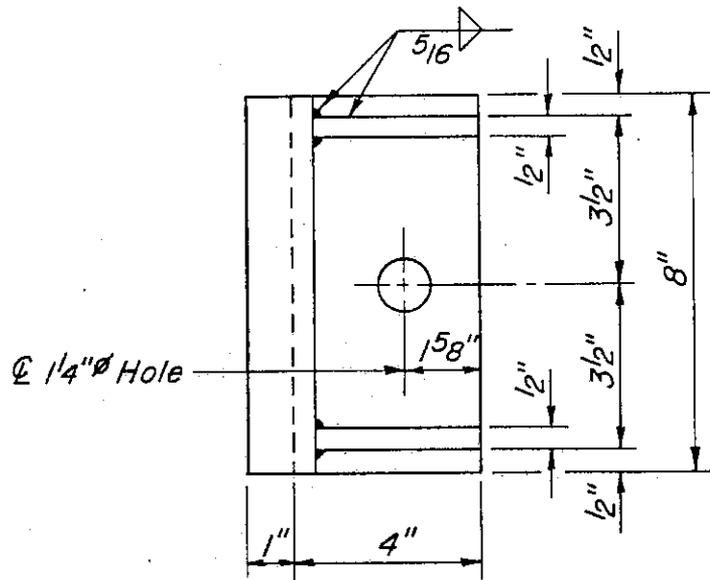


N_s Steel Plates, T_s Thickness

BOTTOM BEARING ASSEMBLY

Note: This design contains certain features for which patents have been granted or applied for. An acceptable alternate may be needed for competitive bidding.

TYPE III
TFE ELASTOMERIC
EXPANSION BEARING

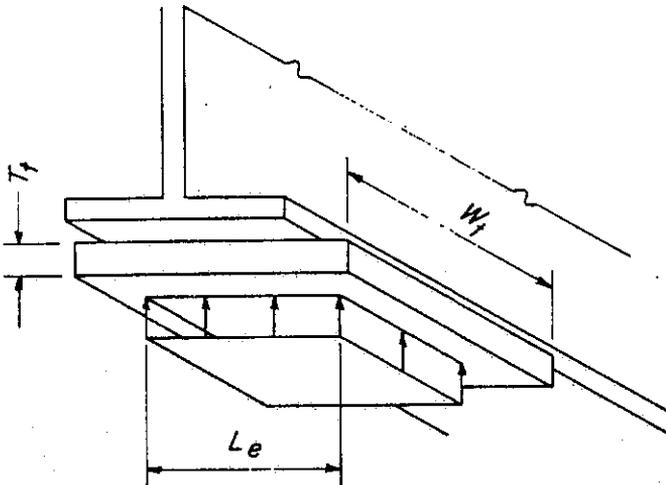


METRIC CONVERSION

1 inch = 25.4 mm

SIDE RETAINER
FOR ELASTOMERIC
EXPANSION BEARINGS

$R = \text{Reaction in Kips}$
 $f_s = 20 \text{ ksi}$

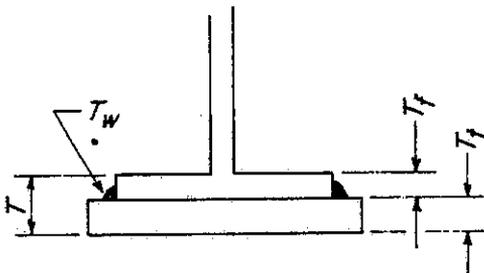


TOP BEARING PLATE THICKNESS

$$\frac{1}{T} = .194 \sqrt{\frac{R L_e}{W_f}}$$

$$T_f = T - T_f$$

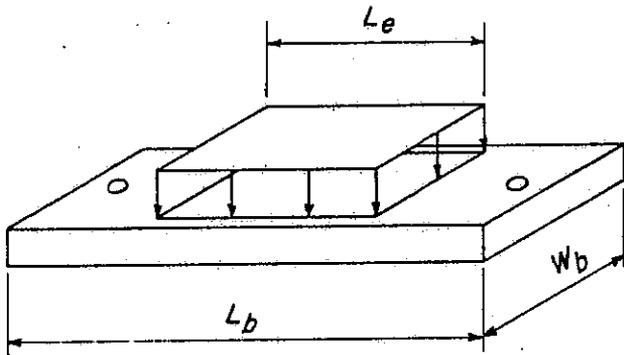
$$\frac{3}{\text{Minimum } T_f = 1\frac{1}{2}''}$$



TOP PLATE WELD DESIGN

$$\frac{2}{S_w} = \text{Stress per inch of weld}$$

$$S_w = \frac{3R T_f T_f L_e}{4(T_f + T_f)^3 (L_f + W_f)}$$



BOTTOM BEARING PLATE THICKNESS

$$T_b = .194 (L_b - L_e) \sqrt{\frac{R}{L_b W_b}}$$

$$\text{Minimum } T_b = 1''$$

$\frac{1}{}$ With bearing stiffeners use 80% T .

$\frac{2}{}$ With bearing stiffeners use $\frac{1}{2}''$ weld.

$\frac{3}{}$ Minimum plate thickness to avoid bond failure with rubber during welding.

METRIC CONVERSION

1 inch = 25.4 mm
 1 psi = 6.89 kPa

ELASTOMERIC

BEARING PLATE DESIGN

TABLE 1

LOAD CAPACITY AND SHAPE FACTOR - TYPE 1, 2, AND 3 BEARINGS

Bearing	ERT	TYPE 1 AND 2 (In Kips) Psi				TYPE 3 (In Kips) Psi			
		200	500	800	S.F.	200	500	800	S.F.
		6-a	15/16"	11.2	28.0	44.9	5.79	10.8	27.0
6-b	1-9/16"	11.2	28.0	44.9	5.79	10.7	26.6	42.6	4.76
6-c	1-7/8"	11.2	28.0	44.9	5.79	10.5	26.3	42.1	4.58
7-a	1-1/8"	15.9	39.7	63.4	5.71	15.4	38.6	61.7	5.03
7-b	1-1/2"	15.9	39.7	63.4	5.71	15.3	38.3	61.2	4.87
7-c	1-7/8"	15.9	39.7	63.4	5.71	15.2	37.9	60.7	4.73
9-a	1-7/8"	20.6	51.4	82.3	6.68	19.7	49.2	78.7	5.50
9-b	2-5/8"	20.6	51.4	82.3	6.68	19.5	48.8	78.1	5.36
9-c	3- "	20.6	51.4	82.3	6.68	19.3	48.3	77.2	5.15
10-a	2-3/16"	26.8	67.0	107.3	6.51	25.9	64.8	103.7	5.51
10-b	2-5/8"	26.8	67.0	107.3	6.51	25.8	64.5	103.1	5.39
10-c	3-1/16"	26.8	67.0	107.3	6.51	25.6	64.1	102.5	5.27
10-d	3-1/2"	26.8	67.0	107.3	6.51	25.5	63.7	101.9	5.13
11-a	2- "	33.9	84.7	135.5	6.39	32.8	81.9	131.1	5.41
11-b	2-1/2"	33.9	84.7	135.5	6.39	32.6	81.5	130.4	5.30
11-c	3- "	33.9	84.7	135.5	6.39	32.4	81.0	129.7	5.19
11-d	3-1/2"	33.9	84.7	135.5	6.39	32.2	80.6	129.0	5.09
12-a	1-11/16"	41.7	104.3	166.9	6.28	40.6	101.5	162.5	5.41
12-b	2-1/4"	41.7	104.3	166.9	6.28	40.4	101.1	161.8	5.32
12-c	2-13/16"	41.7	104.3	166.9	6.28	40.3	100.7	161.1	5.23
12-d	3-3/8"	41.7	104.3	166.9	6.28	40.1	100.2	160.4	5.13
12-e	3-15/16"	41.7	104.3	166.9	6.28	39.9	99.8	159.7	5.04

METRIC CONVERSION

1 psi = 6.89 kPa
1 inch = 25.4 mm

TABLE 2

TABLE OF DIMENSIONS - TYPE I BEARING

Bearing	W _e	L _e	T _p	N _p	T _s	N _s	T _e	Slope Max. %
6-a	6"	10"	5/16"	3	14 ga.	2	1-1/8"	1.88
6-b	6"	10"	5/16"	5	14 ga.	4	1-7/8"	3.12
6-c	6"	10"	5/16"	6	14 ga.	5	2-1/4"	3.75
7-a	7"	12"	3/8"	3	3/32"	2	1-5/16"	1.93
7-b	7"	12"	3/8"	4	3/32"	3	1-13/16"	2.57
7-c	7"	12"	3/8"	5	3/32"	4	2-1/4"	3.21
9-a	9"	12"	3/8"	5	3/32"	4	2-1/4"	2.50
9-b	9"	12"	3/8"	7	3/32"	6	3-3/16"	3.50
9-c	9"	12"	3/8"	8	3/32"	7	3-11/16"	4.00
10-a	10"	14"	7/16"	5	1/8"	4	2-11/16"	2.62
10-b	10"	14"	7/16"	6	1/8"	5	3-1/4"	3.15
10-c	10"	14"	7/16"	7	1/8"	6	3-13/16"	3.68
10-d	10"	14"	7/16"	8	1/8"	7	4-3/8"	4.20
11-a	11"	16"	1/2"	4	1/8"	3	2-3/8"	2.18
11-b	11"	16"	1/2"	5	1/8"	4	3 "	2.73
11-c	11"	16"	1/2"	6	1/8"	5	3-5/8"	3.27
11-d	11"	16"	1/2"	7	1/8"	6	4-1/4"	3.82
12-a	12"	18"	9/16"	3	3/16"	2	2-1/16"	1.69
12-b	12"	18"	9/16"	4	3/16"	3	2-13/16"	2.25
12-c	12"	18"	9/16"	5	3/16"	4	3-9/16"	2.81
12-d	12"	18"	9/16"	6	3/16"	5	4-5/16"	3.38
12-e	12"	18"	9/16"	7	3/16"	6	5-1/16"	3.94

METRIC CONVERSION

1 inch = 25.4 mm

TABLE 3

TABLE OF DIMENSIONS - TYPE 2 AND 3 BEARINGS

Bearing	W _e	L _c	T _p	N _p	T _s	N _s	T _c
6-a	6"	10"	5/16"	3	14 ga.	3	1-3/8"
6-b	6"	10"	5/16"	5	14 ga.	5	2-1/8"
6-c	6"	10"	5/16"	6	14 ga.	6	2-9/16"
7-a	7"	12"	3/8"	3	3/32"	3	1-5/8"
7-b	7"	12"	3/8"	4	3/32"	4	2-1/16"
7-c	7"	12"	3/8"	5	3/32"	5	2-9/16"
9-a	9"	12"	3/8"	5	3/32"	5	2-9/16"
9-b	9"	12"	3/8"	7	3/32"	7	3-1/2"
9-c	9"	12"	3/8"	8	3/32"	8	3-15/16"
10-a	10"	14"	7/16"	5	1/8"	5	3- "
10-b	10"	14"	7/16"	6	1/8"	6	3-9/16"
10-c	10"	14"	7/16"	7	1/8"	7	4-1/8"
10-d	10"	14"	7/16"	8	1/8"	8	4-11/16"
11-a	11"	16"	1/2"	4	1/8"	4	2-11/16"
11-b	11"	16"	1/2"	5	1/8"	5	3-5/16"
11-c	11"	16"	1/2"	6	1/8"	6	3-15/16"
11-d	11"	16"	1/2"	7	1/8"	7	4-9/16"
12-a	12"	18"	9/16"	3	3/16"	3	2-7/16"
12-b	12"	18"	9/16"	4	3/16"	4	3-3/16"
12-c	12"	18"	9/16"	5	3/16"	5	3-15/16"
12-d	12"	18"	9/16"	6	3/16"	6	4-11/16"
12-e	12"	18"	9/16"	7	3/16"	7	5-7/16"

METRIC CONVERSION

1 inch = 25.4 mm

Table 4

TABLE OF DIMENSIONS - TYPE 3 BEARING (continued)

Bearing	$\frac{1}{T_b}$	D_p	H_p	LD	R_s
6-a	1- "	1- "	1-1/8"	1- "	5/8"
6-b	1- "	1- "	1-7/8"	1-1/2"	5/8"
6-c	1- "	1- "	2-1/4"	2- "	5/8"
7-a	1- "	1- "	1- 5/16"	1- "	5/8"
7-b	1- "	1- "	1-13/16"	1-1/2"	5/8"
7-c	1-1/4"	1- "	2- 1/4 "	2- "	5/8"
9-a	1-1/4"	1-1/4"	2- 1/4 "	2- "	3/4"
9-b	1-1/2"	1-1/4"	3- 3/16"	2-1/2"	3/4"
9-c	1-3/4"	1-1/4"	3-11/16"	3- "	3/4"
10-a	1-1/2"	1-1/4"	2-11/16"	2- "	3/4"
10-b	1-1/2"	1-1/4"	3- 1/4 "	2-1/2"	3/4"
10-c	1-3/4"	1-1/4"	3-13/16"	3- "	3/4"
10-d	2-	1-1/4"	4- 3/8 "	3-1/2"	3/4"
11-a	1-1/2"	1-1/2"	2- 3/8 "	2- "	7/8"
11-b	1-1/2"	1-1/2"	3"	2-1/2"	7/8"
11-c	1-3/4"	1-1/2"	3- 5/8 "	3- "	7/8"
11-d	2- "	1-1/2"	4- 1/4 "	3-1/2"	7/8"
12-a	1-1/4"	1-1/2"	2- 1/16"	2- "	7/8"
12-b	1-3/4"	1-1/2"	2-13/16"	2-1/2"	7/8"
12-c	2- "	1-1/2"	3- 9/16"	3- "	7/8"
12-d	2- "	1-1/2"	4- 5/16"	3-1/2"	7/8"
12-e	2-1/4"	1-1/2"	5- 1/16"	4- "	7/8"

1 Based on minimum thickness required for seating restrictor pin.

METRIC CONVERSION

1 inch = 25.4 mm

TFE EXPANSION BEARINGS FOR HIGHWAY BRIDGES

INTRODUCTION

The use of TFE (tetrafluoroethylene) as a sliding bearing for highway bridges is of interest to bridge engineers who are concerned with past problems relating to the performance of existing types of steel and graphite impregnated bronze bearings. In certain cases the lack of performance under normal service has resulted in serious damage to the main structural elements of a bridge. Consequently, extensive remedial work is required to restore the structure.

Since the collapse of the bridge at Point Pleasant, the Illinois Department of Transportation has undertaken an extensive program of bridge inspection to avoid any similar failures within the State. As a result of this program, bridge inspection crews have found several bridges with serious signs of structural distress relating to seized bearings. Examples of major and costly failures within the State are presented in the appendix. The examples illustrate the severity of distress commonly associated with seized or nonfunctional bearings.

The potential of failure and the cost of replacing nonfunctional bearings as cited in these examples and the frequency with which these failures are occurring are of great concern to bridge design and maintenance engineers. With rising costs and with greater demands toward conserving present resources, it will become necessary to design bridge structures for a longer life and with less required maintenance.

An in-depth investigation of the Poplar Street complex in East St. Louis revealed that problems could develop with certain pin-connected details, resulting in major structural damage to main supporting members of a bridge. ^{1/} Observations of

^{1/} Floyd K. Jacobsen, "Investigation Of Bridge Approach Spans To Poplar Street Bridge," Physical Research Report No. 66, October 1975

pin-connected bearings removed from the Poplar Street complex had shown the accumulation of tightly packed rust between the contact surfaces of the pin and the supporting saddles which eventually seized the pin. Seizure of the bearings at several locations on the complex had resulted in web tearing and web buckling of the main girders, separation between the bottom flange of the girder and top bearing plate, and tearing of the bottom flange near the web. Conclusions from the investigation indicated that the use of pin-connected details subjected to large rotations and utilizing untreated, corrosive-mild steels should be avoided for highway bridges.

The purpose of an expansion bearing is to provide free translational and rotational movement while supporting the main structural elements of the superstructure. By permitting free movement at the supports, longitudinal forces are relieved or reduced with the use of expansion bearings. These are forces that are commonly induced by thermal expansion and contraction, creep and shrinkage, shifting of abutments, and beam shortening and rotation due to dead- and live-load deflections.

Nonparallel load surfaces resulting from the profile grade of the girders, camber in prestressed concrete members, and vertical misalignment of the girders and bearing seats during construction are other factors to be considered in the design of the bearing. The design of the bearing should provide rotational freedom to adjust to the varying conditions encountered with nonparallel surfaces.

Most maintenance problems occur when the free movement of the bearings becomes restricted due to galling and corrosion. Seized bearings can result in excessive deflection of the pier caps, cracking and disintegration of the masonry bearing seats, and severe damage to the ends of the main girders. Considerable maintenance costs often are required to correct these situations when they occur.

Recent developments in the use of elastomeric bearings and in the technology of TFE or fluorocarbon resins have made it possible to consider new concepts in the design of structural bridge bearings. The material has certain physical and chemical properties which make it potentially useful as a structural bearing material. The most desirable properties of TFE as a bridge bearing material are an anti-stick surface, a low coefficient of friction, and a chemical inertness to deterioration. These characteristics are very suitable for expansion bridge bearings that are normally exposed to a corrosive environment.

Various concepts regarding the optimum design of highway bridge bearings using elastomeric and TFE sliding bearings have been developed and promoted by several of the bearing manufacturers. Many combinations of TFE and backing materials are commercially available, and the selection of the optimum bearing for a specific application is complicated by this variety of different products. A series of initial laboratory and field tests were conducted to evaluate various designs as recommended by the manufacturers. The results of the tests indicate that TFE expansion bearings of a suitable design could be used for highway bridges and that preference should be given to the use of TFE bearings in lieu of graphite-impregnated bronze bearings.

A tentative design based on the above recommendation was developed for use on prestressed concrete bridges as a replacement for the bronze bearings. This design, which is presented in Illinois Research and Development Report No. 31, was accepted by the Illinois Department of Transportation as a temporary standard for bridges incorporating precast prestressed concrete I-beams.

The specific aim of this project was to develop an acceptable TFE bearing to replace the graphite-impregnated bronze bearing for precast prestressed concrete bridges. Although several of the designs submitted by manufacturers appeared to be

acceptable, there were certain deficiencies or limitations in the various designs which suggested a need to continue the research to improve the design. The study also was extended to develop a standard design for steel bridges. The factors considered for developing an appropriate design were economy, maintenance-free durability, and performance under various conditions of loading.

An evaluation was made on the performance of several types and combinations of TFE, steel, and elastomer materials. On the basis of this evaluation, a final design was selected and implemented as a standard by the Illinois Department of Transportation.

The investigation consisted of three major phases of evaluation: (1) a direct field application incorporating a series of different prototypes into a bridge structure, (2) laboratory tests of diverse specimens subjected to various loading conditions, and (3) development of a final design based on the experimental field and laboratory data. This final report on the project presents a summary of the field and laboratory tests. Conclusions derived from the study and documentation of the final design adopted by the Illinois Department of Transportation also are included in this report.

FIELD TEST

A detailed description of the field test is presented in the interim report published in 1971^{2/} for this project. The structure selected for the trial installation is identified as FAI Route 57, Section 41-HB-1, Jefferson County, which carries the traffic of Township Road 101 over Interstate 57. In July 1967, five

^{2/} F. K. Jacobsen and R. K. Taylor, "TFE Expansion Bearings for Highway Bridges," Research and Development Report No. 31, June 1971

different types of TFE sliding bearings were incorporated as the experimental feature at one end of the structure. Five self-lubricating bronze graphite bearings designed according to current standards were installed at the opposite end to serve as the control for making a comparative evaluation of the performance of the two types of sliding bearings. Laminated elastomeric bearing pads, which are conventionally used for this type of construction, were provided at the intermediate piers.

Throughout the duration of the field tests, periodic inspections were made to determine the physical condition and performance of the bearings. After three years of service, the bearings were removed to observe the condition of the bearings.

The TFE surfaces of two experimental bearings, backed with 50-durometer rubber and with a stainless steel laminate bonded between the rubber and TFE, gave little or no indication of sliding or wear. The thermal movements of the structure did not appear to be of sufficient magnitude to induce sliding between the two surfaces. The movement appears to be accommodated by the horizontal strain deformation of the 50-durometer rubber backing. Upon removal, the only evidence of permanent deformation was a slight bulging at the sides of the elastomer due to creep of the elastomeric material under sustained loading. This deformation did not appear to affect the performance of the bearing. However, this could have been a serious problem if movement had occurred between the two surfaces, which was later substantiated by laboratory tests.

Another experimental bearing consisting of a TFE layer bonded directly to the neoprene backing distorted upon removal of the load as did laboratory specimens of the same configuration. When removed from the structure, the specimen deformed with a slight curvature which was convex when viewed from the top surface. This distortion did not occur, however, until the load was removed and did not appear to

affect the performance of the bearing while installed in the structure.

Present on the TFE surfaces of all five experimental bearings were depressed and raised areas indicative of voided areas beneath the TFE surface (Figure 1). Close examination of one specimen indicated that an uneven layer of adhesive was used to bond the TFE layer to the backing material. These surface irregularities also were noted on the laboratory specimens.

There was no visible evidence of wear on the TFE surfaces of the experimental bearings. However, contamination was most evident on all specimens. Minute particles of grit were found embedded in the TFE within the contact areas of the bearing surfaces. Dirt and dust particles also had accumulated on the exposed surfaces of the mating units. This accumulation of contaminants could have a major effect on the frictional properties of the bearing.

The most significant result gained from the field test was the direct comparison of the performance of TFE bearings with respect to the bronze bearings. Measurements taken during the field test indicate nearly twice as much movement was taking place at the TFE bearings as compared with the movements measured at the bronze bearings. From this comparison it appears that the TFE bearings were more effective in allowing longitudinal expansion and contraction of the superstructure than the bronze self-lubricated bearings.

LABORATORY TEST

A program of laboratory testing was undertaken as a means of accelerating horizontal translational movements of typical bearing assemblies under vertical loads simulating normal and extreme field conditions. This program of accelerated testing was implemented so that results could be obtained quickly for an early evaluation of the possible application of TFE sliding bearings for highway bridges.

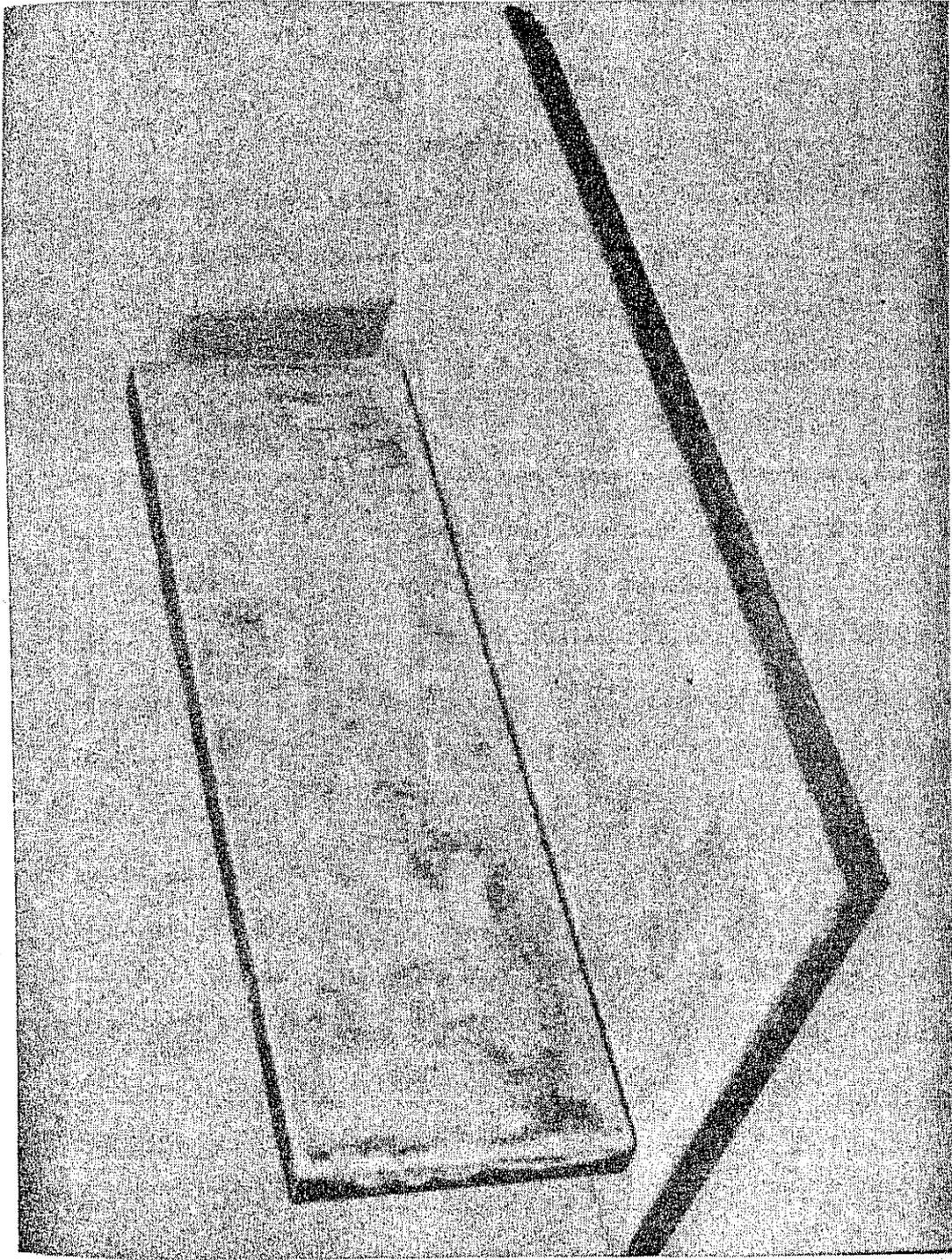


Figure 1. Field specimen showing surface irregularities and contamination.

A description of the test equipment and of the experimental test procedures is presented in the interim report for the project.^{2/}

The laboratory program consisted of two types of tests for evaluating the possible use of TFE bearings for highway bridges. The program included (1) dynamic or repetitive translational tests for analyzing the durability or fatigue life of the bearing units, and (2) static slip tests for determining the coefficient of friction for various compositions of TFE and filler materials.

A 20-year service life was established as a basis for evaluating the performance and the durability of the laboratory test specimens. One year of service life is interpreted as the equivalent of 365 complete translation cycles of dynamic testing. From this criterion the selected minimum number of translational cycles needed to determine the fatigue life and to evaluate the long-term performance and durability of the bearings was 7000. The frequency of translation based on two-directional displacement is approximately two cycles per minute. With this rate of cycling, each test undergoing 7000 cycles of lateral translation took about 60 hours or 2 1/2 days to complete. If the performance of the bearings could be demonstrated with no evidence of distress or incipient failure during the test period, it was assumed that the predicted service life could be projected to that of the bridge structure.

The test specimens were subjected to horizontal translational movements measuring 1.28 inches (32.5 mm) maximum displacement at various vertical load increments based on the design unit pressures as determined from the dead-load reactions calculated for the experimental bridge installation. The range of load levels for which the bearings were tested was limited to the maximum capacities recommended for the materials tested. The load increments generally used for the

^{2/} Ibid.

testing were design, design plus 50 percent, and design plus 100 percent vertical dead load. The load level representing design dead load plus 50 percent approximates the combination design dead- plus live-load conditions in the field.

Live-load rotational effects also were considered at the beginning of the test program. The original testing apparatus included a drive mechanism for inducing rotational movements at a rate of six cycles per minute. A malfunction in this device, however, developed within the early part of the testing program and became a continual maintenance problem. Finally, it was decided to discontinue this feature of the test.

During the testing of the first few pads the imposed live-load rotational effect appeared to have little influence on the performance of the bearings. Because of the apparent insignificant effect of live-load rotation, tests involving the rotational movement were suspended in lieu of later tests incorporating the more critical condition of nonparallel loaded surfaces. The condition of nonparallel surfaces was induced by using shims to raise one end of the upper load plate at slopes of 0, 2 1/2, and 5 percent with the horizontal plane.

Static slip tests were conducted to compare the frictional properties of various TFE materials under varying conditions of sliding. The horizontal forces needed to induce sliding across the TFE surface were measured in relation to the applied normal pressures, which ranged from 200 psi to 1400 psi (1.38 to 9.65 MPa). Values for the coefficient of friction were computed on the basis of the maximum frictional forces obtained for the corresponding normal pressures applied to the test specimens.

The data from the slip tests were used to compare the frictional properties of both filled and unfilled TFE materials, to study the change in friction properties during repetitive translational cycling, and to determine the effect of

contamination on TFE surface conditions.

UNFILLED TFE VS FILLED TFE

In the initial stages of this study the filled TFE was considered to be the most likely material suitable for application as bridge bearings. Consequently, the earlier tests were conducted on TFE with 25 percent glass fiber filler. As the study progressed, tests were made on 15 percent glass-filled TFE and unfilled TFE to determine the effect of varying amounts of glass fiber filler on the performance of the bearings. The results of this comparison, as presented later, show that the performance of the unfilled samples under the test conditions was significantly better than that of the filled specimens.

The test procedures consisted of measuring the horizontal forces required to slide the TFE sample bearings which were subjected to normal loads ranging from 200 psi to 1400 psi (1.38 to 9.65 MPa). The values recorded were the breakaway or maximum static forces required to induce sliding between the bearing interfaces. From this information the coefficients of friction at the various load levels were determined. The values of the coefficient of friction for the unfilled TFE and the 15 to 25 percent glass-filled TFE specimens are plotted in Figures 2 through 4. The curves represent maximum and minimum values obtained from specimens of like composition. The results show that the coefficient of friction varies significantly with respect to normal loads for vertical pressures up to 1400 psi (9.65 MPa). The coefficient tends to decrease with increasing pressures.

The charts also show a substantial increase in the coefficient of friction for the filled TFE after completing 7000 cycles of testing. This large increase in frictional forces was induced by the exposure of the glass filler that accumulated on the surface of the TFE layer. However, little or no variation was found in the friction forces for either unfilled or filled TFE at the beginning of each test. It

METRIC CONVERSION

1 psi = 6.89 kPa

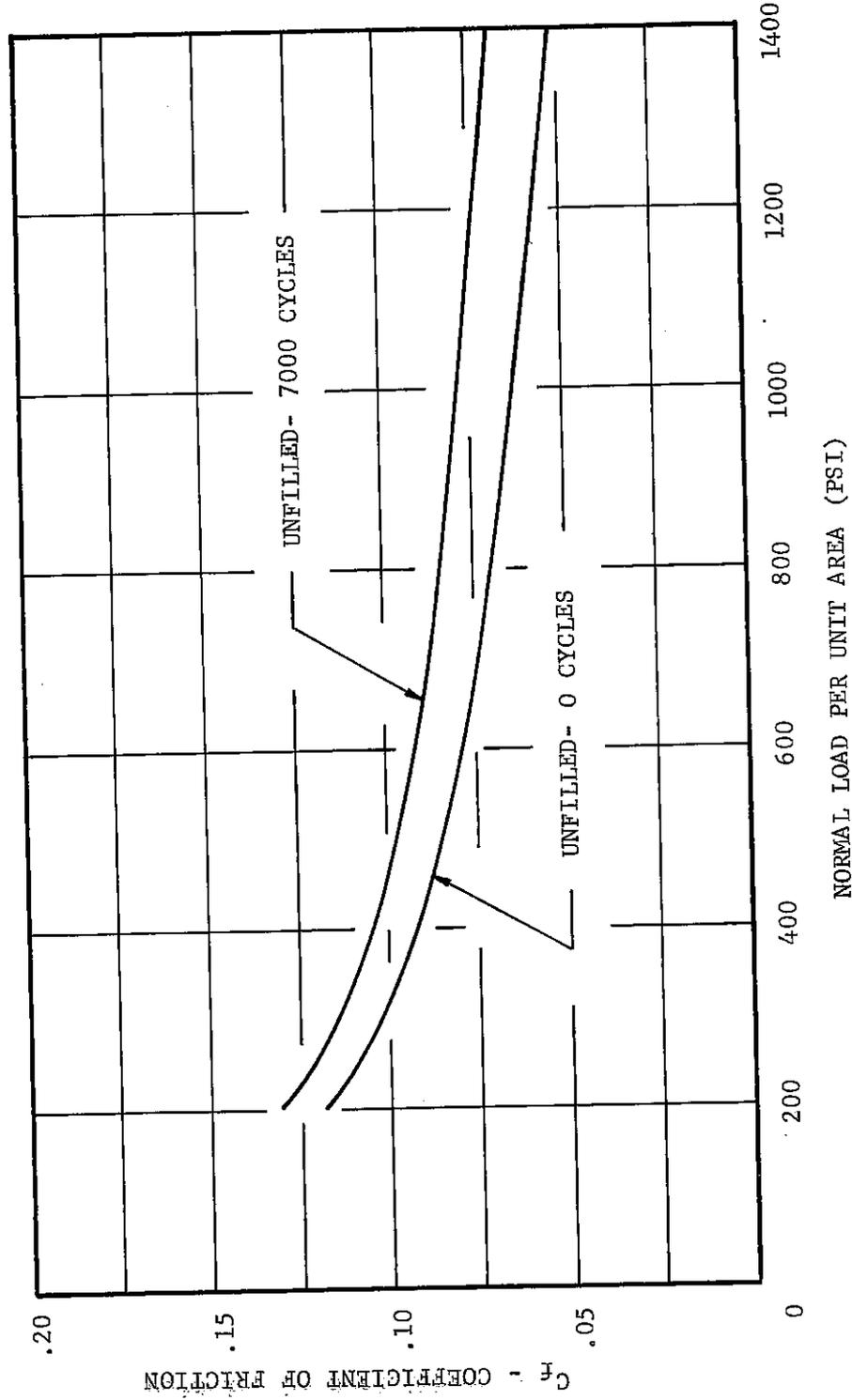


Figure 2. Coefficient of friction vs vertical pressure for unfilled teflon at 0 and 7000 cycles.



METRIC CONVERSION

1 psi = 6.89 kPa

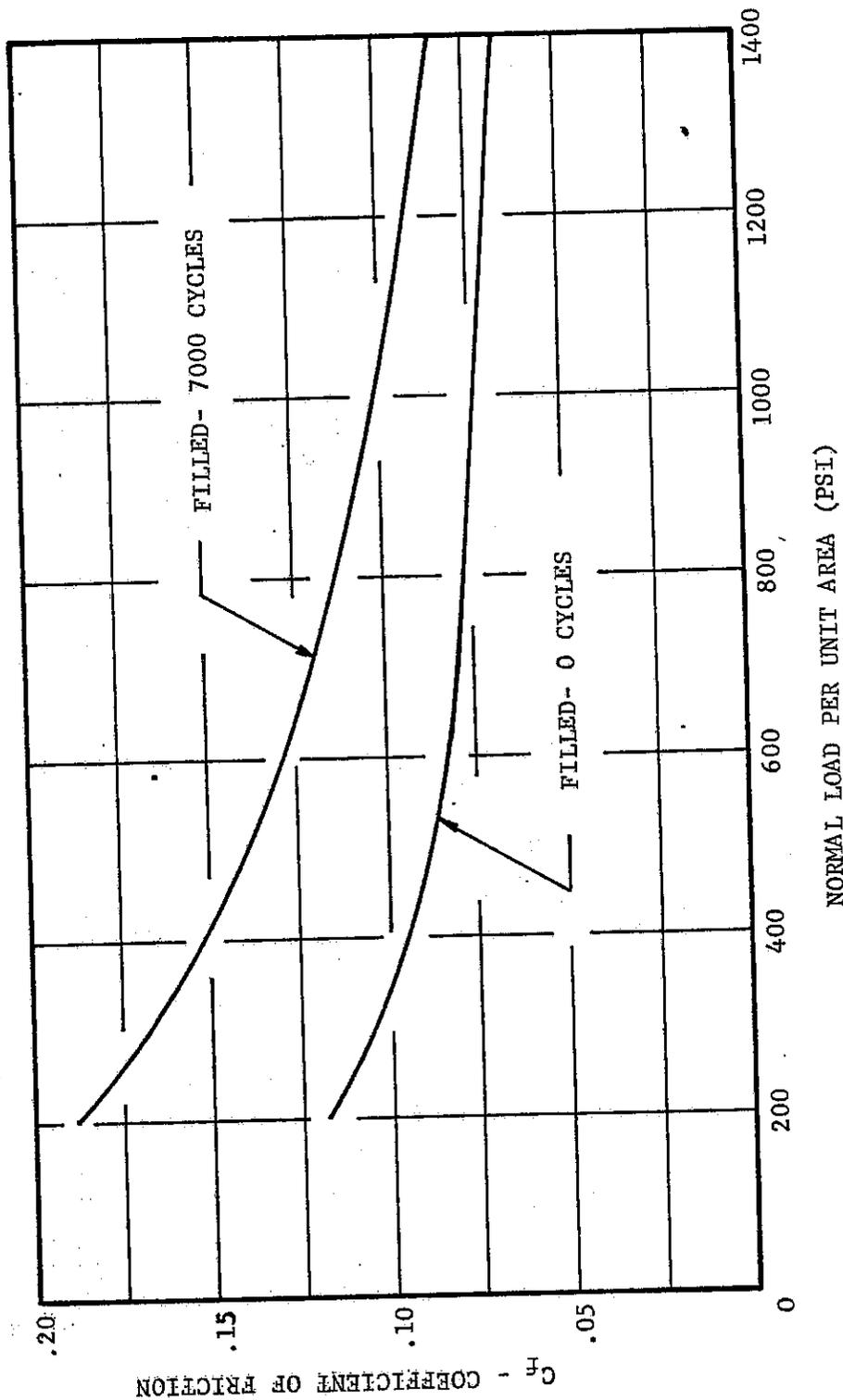


Figure 3. Coefficient of friction vs vertical pressure for filled teflon at 0 and 7000 cycles.



METRIC CONVERSION

1 psi = 6.89 kPa

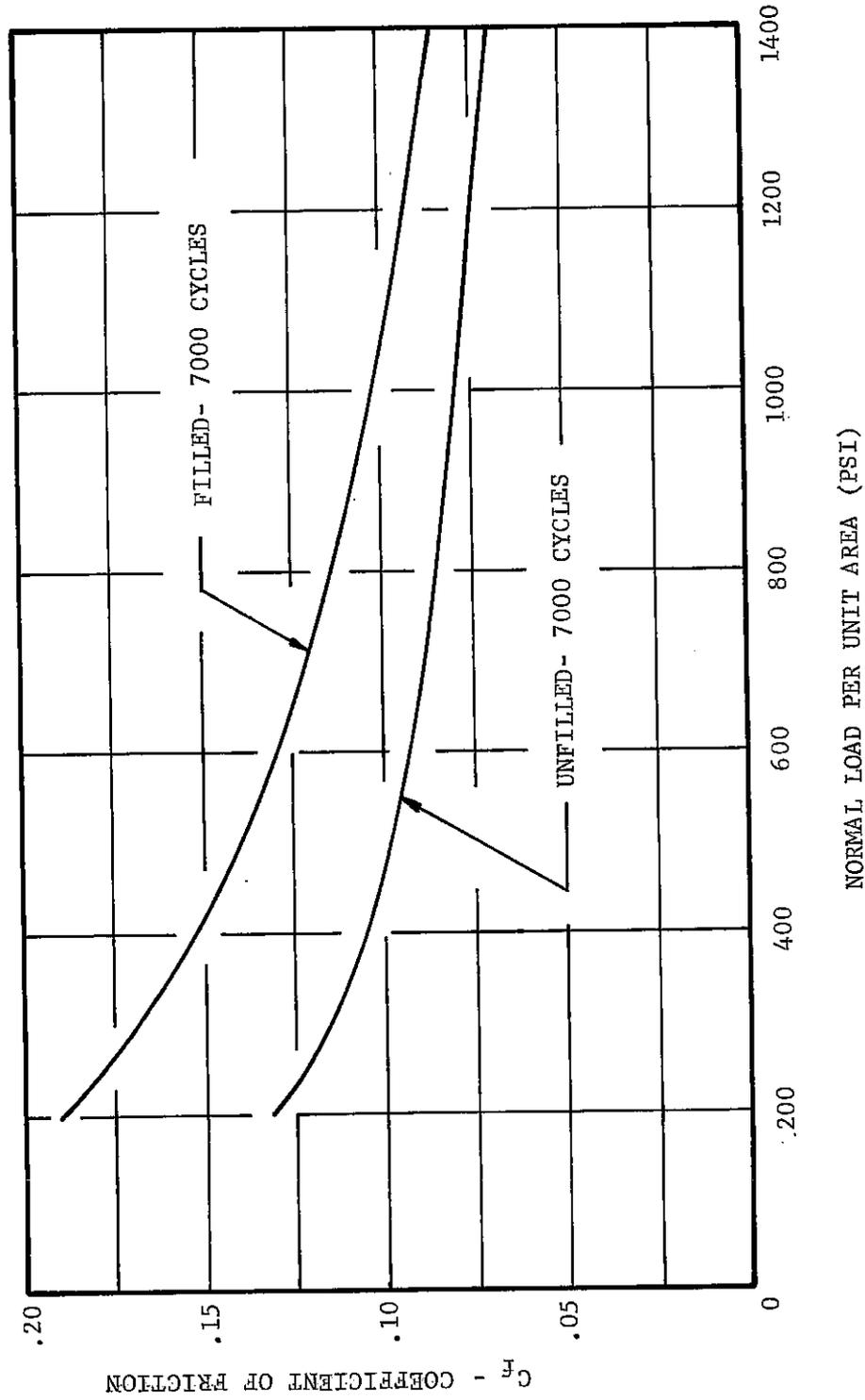


Figure 4. Coefficient of friction vs vertical pressure for unfilled and filled teflon at 7000 cycles.

was also of interest to find little difference in the behavior between the 15 and 25 percent filled specimens at the beginning and end of each test.

The primary reasons for adding filler material to TFE are to increase the resistance of the pure TFE to creep under sustained load and to improve the wear-ability of the material when subjected to high-speed moving loads. Although some applications of the TFE material may require that a reinforcing filler be used, it is improbable that the loads of 400 to 800 psi (2.76 to 5.52 MPa) and the rate of movements on a typical bridge will approach the magnitude necessary to influence the effect of creep or wear on the TFE.

Since the results of the first series of tests indicated that a significant reduction in the coefficient of friction can be achieved by using unfilled TFE, further study was made of the unfilled TFE material. In order to investigate the cold-flow characteristics of both filled and unfilled TFE under static load conditions, a creep rack was built, and samples containing 0, 15, and 25 percent glass filler were installed. The compressive load levels applied to the specimens range from 400 psi (2.76 MPa) on 6- x 18-inch (152.4- x 457.2-mm) rectangular samples to 1600 psi (11.03 MPa) on circular samples 5.85 inches (148.6 mm) in diameter. The duration of the test was five years, with annual inspections made to determine the creep characteristics of the various compositions of the filled and unfilled TFE materials. After five years of sustained static loading, there was no visual evidence of cold flow even for the unfilled specimens containing no glass filler. (Figures 5 and 6)

FABRIC REINFORCED RUBBER VS PLAIN RUBBER

The specimens tested during the first phase of laboratory work included various combinations of TFE bearings backed with either rubber-impregnated fabric

0% GLASS-FILLED

3/32 INCH (2.38 mm) THICKNESS

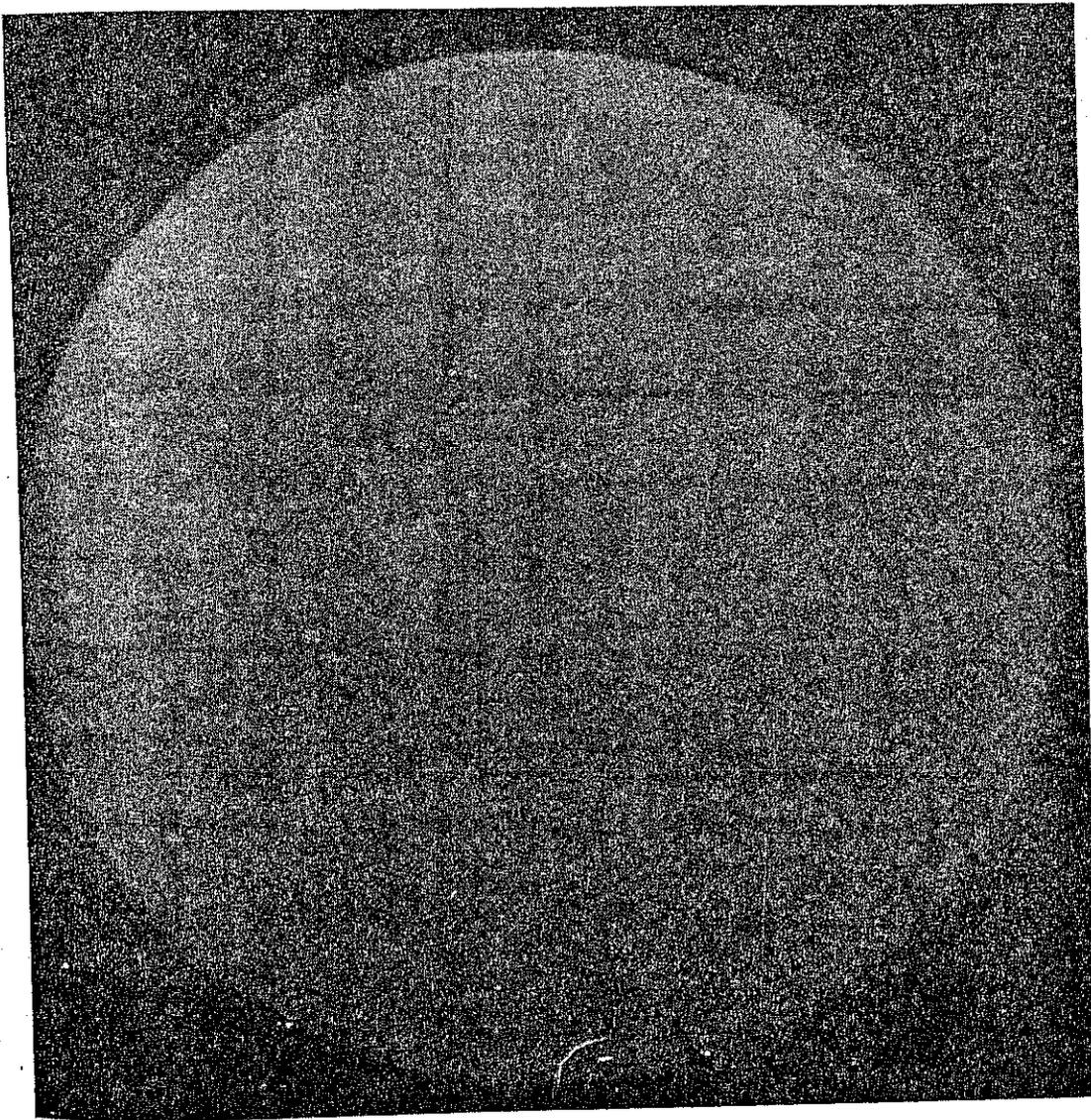


Figure 5. Unfilled TFE after subjected to sustained loading of 1600 psi (11.03 MPa) for 5 years.

25% GLASS-FILLED
3/16 INCH (4.76 mm)
THICKNESS

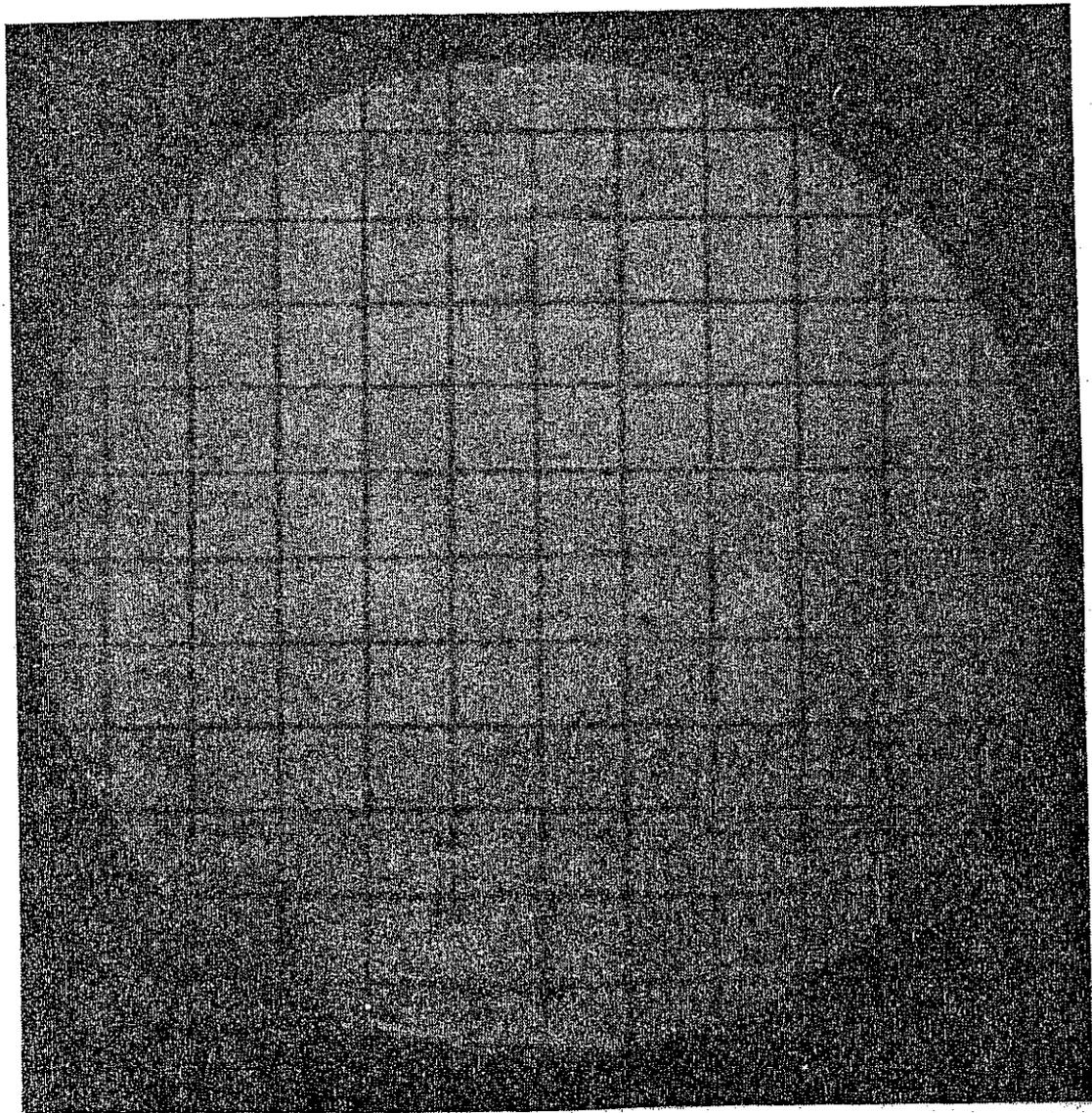


Figure 6. Filled TFE after subjected to sustained loading of 1600 psi (11.03 MPa) for 5 years.

or elastomeric rubber composition. The test specimens included samples with and without stainless steel laminates bonded between the TFE facing and elastomeric or fabric backing. Tests of the self-lubricating bronze plate also were conducted so that a comparative evaluation could be made with the samples utilizing the TFE sliding surface.

The bearings were tested for performance and durability to determine the effect of various types of rubber backing and combinations of rubber backing with stainless steel interlayers. Parameters such as hardness of the rubber and shape factor of the elastomeric backing were considered during the investigation.

Except for two specimens which were backed by adiprene of 80 hardness, the rubber compound for the elastomeric backing was neoprene with a 50, 60, or 70 hardness (Shore A durometer). The shape factor of an elastomeric pad is the ratio of the surface area of the bearing to the perimetrical edge area. This factor provides an indication of the deflection characteristics of the bearing under compressive loads with a lower shape factor indicating more deflection of the bearing pad. Shape factors of 2.7 and 5.4 were included in this series of tests. All TFE surfaces with rubber backing had surface areas measuring 5 x 6 inches (127.0 x 152.4 mm) and were reinforced with 25 percent glass filler.

Excessive bending of the neoprene-backed top elements was observed when a 1/2-inch (12.7 mm) rubber backing material was used in conjunction with the thin steel reinforcing sheet. The top component, which is longer and wider than the lower element, was designed to accommodate maximum expansion and prevent contamination of the lower element. The top component, being larger, was subject to bending moments developing in that portion of the upper pad which extended beyond the edge of the lower element. The thin steel sheet between the TFE and rubber materials was found to be inadequate for resisting the moment, and curvature of the top component would

develop as the vertical loads were increased. In order to have minimized the curvature, the steel laminate should have been analyzed as a base plate subject to unequal load distribution and designed accordingly. Because of the bending of the upper component, the possibility that the edges of the smaller bottom element might plow into the surface of the upper pad as movement occurred was considered. In order to determine the extent to which this plowing affects the horizontal force required to move the bearing, the specimens were tested with the neoprene backing on both the upper and lower elements. The test was then repeated with the neoprene backing removed from the upper pad. Visual observations during the test indicated that much less bending occurred in the upper pad with the neoprene backing removed. The results of this test indicated, however, that less force was required to slide the bearing with the neoprene backing in place, resulting in a lower coefficient of friction for the neoprene-backed pad. Apparently, the expected plowing effect does not exist despite the increased bending of the upper pad.

Of the six samples tested, two specimens failed by a horizontal separation of the neoprene backing near the mid-height of the upper component. The remaining four samples showed no evidence of physical damage, and none of the tested specimens indicated inelastic deformation of the steel laminates. Despite the decreased coefficient of friction recorded for the rubber-backed top pad, the excessive deflection and the horizontal separation of two of the six tested samples were considered sufficient cause to eliminate this type of sliding surface from further consideration.

Permanent deformation of specimens without a steel laminate between the TFE sheet and rubber backing was evident after removing the samples from the test. The deformation, however, appeared to have no effect on the performance of the bearings, provided the load was sustained throughout the test. When the load was removed, the rubber would tend to regain its original shape and collapse the non-elastic TFE sheet,

causing excessive wrinkling of the TFE surface layer (Figure 7). This type of failure was more critical at the 750 and 1000 psi (5.17 and 6.89 MPa) load levels than at the 400 psi (2.76 MPa) level. The tests indicated that the steel laminate or layer of hard rubber inserted between the TFE and rubber elements was beneficial, especially for the higher load levels.

After testing, most neoprene-backed specimens contained surface irregularities in the form of depressed and raised areas in the TFE layer similar to those observed in the field-test specimens. Close inspection of the specimens revealed voids in the epoxy used to bond the TFE layers to the stainless steel sheets (Figure 8). Most of the irregularities in the TFE surface layers occurred at the location of these voids in the bonding material. Although the voids represented from approximately 15 to 20 percent of the total bonded area, no failures which could be attributed to poor bonding occurred during the tests.

One of the major aspects in specimen behavior observed during the testing was the horizontal strain induced in the rubber when sliding was impending at the TFE interface. Lateral deflection of the rubber of the bottom components appeared to reach approximately 80 to 100 percent of the rubber thickness. Excessive distortion or lipping of the rubber at the exposed edges also occurred. The distortion became more apparent as the applied vertical loads were increased. Although this behavior was more severe for the 50-durometer rubber, the strains induced did not appear to have a damaging effect on the bearings.

Based on the short term laboratory tests, the excessive horizontal strains for the pure rubber backing materials appeared to have little influence on the performance and durability of the bearings. Certain modifications in the design, however, were considered necessary to minimize the likelihood of structural damage throughout the service life of the bearing. The 50 percent strain limitation

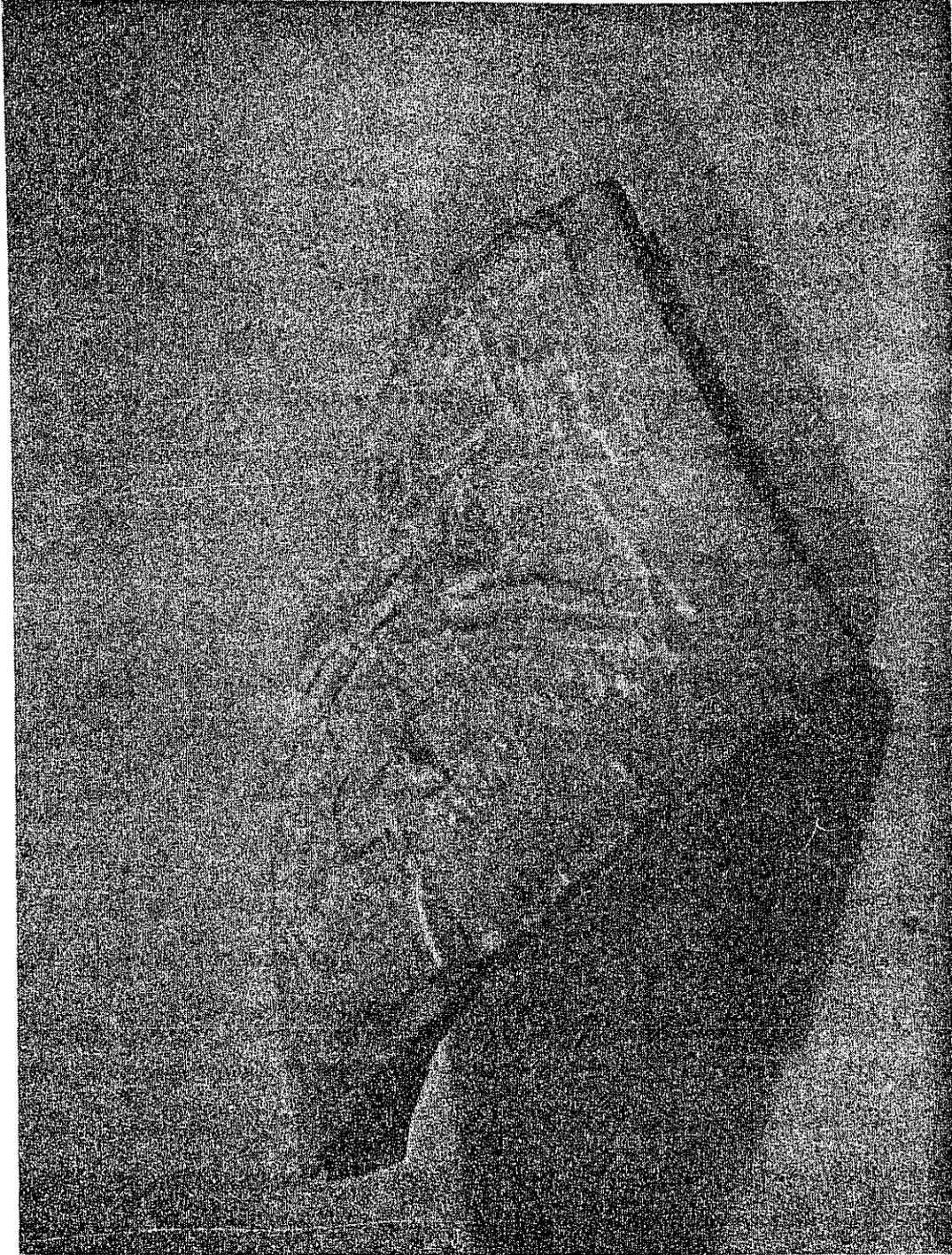


Figure 7. Curvature and wrinkling of specimen subjected to 750 psi (5.17 MPa) test load.

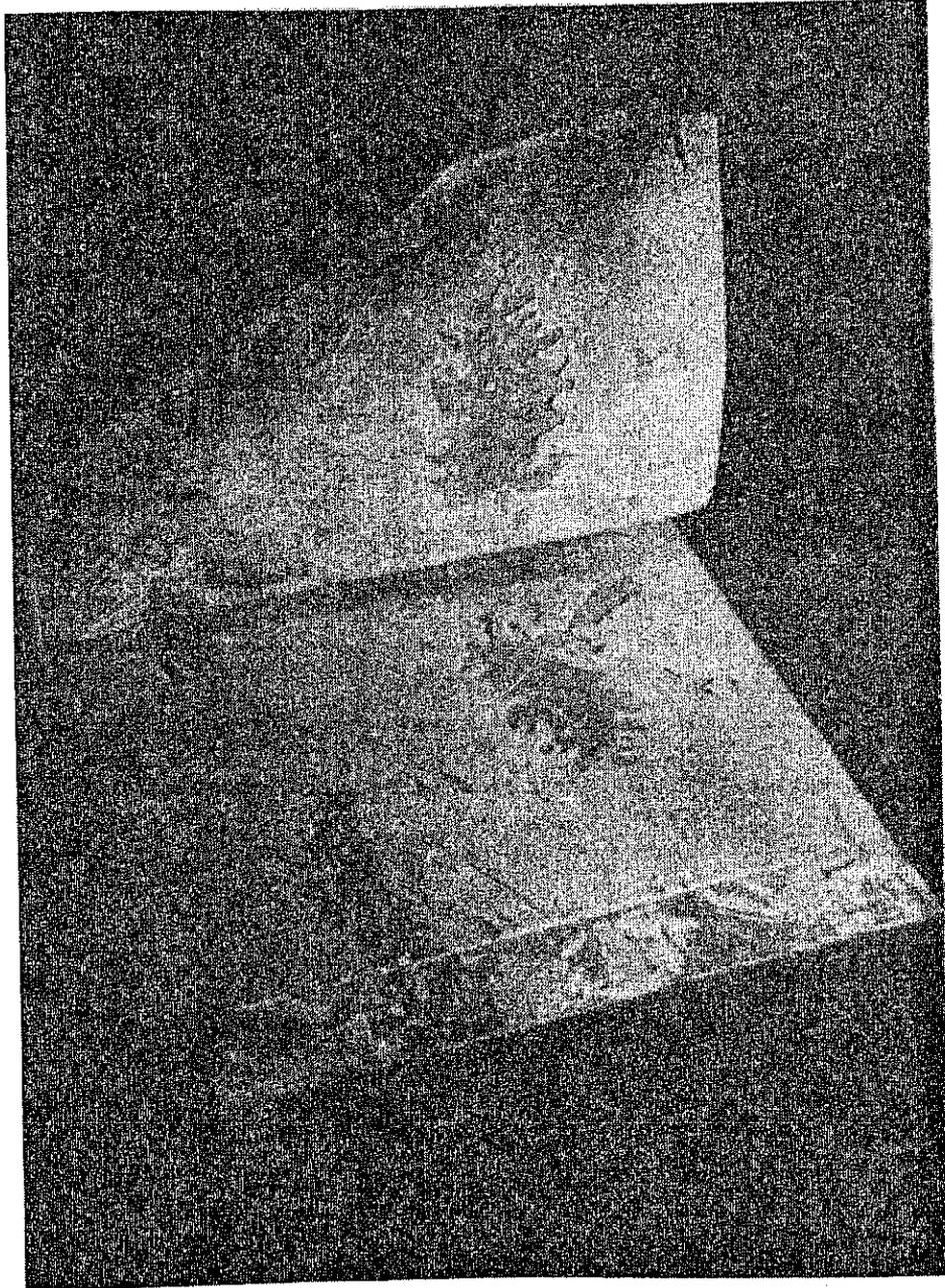


Figure 8. Laboratory specimen showing voids in the adhesive.

currently specified for the design of nonsliding elastomeric bearings was used as a criterion for developing a suitable bearing design.

Various combinations of the basic material elements were tested for evaluating the effect of certain parameters for keeping the horizontal strains within the established limits. The primary factors considered were rubber hardness, shape factor, and the effect of an additional steel plate bonded to the bottom surface of the rubber material.

Visual observations of the tests indicated that, of all parameters studied, the 70-durometer rubber composition had the most significant influence on the stiffness or shear resistance of the bearing. Increasing the shape factor from 2.7 to 5.4 had the least effect on shear stiffness. The addition of a steel plate bonded to the bottom of the rubber reduced the lipping which previously occurred with the 50-durometer samples, but its use appeared less significant when used in combination with the 70-hardness materials.

From the initial test data the theoretical effect that the hardness of the neoprene has upon the percent strain of the elastomer was computed and plotted in Figures 9 through 12. The shear strain occurring in an elastomeric bearing is defined as the ratio of horizontal deflection to the thickness of the elastomer. Tests have shown that the stress-strain relationship for neoprene in shear is linear for shear strains up to 50 percent and may be expressed as a modulus. Tests conducted at room temperature by an elastomer manufacturer have established values for this modulus for neoprene of different hardness. Values for this modulus are 110 psi (0.76 MPa) for 50-hardness, 160 psi (1.10 MPa) for 60-hardness, and 215 psi (1.48 MPa) for 70-hardness neoprene. It should be remembered that this modulus is accurate only for strains up to 50 percent. Beyond this strain level the modulus gives only approximate results, especially for the lower grades of hardness.

METRIC CONVERSION

1 psi = 6.89 kPa

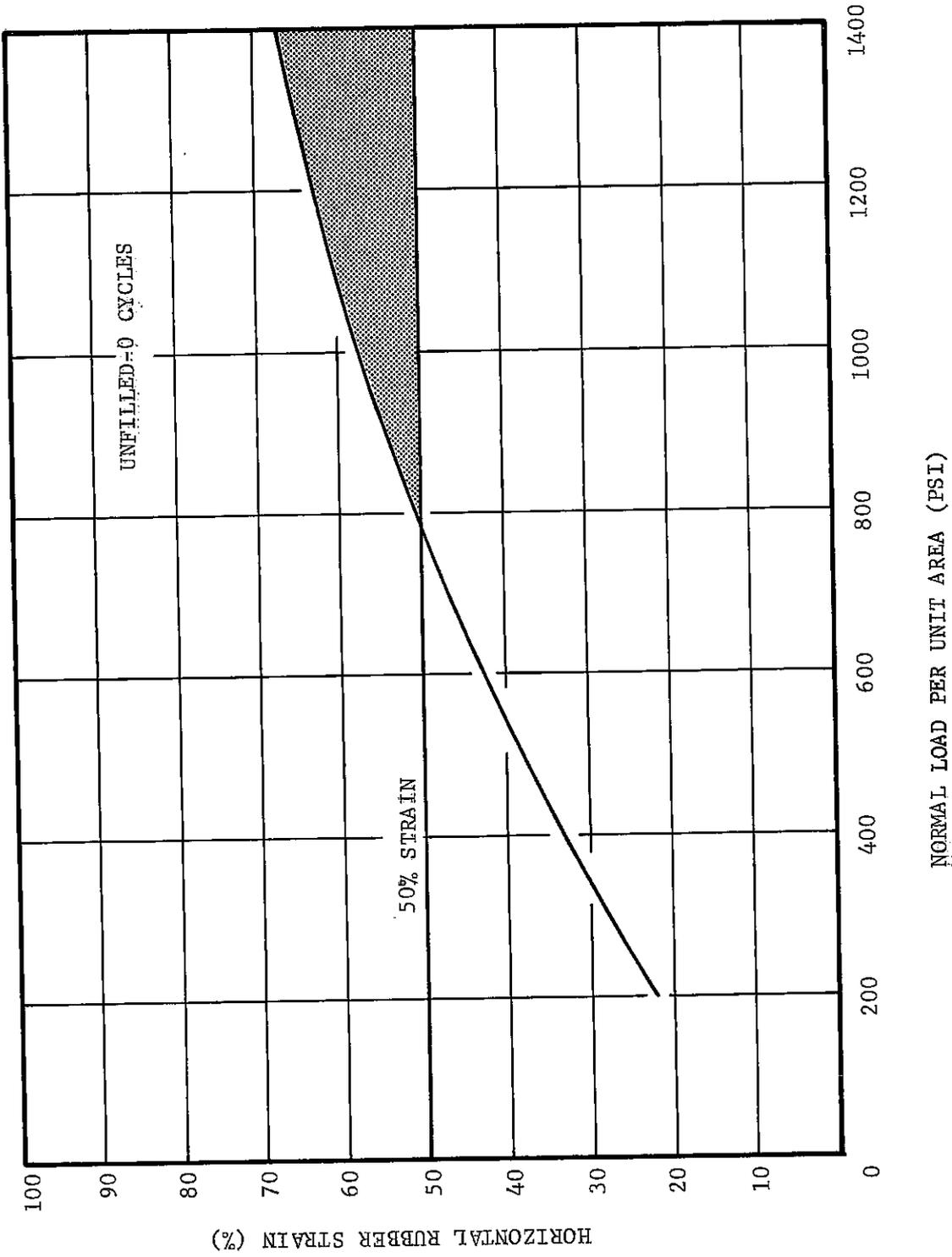


Figure 9. Horizontal rubber strain for 50 durometer rubber vs vertical pressure for unfilled teflon at 0 cycles.



METRIC CONVERSION

1 psi = 6.89 kPa

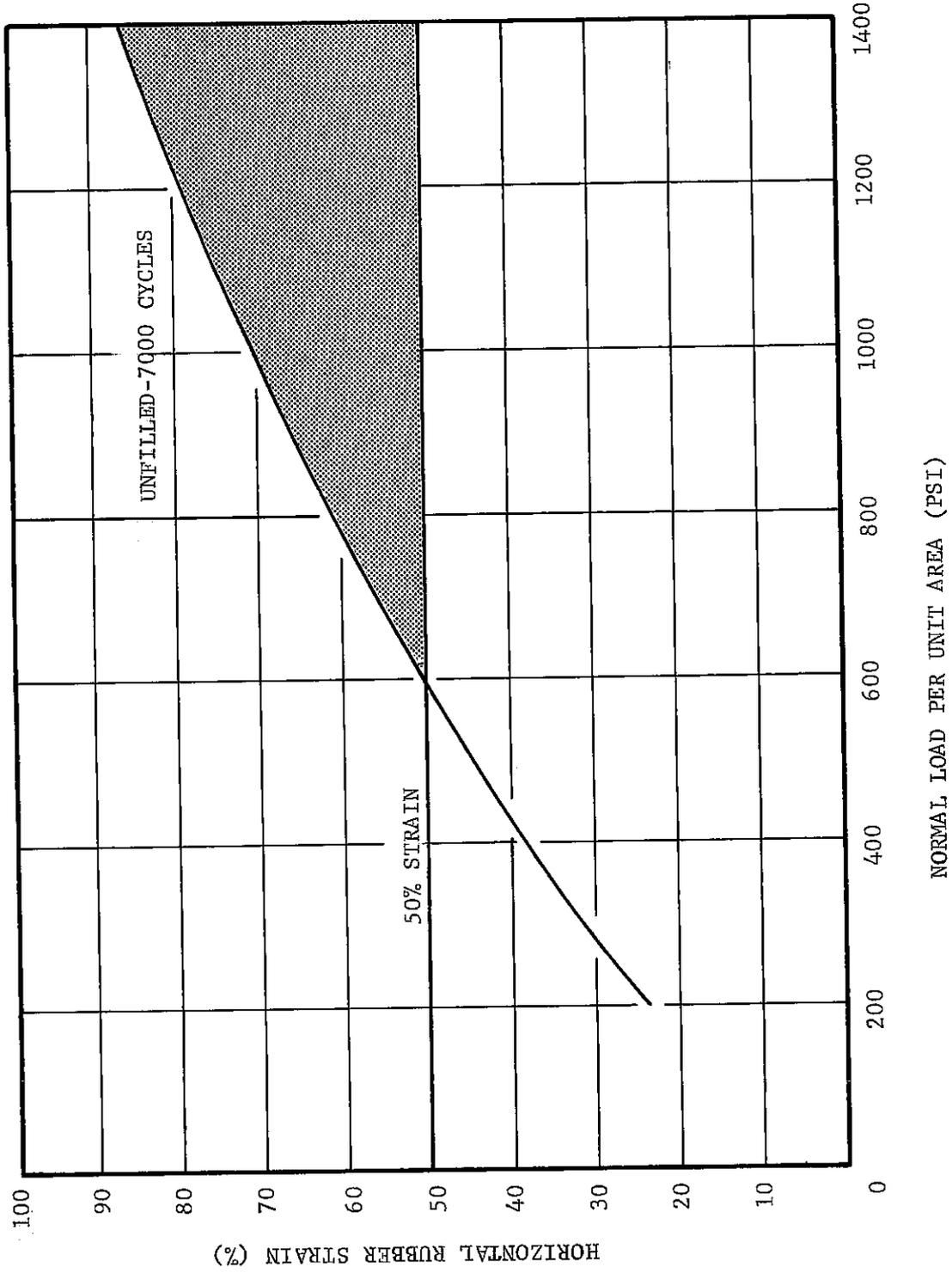


Figure 10. Horizontal rubber strain for 50 durometer rubber vs vertical pressure for unfilled teflon at 7000 cycles.



METRIC CONVERSION

1 psi = 6.89 kPa

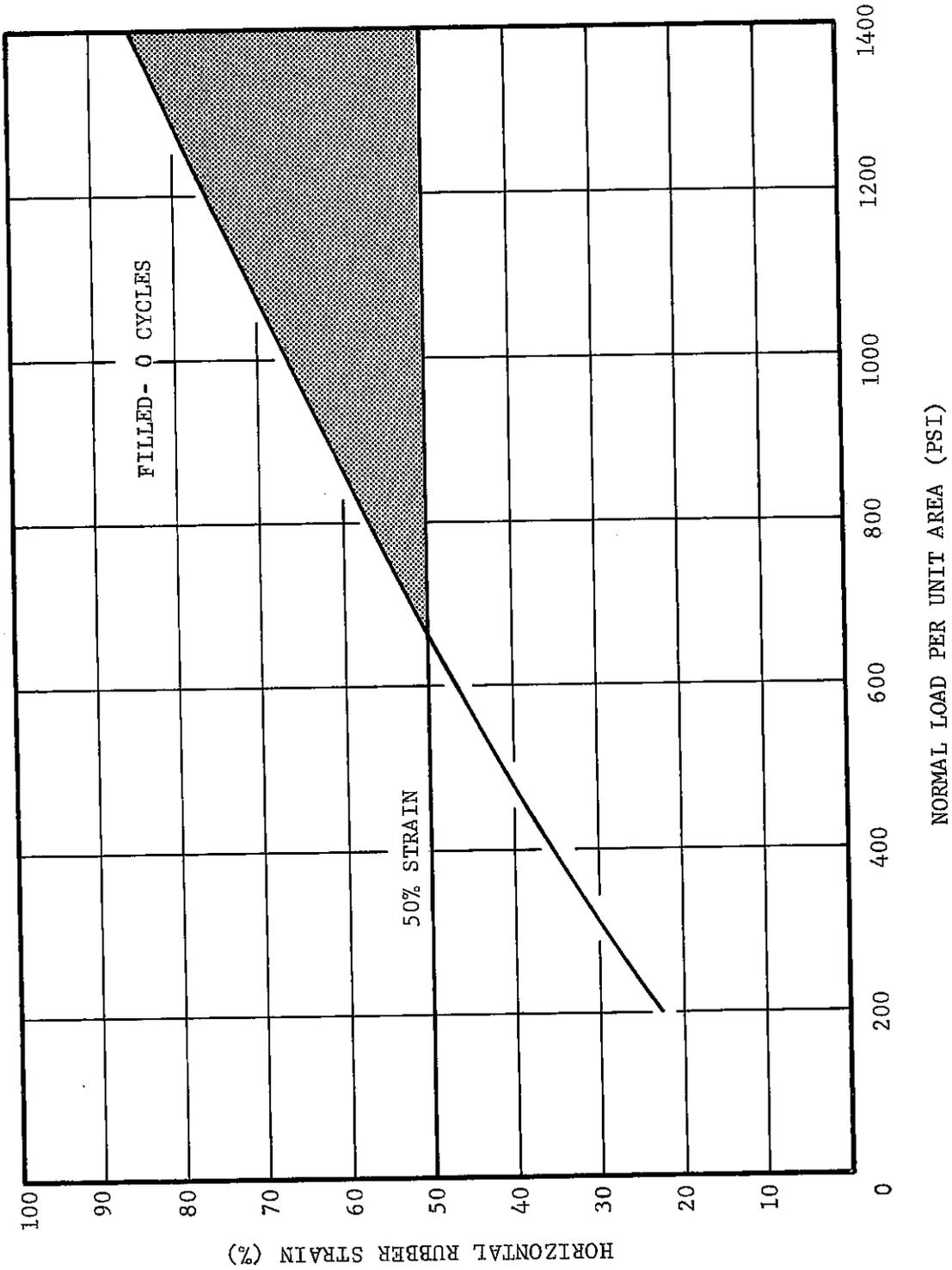


Figure 11. Horizontal rubber strain for 50 durometer rubber vs vertical pressure for filled teflon at 0 cycles.



METRIC CONVERSION

1 psi = 6.89 kPa

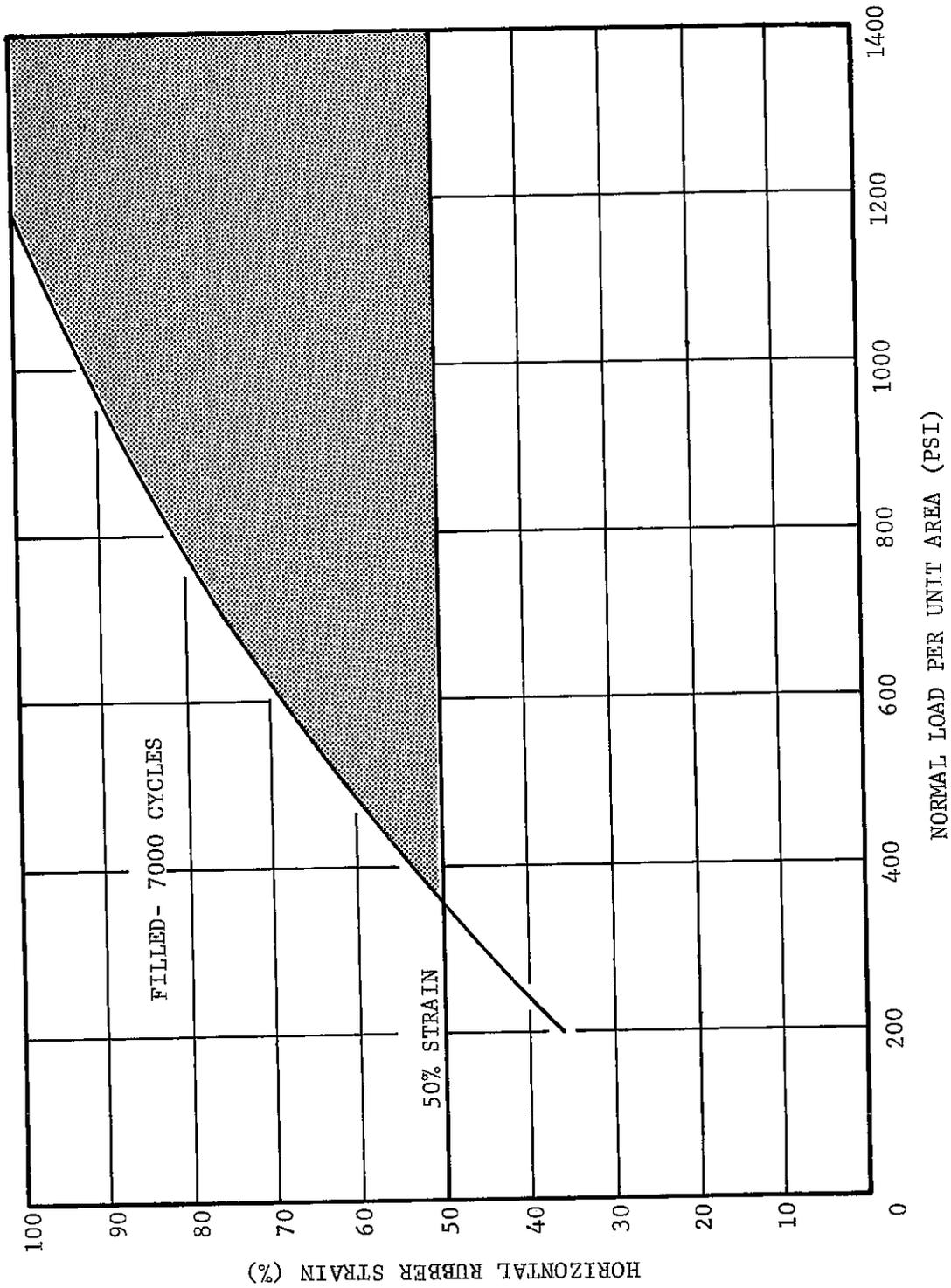


Figure 12. Horizontal rubber strain for 50 durometer rubber vs vertical pressure for filled teflon at 7000 cycles.

The theoretical shear strains as plotted in Figures 9 through 12 show the effect of using either unfilled or filled TFE. The shear strain behavior for both filled and unfilled TFE at the beginning and end of each test indicates that less shear strain is produced by the unfilled TFE at all load levels.

The effect of rubber hardness comparable to the frictional forces developed after completing 7000 cycles of testing is shown for both unfilled and filled TFE in Figures 13 and 14. The curves show a substantial reduction in shear strain with increasing hardness of the elastomer.

Tests also were made of specimens backed by rubber-impregnated fabric to determine the suitability of this backing material for bridge bearings. The specimens included different thicknesses of TFE and backing material and various percentages of glass filler. A polished stainless steel surface was used for the opposing sliding element for all fabric-backed samples.

Delamination between the fabric layers was a predominant source of failure when conducting the tests on the glass-filled TFE specimens (Figure 15). Signs of initial damage became evident before reaching 2000 to 3000 cycles of translation, and complete delamination often occurred before completing 2/3 of the 7000-cycle test period. Delamination began with the formation of minute particles of rubber raveling at one of the outer edges of the pad and slowly progressed toward the opposite end until complete delamination occurred. The delamination took place at one of the thin rubber layers between fabric plies near the mid-height of the pad or at the outer layers near the top or bottom surfaces. On two occasions damage was initiated in both areas, with complete failure occurring near the outer surface. Tests of other specimens resulted not only in a failure in delamination of an outer ply but also in a separation of the TFE sheet.

Heat generated within the samples during testing was considered one of the possible contributing factors that could influence the problem of delamination.

METRIC CONVERSION

1 psi = 6.89 kPa

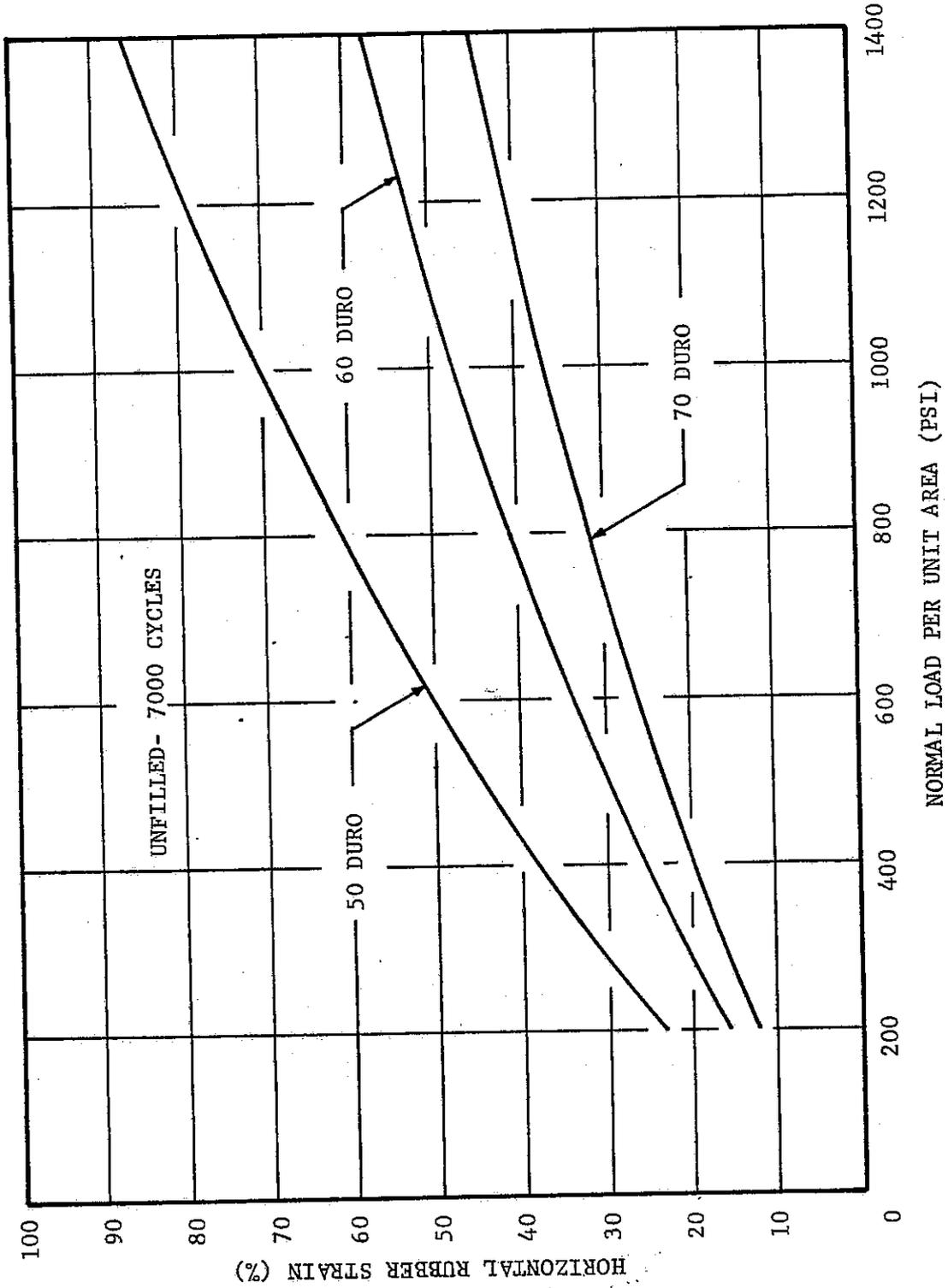


Figure 13. Horizontal rubber strain for 50, 60, and 70 durometer rubber vs vertical pressure for unfilled teflon at 7000 cycles.

METRIC CONVERSION

1 psi = 6.89 kPa

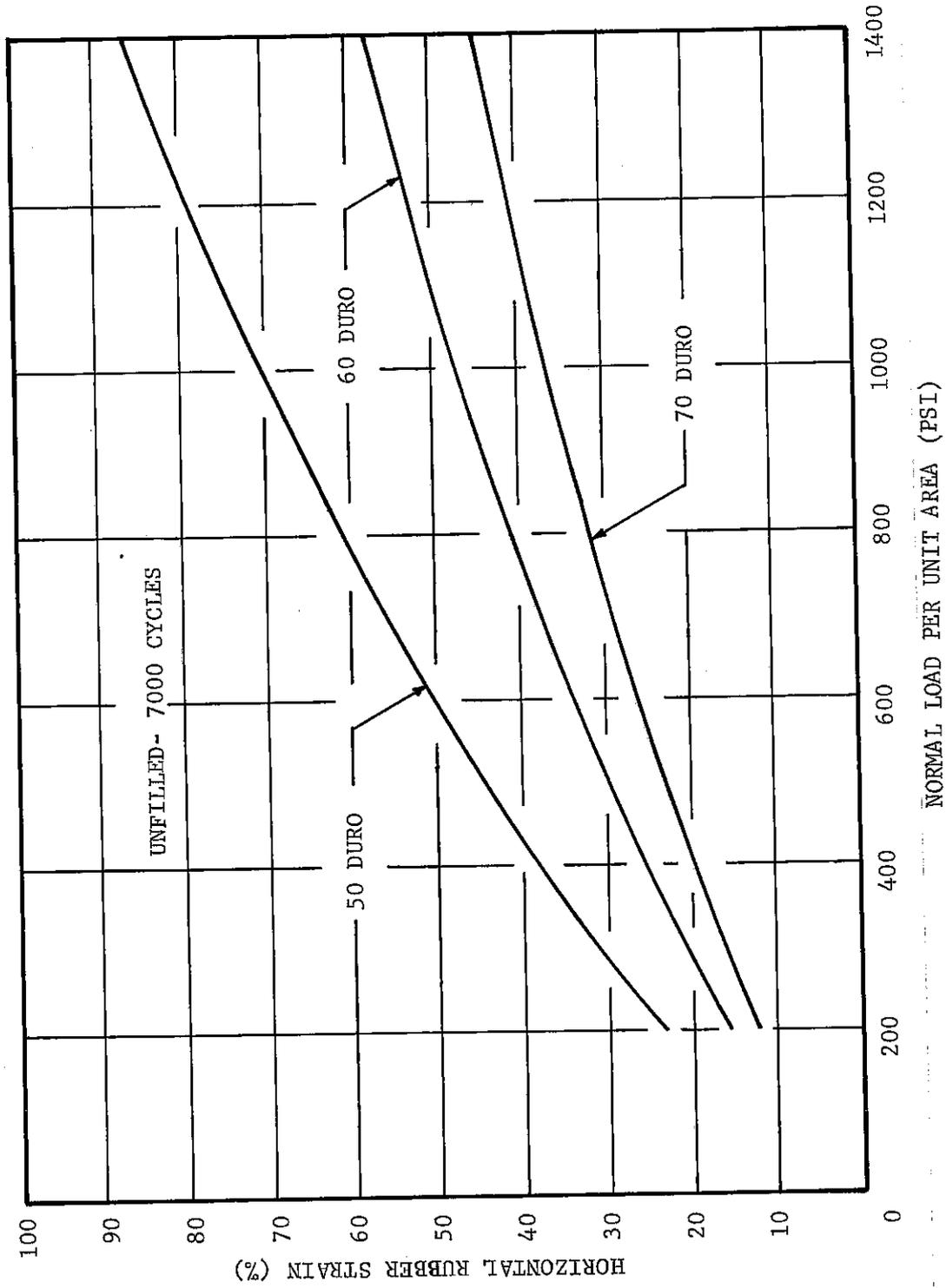


Figure 13. Horizontal rubber strain for 50, 60, and 70 durometer rubber vs vertical pressure for unfilled teflon at 7000 cycles.

METRIC CONVERSION

1 psi = 6.89 kPa

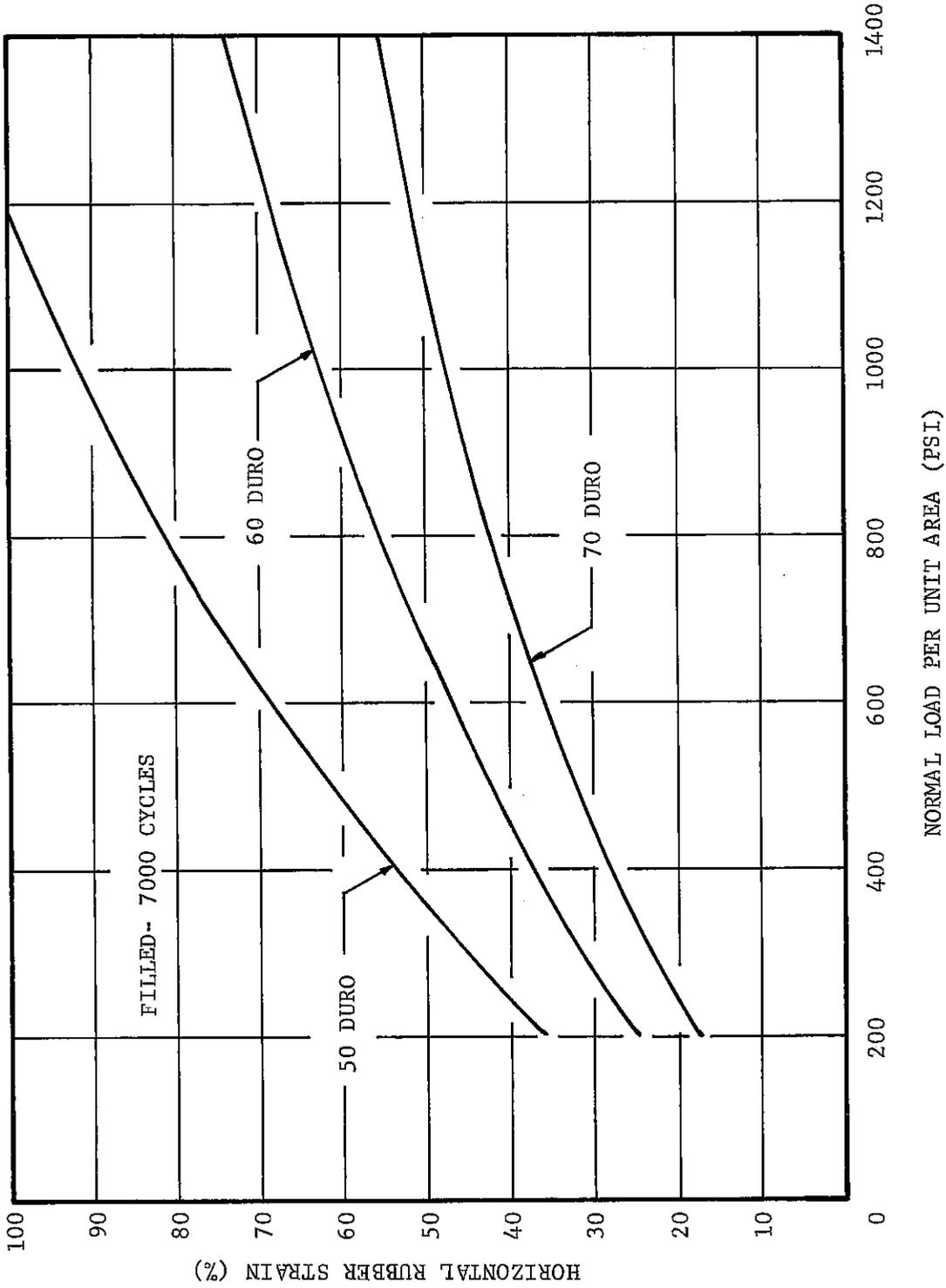


Figure 14. Horizontal rubber strain for 50, 60, and 70 durometer rubber vs vertical pressure for filled teflon at 7000 cycles.

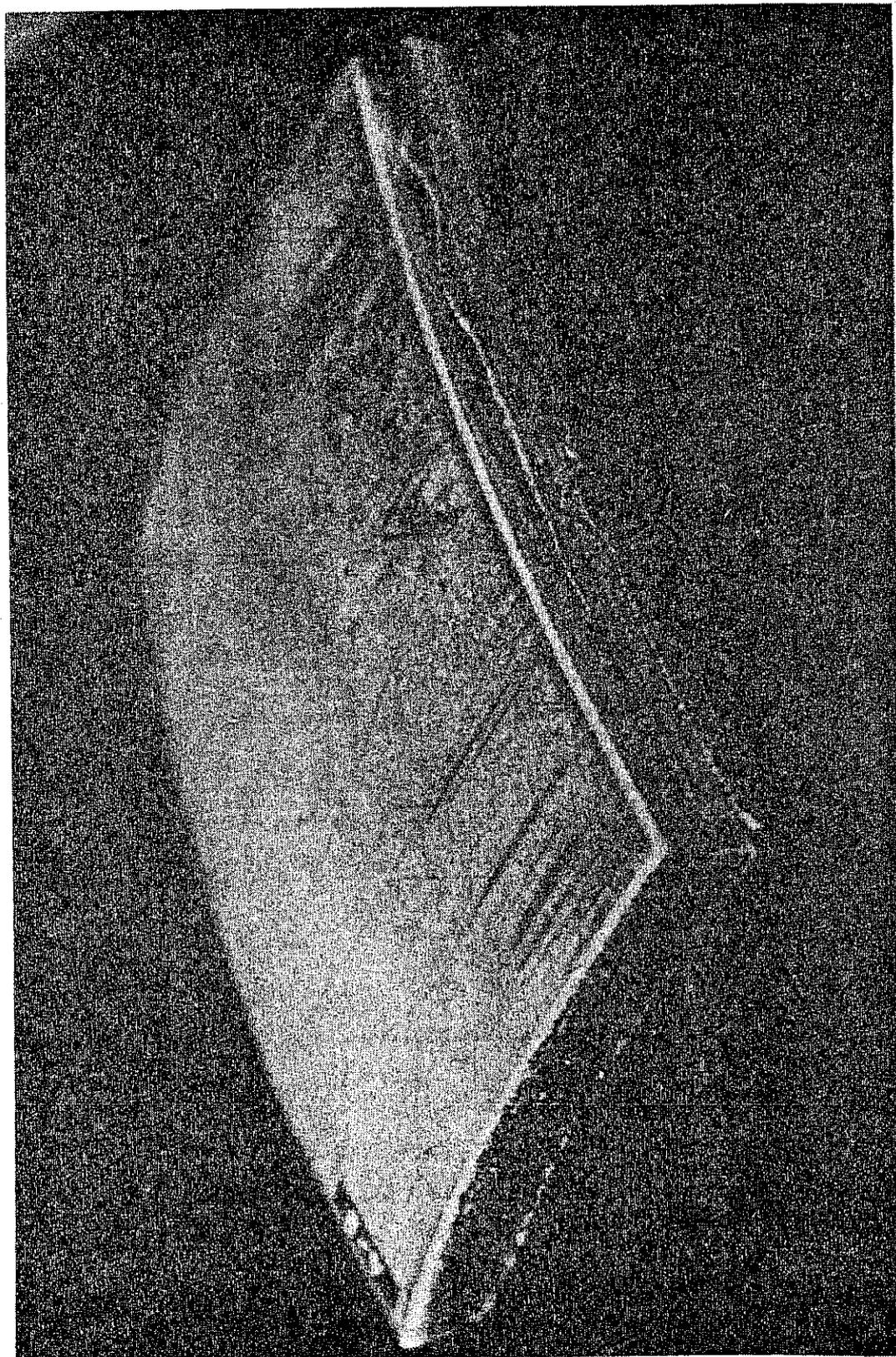


Figure 15. Delamination of rubber impregnated fabric.

Thermocouples were installed in one sample to measure the internal temperature and to determine the amount of heat that developed within the specimen while under test. The maximum temperature recorded was 86°F (30°C), which was approximately 10° to 12°F (5.6 to 6.7°C) above room temperature. The heat generated was not of sufficient magnitude to cause delamination.

The use of a steel laminate between the fabric pad and the TFE sheet appears to have some benefit toward extending the life of the bearing. Close examination of the components without steel reinforcement indicated more wear near the edges resulting from high edge loads. The wear and load distributions were more uniform throughout the surface of the bearings utilizing the steel elements. When the load was removed, slight permanent deformations also were evident for the pad unreinforced with a steel sheet.

Additional laboratory work was undertaken to find a combination of TFE and rubber-impregnated fabric materials which would not develop the delamination of the fabric backing observed with the previously tested specimens. The TFE filler content and the thickness of the fabric backing pad were considered possible factors influencing the performance of the bearing.

Specimens with 0, 15, and 25 percent glass-filled TFE surface elements were tested to determine the relationship of fatigue damage of the fabric pad and the frictional forces developed by the various fill compositions. Two samples with 15 percent filler sliding against a polished stainless steel surface resulted in partial delamination upon completing 7000 cycles of translational movement, which indicated that the rate of accumulative damage became less with a decrease in the coefficient of friction resulting from less filler. This relationship was further substantiated by tests of two unfilled specimens which showed no signs of deterioration after completing 7000 and 28000 cycles of testing.

A decrease in accumulative damage also was indicated when testing pads of greater thicknesses incorporating the 25 percent glass-filled surface. Although signs of partial delamination were evident for the 3/4-inch (19.0 mm) specimen, damage had not progressed as rapidly as observed for the 1/2-inch (12.7 mm) samples previously tested. Testing of the 1 1/2-inch (38.1 mm) sample indicated no evidence of damage resulting from the tests.

TFE VS STAINLESS STEEL FOR TOP MATING SURFACE

Other tests were also conducted to compare the coefficients of friction of TFE sliding against TFE, and TFE sliding against stainless steel. For the specimens tested, the TFE surfaces were reinforced by a 25 percent glass fiber filler. The results as shown in Table 1 indicate no significant difference in the coefficient of friction for either TFE or Stainless Steel mating surfaces.

TABLE 1
COEFFICIENT OF FRICTION FOR TFE SLIDING
AGAINST TFE AND STAINLESS STEEL

Vertical Pressure (psi)	C_f	C_f
	TFE vs. TFE	TFE vs. Stainless Steel
200	.13	.14
400	.12	.12
600	.10	.11
800	.10	.10
1000	.09	.09
1200	.08	.08
1400	.08	.07

Metric Conversion: 1 psi = 6.89 kPa

WOVEN TFE FIBER VS SHEET TFE

In addition to the neoprene- and fabric-backed bearings already discussed, other related types of TFE specimens were tested to include other types of bearing designs currently under consideration for use as bridge bearings. The tests included two other types of surfaces made of interwoven strands of TFE.

The first specimen consisted of a surface layer of interwoven strands of bondable fibers and tightly woven TFE fibers bonded to a 10 gage stainless steel sheet which was in turn bonded to a 5- x 6- x 1/2-inch (127.0 x 152.4 x 12.7 mm) neoprene pad with 50 hardness. The opposing sliding surface for this specimen was a polished stainless steel sheet.

The bearing was first subjected to slip tests with normal loads increasing from 500 psi to 1500 psi (3.45 to 10.34 MPa) in 250 psi (1.72 MPa) increments. The decrease in friction coefficient with increasing load is illustrated in Figure 16. The bearing was then fatigue tested for 7700 cycles under a constant normal load of 500 psi (3.45 MPa) (Figure 17). Near the end of the translational fatigue test the intermediate stainless steel layer had separated from the neoprene pad to the extent that only about 25 percent of the bonded area was still intact. The use of a harder rubber backing and a stronger bonding agent would add greatly to the durability of this bearing.

The second test specimen had a surface layer of loosely woven strands of pure TFE fiber that was mechanically bonded to 3- x 4- x 7/16-inch (76.2 x 101.6 x 11.1 mm) bronze plate with the plate grid-embossed for bonding. The specimen was tested under varying and constant normal loads. Since the bronze-backed bearing is capable of supporting heavier loads, the normal loads were increased during the slip test from 500 psi to 3500 psi (3.45 to 24.13 MPa) in increments of 500 psi (3.45 MPa) (Figure 18). The bearing was then fatigue tested for 9700 cycles at a constant

METRIC CONVERSION

1 psi = 6.89 kPa

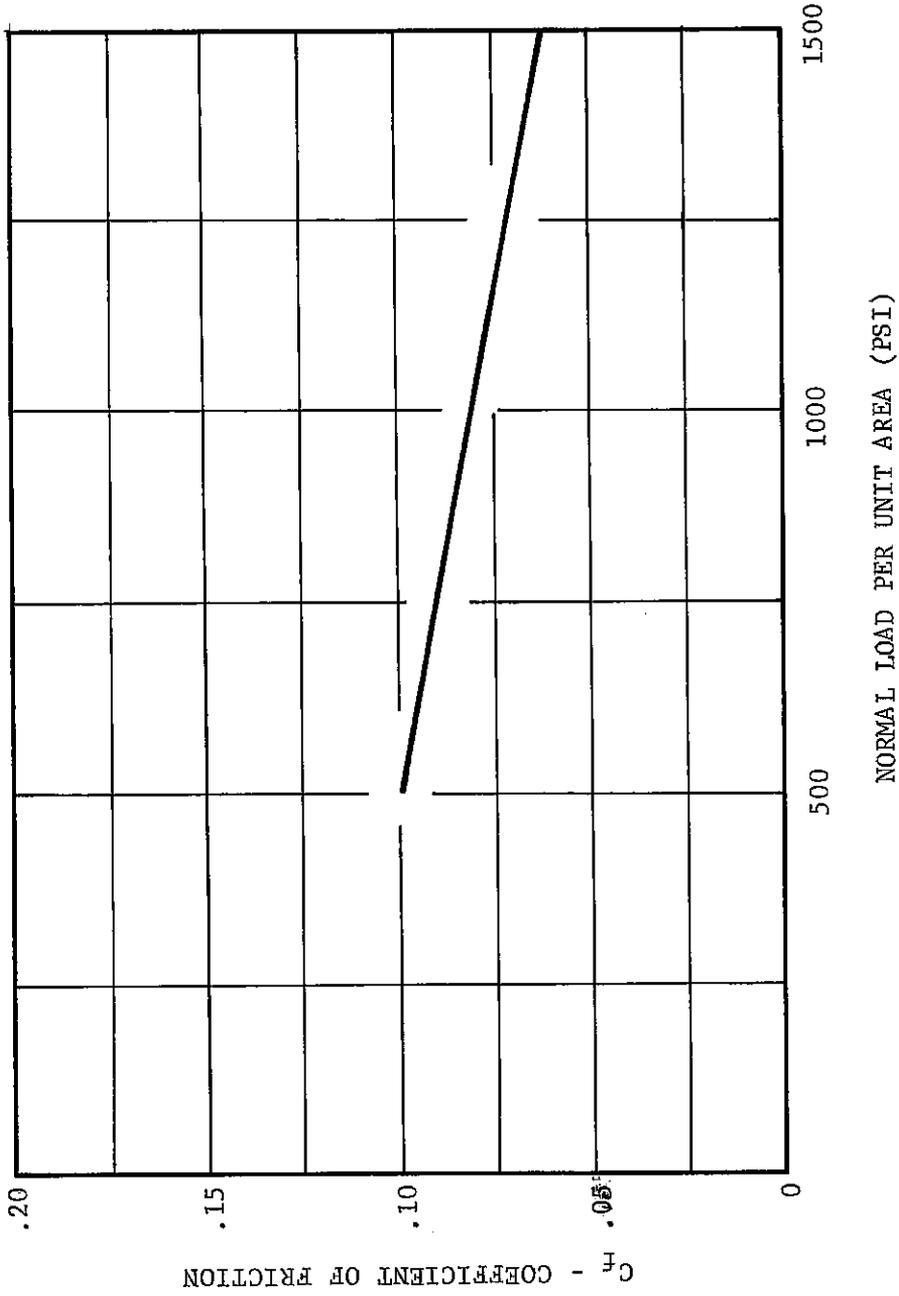


Figure 16. Coefficient of friction vs vertical pressure for inter-woven non-TFE fiber.



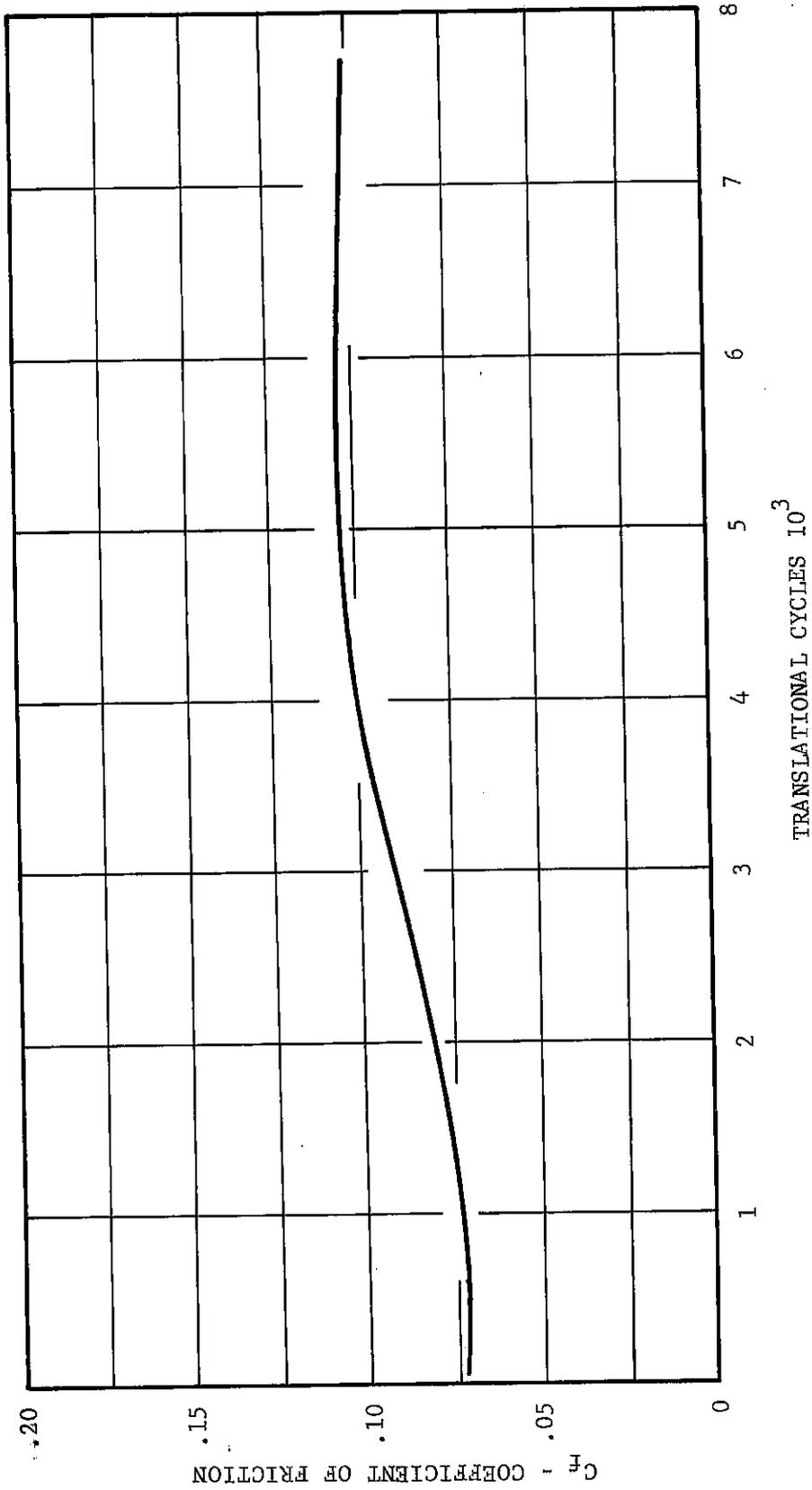


Figure 17. Translational test of inter-woven non-TFE and TFE fiber at 500 psi. (3.45 MPa).



METRIC CONVERSION

1 psi = 6.89 kPa

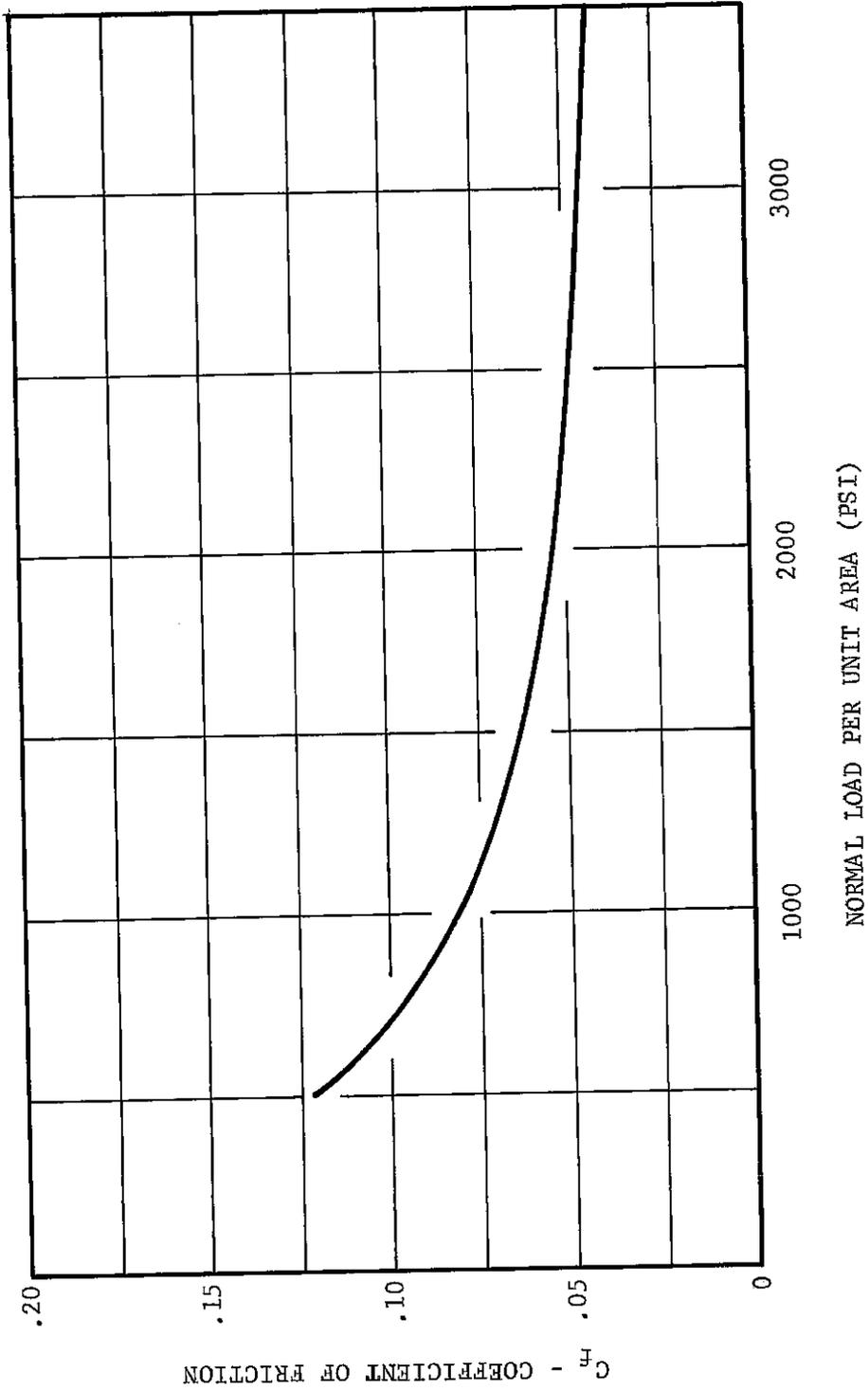


Figure 18. Coefficient of friction vs vertical pressure for pure TFE fiber.

normal load of 2000 psi (13.79 MPa) (Figure 19). Little change in the friction coefficient occurred during the translational fatigue test.

GRAPHITE-IMPREGNATED BRONZE BEARING VS TFE BEARINGS

Translational fatigue laboratory tests also were conducted on graphite-impregnated, self-lubricating bronze bearings. Since this type of bearing currently is used for expansion bearings at the abutments of concrete bridges, the tests on this bearing were made for comparison with similar tests on the experimental TFE bearings.

As indicated in Figure 20, cyclic tests of the bronze bearing conducted at various load levels indicated a degree of inconsistency since the highest and lowest test loads yielded intermediate values for the friction coefficient. The reason for this inconsistency is unknown. At all test load levels the coefficient of friction increased to a maximum value after a few thousand cycles and then tapered off to a reduced value at 7000 cycles.

The coefficient of friction of the bronze bearing compares favorably with that of the fabric-backed 25 percent glass-filled specimens. However, the unfilled fabric-backed samples and the neoprene-backed filled bearings recorded a lower and more consistent friction coefficient at all load levels. From the results of the laboratory and field tests, it appears that several TFE bearing configurations offer less resistance to sliding than the graphite-impregnated bronze counterparts.

Although laboratory tests indicate that the performance of the bronze bearings may be equivalent to certain filled TFE specimens, it should be noted that the laboratory tests involved movements greatly accelerated above those encountered in field applications. For slow movements such as those that occur at a bridge structure, the bronze bearings lack the anti-stick characteristics inherent in the TFE material and, after prolonged use, the bronze bearings tend to freeze. As

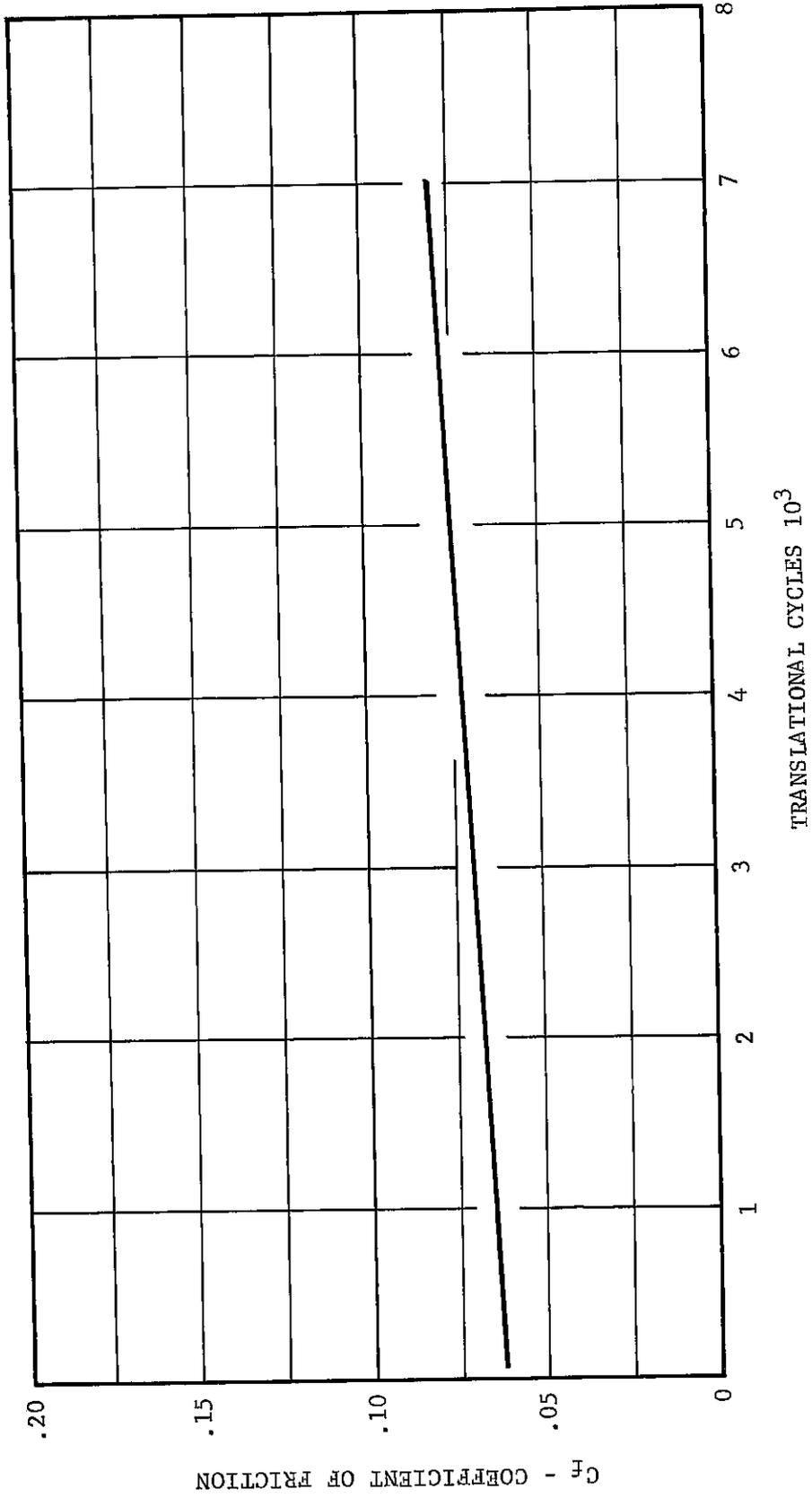


Figure 19. Translational test of pure TFE fiber at 2000 psi.
(13.79 MPa).



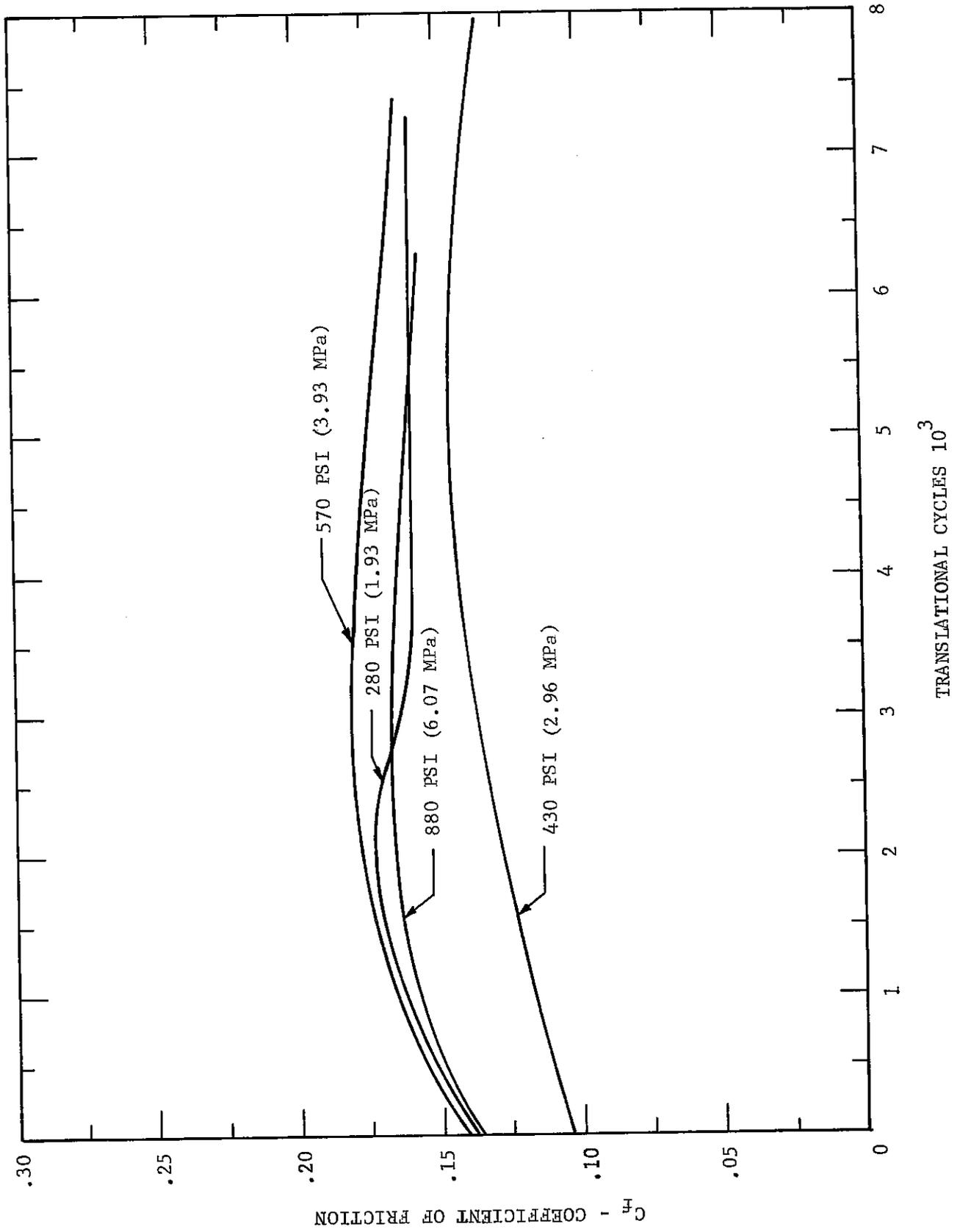


Figure 20. Translational test of graphite impregnated bronze bearing.

indicated in the field-test results, nearly twice as much daily movement occurred at the TFE bearings as occurred at the bronze bearings.

EFFECT OF CONTAMINATION

One source of possible damage to the bearings under field conditions is the contamination of the TFE surfaces with dirt and grit. An alleged advantage of the TFE bearings over their metal counterparts is the ability of the TFE layers to absorb particles of grit by embedment within the surface. This property would prevent large sustained increases in the coefficient of friction. Upon completion of the typical cyclic tests, certain bearing surfaces were contaminated with sand particles, and limited additional tests were made to investigate the ability of the TFE layers to absorb the contamination.

A pure TFE sample with an initial friction coefficient of 0.05 and a final coefficient of 0.06 after 7300 test cycles at a vertical load of 940 psi (6.48 MPa) was contaminated with sand particles and subjected to 6700 additional cycles at a load of 625 psi (4.31 MPa). At the beginning of the contamination test, a coefficient of friction of 0.27 was recorded which diminished to 0.14 after 6700 cycles.

Another unfilled sample which maintained a friction coefficient of 0.08 throughout 7700 cycles at a load of 600 psi (4.14 MPa) was contaminated with sand particles and retested at 600 psi (4.14 MPa). After 1770 cycles the TFE surface layer had completely separated from the fabric backing and the test was halted. The friction coefficient decreased slightly from 0.29 to 0.21 during the test.

A contamination test also was conducted on a 25 percent glass-filled specimen backed by adiprene. The friction coefficient decreased from 0.20 to 0.16 after 7400 cycles. This compares to a constant value of 0.09 for the coefficient of friction throughout 7600 cycles of testing before contamination. After

testing under contaminated conditions, the surface of this sample was severely striated.

Interwoven strands of TFE fibers have been proposed as a bearing surface which is more effective in absorbing contaminating grit particles. This absorbing characteristic is based on the premise that any dirt particles will work their way between the loosely woven fibers and become embedded beneath the surface of the material, and therefore have less effect on the coefficient of friction of the surface.

After the initial test, the bronze bearing with loosely woven teflon was contaminated with sand particles and tested for 7000 cycles at a constant normal load of 2000 psi (13.79 MPa) as shown in Figure 21. The coefficient of friction decreased rapidly early in the test, and after 1200 cycles remained nearly equal to the coefficient of friction of the uncontaminated specimen. The interwoven fibers appear to absorb grit particles better than any solid TFE surface tested.

FINAL DESIGN - LAMINATED ELASTOMERIC - TFE BEARING

The final design selected by the Illinois Department of Transportation was developed from the results of the experimental data obtained from the first series of tests. The excessive deformations of the rubber found during the test indicated that certain design criteria had to be established to avoid permanent damage to the bearing. To satisfy this criteria a minimum shape factor of 5 would be required to minimize the compressive strains in the rubber backing. For most applications, this limits the thickness of the plain rubber backing to a maximum 1/2 inch (12.7 mm). Also, a 70-hardness rubber is needed to reduce the horizontal shear strain produced by the frictional forces at the sliding TFE surface. The slope that can be accommodated by the elastomer is very limited, and in most cases a mechanical device or rocker would be required within the assembly to accommodate rotation and non-parallel load surfaces. A new design based on the principles of a laminated

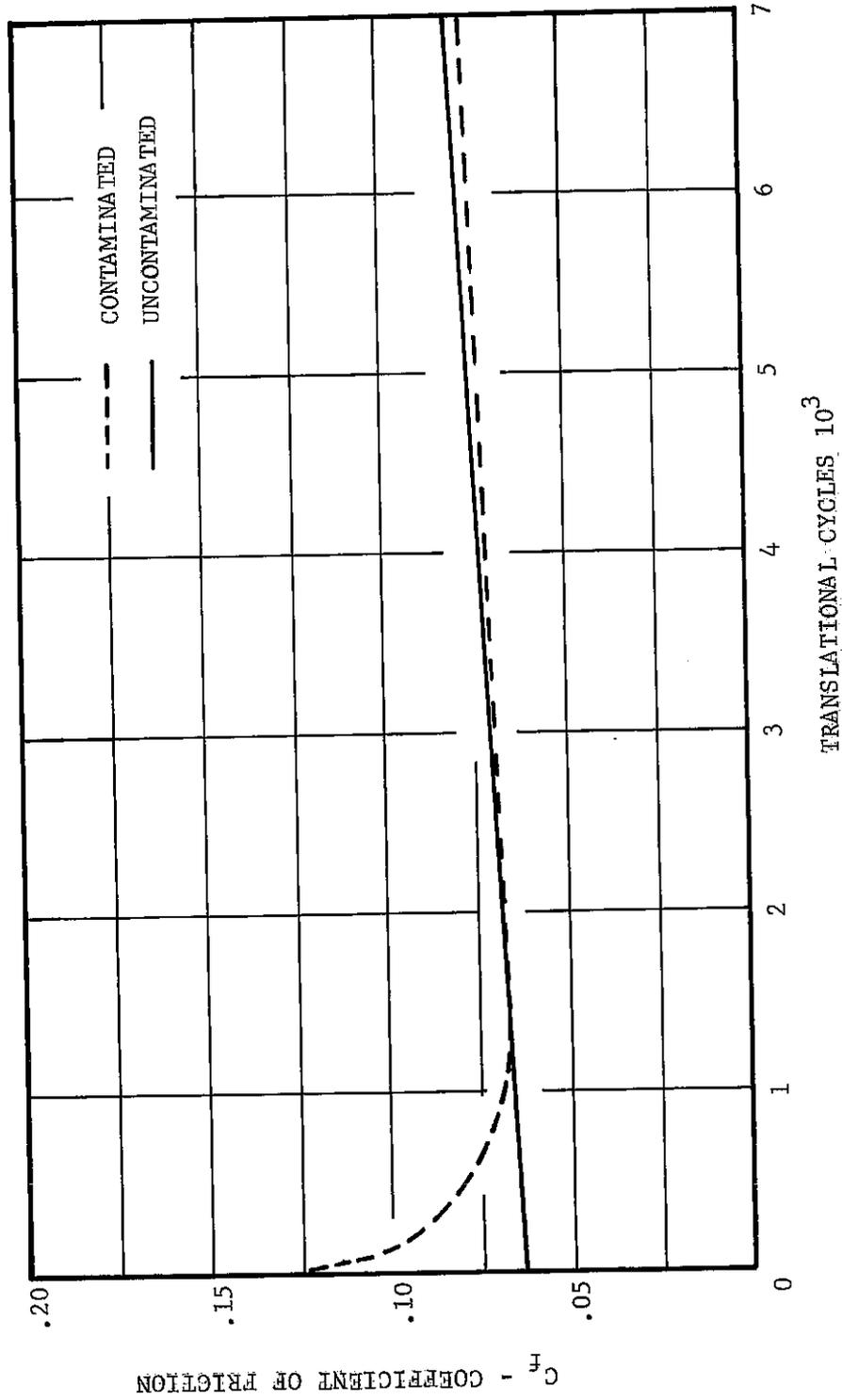


Figure 21. Comparison of normal and uncontaminated translational test of pure TFE fiber at 2000 psi. (13.79 MPa).

elastomeric bearing was conceived to provide rotational freedom (Figure 22). An interior retaining pin is used to limit the shear strain for bearings exceeding the present design limits for expansion.

A test specimen was fabricated and translational load tests were performed in accordance with the procedures used for the earlier specimens. Normal loads up to 1000 psi (6.89 MPa) were applied at the beginning and after 3000 cycles of testing. The results of the tests are shown in Figure 23. The coefficient of friction at the various load levels is typical for most unfilled TFE materials. This bearing also was subjected to a contamination test under a normal load of 500 psi (3.45 MPa) for 4000 cycles (Figure 24). No visual evidence of damage was observed after completing the test.

From the results of this study, three different types of standard expansion bearings were developed to satisfy most requirements for highway bridges (Appendix B). The first type included in the standards is the conventional laminated bearing which has no provisions for slippage within the assembly. Thermal or longitudinal movement is taken by internal deformation within the rubber. This bearing is used when the total rubber thickness is not critical for the amount of expansion taking place. Horizontal shear within the bearing is limited to 50 percent of the elastomer thickness.

The second standard design incorporates a teflon sliding surface to provide initial slippage shortly after installing the bearing. The design takes into account the extreme ambient temperature that may occur when installing the bearing. The assembly is self adjusting regardless of the installation temperature, and the design permits the bearing to align itself to a normal temperature. Once the bearing becomes aligned to the normal temperature, the travel is taken by horizontal shear within the rubber.

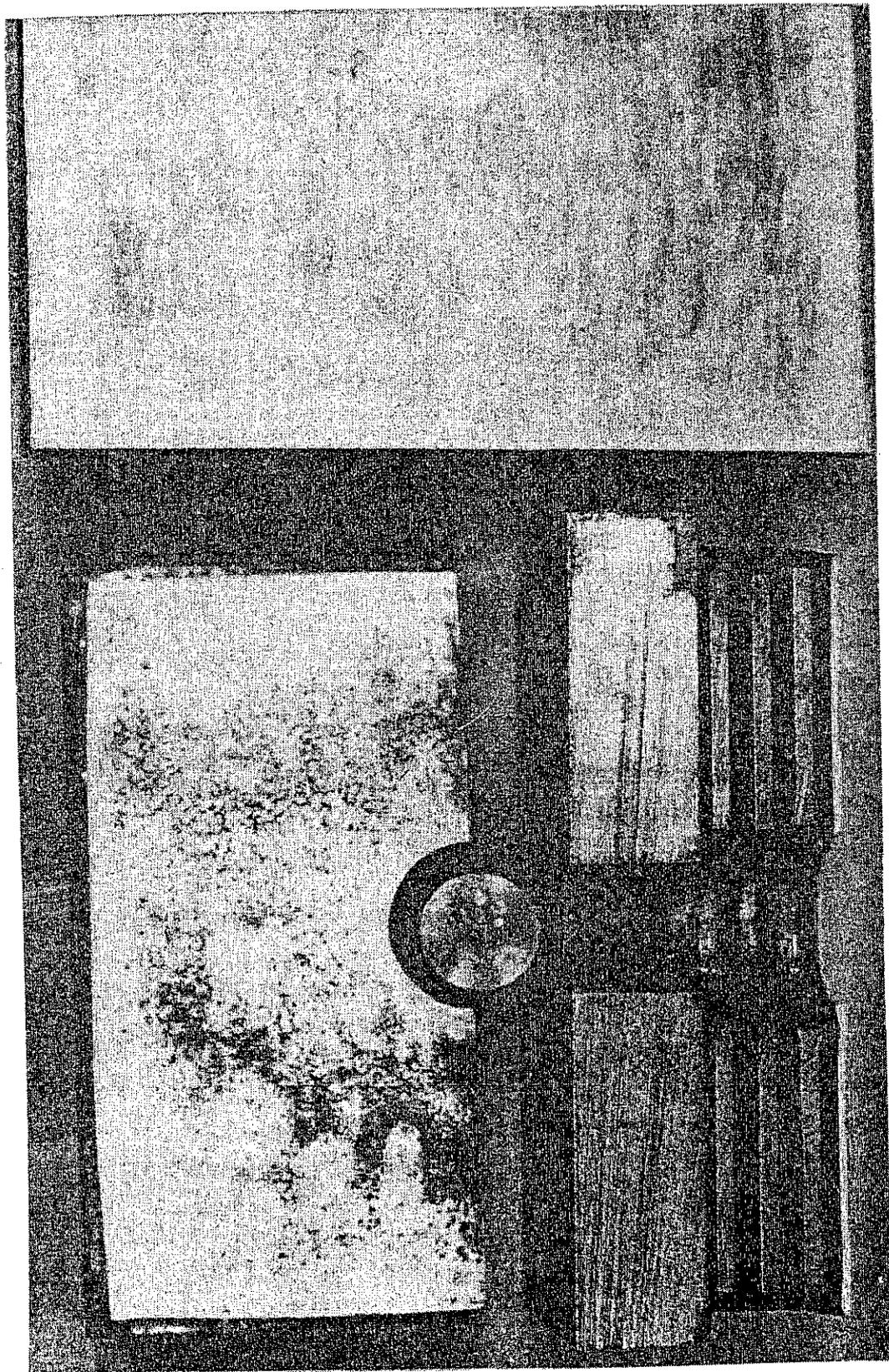


Figure 22. Laminated elastomeric - TFE expansion bearing with restrictor pin after completing contamination test.

METRIC CONVERSION

1 psi = 6.89 kPa

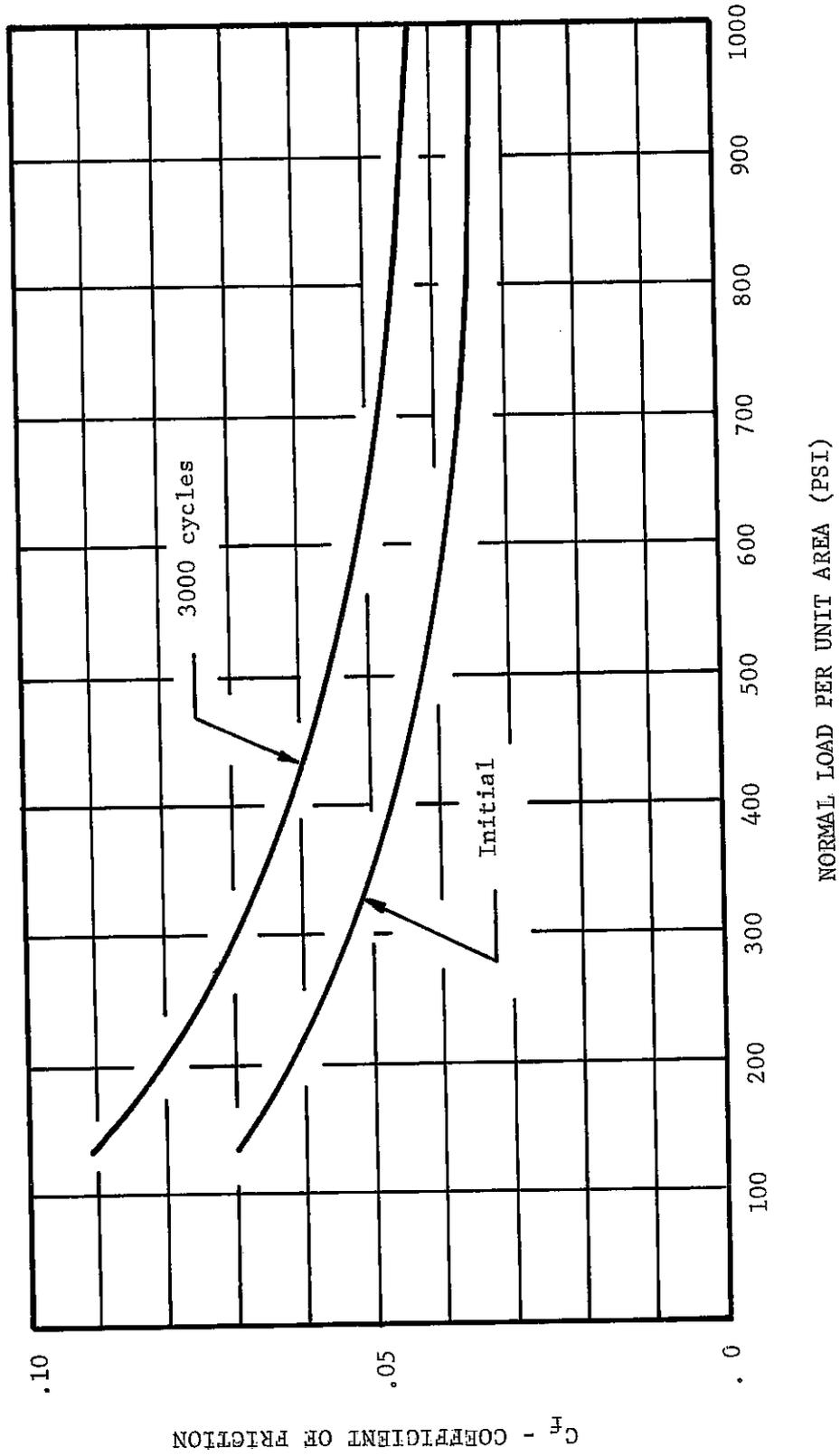


Figure 23. Coefficient of friction vs vertical pressure for laminated elastomeric - TFE sliding bearing.



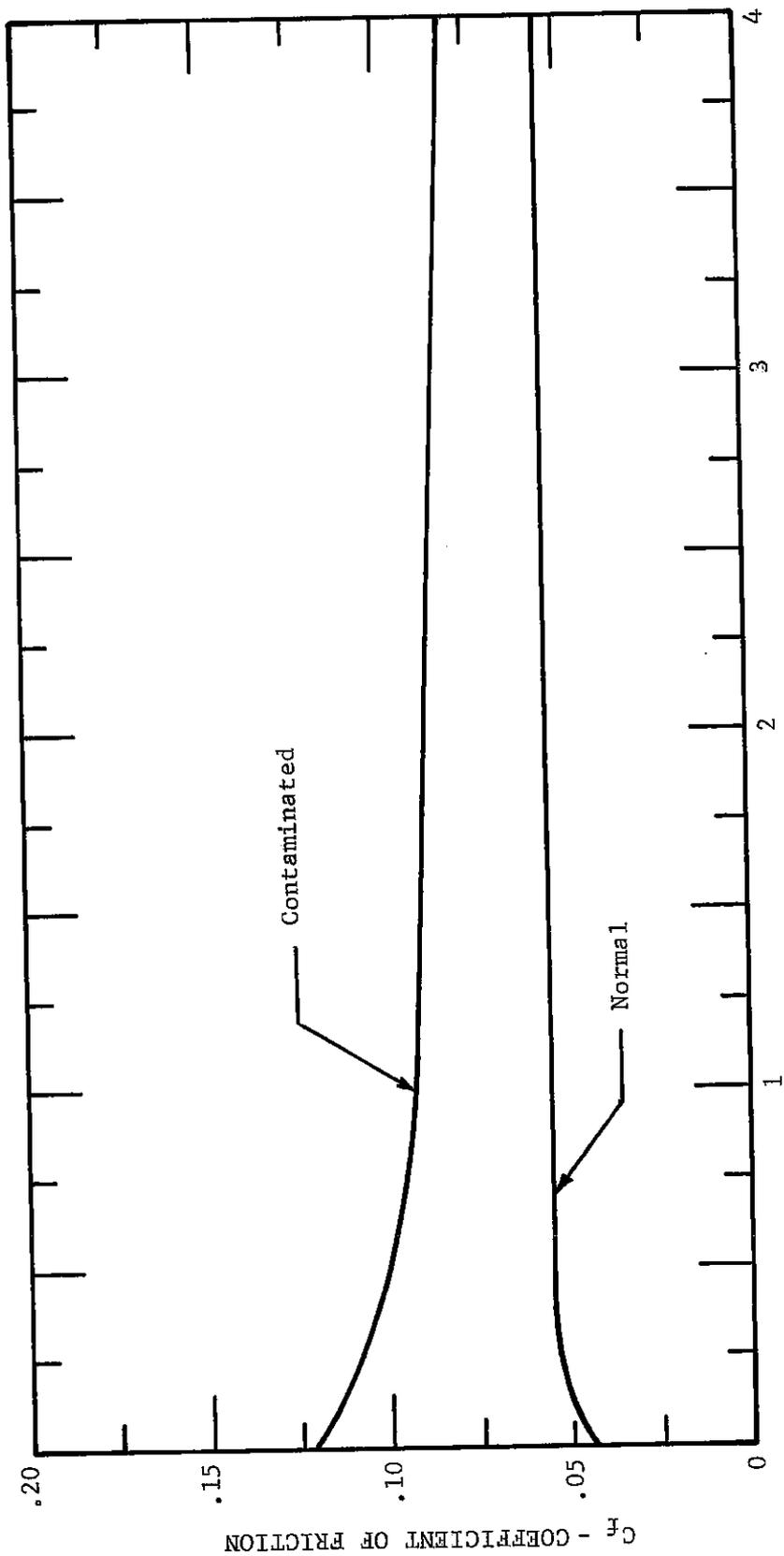


Figure 24. Comparison of normal and contaminated translational test of laminated elastomeric - TFE sliding bearing.

The third standard design is used to accommodate large thermal movements which exceed the limits of the second type of bearing. The design provides an internal restrictor pin to avoid overstressing the rubber in shear. The design permits continual slippage at the TFE surface and has no limitation relative to expansion length. The required rubber thickness is based on the rotational requirements for non-parallel load surfaces.

A 90-durometer rubber is vulcanized between the TFE surface and the steel laminate which eliminated the surface irregularities commonly found when using other adhesives. The type of bonding appears to be superior to other methods which utilize adhesives. The laminated rubber pad is also bonded by vulcanization to either a top sole plate or bottom masonry plate to prevent slippage of the bearing while in service.

CONCLUSIONS AND RECOMMENDATIONS

The results of this study indicate that the performance of the TFE bearing is better than the graphite-impregnated bronze bearings currently used for abutment expansion bearings on concrete bridges. The field tests show that, for the same expansion length of a prestressed concrete I-beam structure, twice as much daily movement occurred at the TFE bearings as at the bronze bearings. The tendency for the bronze bearings to bind up or freeze and not to allow free expansion of the structure is verified by the data collected during the field tests. The theoretical expansion that would have taken place if the structure were completely free to expand cannot be accurately correlated with the actual movement of the structure due to the lack of temperature data throughout the depth of the superstructure. The TFE bearings, however, with the qualities of anti-stick surfaces and low coefficients of friction, appear to be a significant improvement over previous bearing designs.

Many combinations of TFE surfaces and backing materials are commercially available, and the selection of the optimum bearing for a specific application is complicated by this variety of products. The bearings tested during the research consisted of samples obtained from several manufacturers. The test results illustrate the differences in the performance of specimens obtained from the several manufacturers as well as differences in the performance of specimens obtained from the same manufacturer.

The bearing surfaces laboratory tested in the research include unfilled TFE, filled TFE containing 15 and 25 percent glass fiber filler, and the graphite-impregnated bronze surface. The performance of the bronze bearing compared well with the glass-filled TFE surfaces; however, the coefficient of friction of the bronze samples was higher and less consistent than the unfilled specimens.

Because a comparison of the TFE surfaces shows that the unfilled TFE performed better than the filled specimens, it is the recommendation of this report that the unfilled TFE be used for bridge bearings. Although the glass fiber reinforcement improves the resistance of TFE bearings to wear and creep effects, the magnitude of the loads and the rate of movement of a bridge structure are not believed to be severe enough to cause a critical amount of wear and creep.

The parameters of rubber hardness, degree of slope, and shape factor were investigated for the rubber-backed specimens. Neoprene backing with 50, 60, and 70 hardness and adiprene backing with 80 hardness were evaluated. During the tests the softer specimens were observed to deform appreciably more than the harder samples, with lipping of the rubber at the exposed edges increasing with decreasing hardness. This distortion appeared to have little effect on the performance of the bearings, although the backing did separate slightly from the stainless steel interlayer. Because less strain occurs in the harder rubber under horizontal loads, it was concluded that 70 or more hardness rubber is needed when using a single-ply or plain rubber backing. The use of the harder backing, however,

limits the amount of slope that can be accommodated by the rubber. A laminated rubber bearing was selected in the final design since it eliminated the need for a mechanical rocker to accommodate rotation. When using softer rubbers, 50- to 60-durometer, a restraining device is needed to restrict the horizontal shear when the anticipated movement exceeds 50 percent of the total rubber thickness,

Shape factor also was considered as a parameter which could influence the performance of the rubber backing material. The tests indicate, however, that the difference in behavior of the harder rubber-backed specimens, 70-durometer, with shape factors of 2.7 and 5.4, is negligible. Consequently, no recommendation is made concerning the shape factor of the bearing backing material.

Laboratory tests on the 1/2-inch (12.7 mm) thick fabric-backed specimens with 25 percent glass-filled surface layers had to be halted before completion of 7000 translation cycles because of delamination of the fabric material. Signs of initial damage appeared at about 2000 to 3000 cycles. Two samples with 15 percent glass filler completed 7000 test cycles with only partial delamination occurring. In addition, two unfilled specimens completed 7000 and 28000 test cycles with no sign of delamination. From the laboratory test results it is concluded that the fabric material is suitable for backing bridge bearings when using unfilled TFE as the sliding element. The performance of the fabric backing with a filled TFE surface was substantially improved by increasing the thickness of the fabric material. Fatigue testing of a specimen backed with a 1 1/2-inch (38.1 mm) fabric pad indicated no evidence of damage after completing 7000 cycles.

The fabric-backed bearings with 25 percent glass filler performed well during the field test, which lasted three years and four months. No visible signs of damage were apparent in fabric specimens.

In addition to specimens with a surface of solid TFE, other samples with surfaces of woven TFE fibers were tested. One sample with interwoven strands of

bondable fibers and TFE fibers backed by stainless steel bonded to 50-hardness neoprene suffered 75 percent separation of the neoprene from the stainless steel after 7700 cycles at 500 psi (3.45 MPa). The use of a harder rubber backing and a stronger bonding material would greatly improve the performance of this bearing.

Another sample with a surface of loosely interwoven pure TFE fibers backed by an embossed bronze plate performed well under a constant load of 2000 psi (13.79 MPa) for 9700 cycles. Under contaminated conditions this bearing performed better than any other specimen. The coefficient of friction after contamination quickly approached the friction coefficient recorded during the uncontaminated test.

From the results of this research, it appears that the most economical and durable bearing design for highway bridges should have a sliding surface of pure unfilled TFE. The backing material should consist of a laminated rubber with preferably a thin hard grade of rubber bonded between the intermediate steel plate and the TFE surface layer. The opposing sliding surface may be either stainless steel or TFE bonded directly to a steel fill plate. Although other TFE bearing designs may provide adequate performance, for optimum durability and economy the suggested prototype is recommended.

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