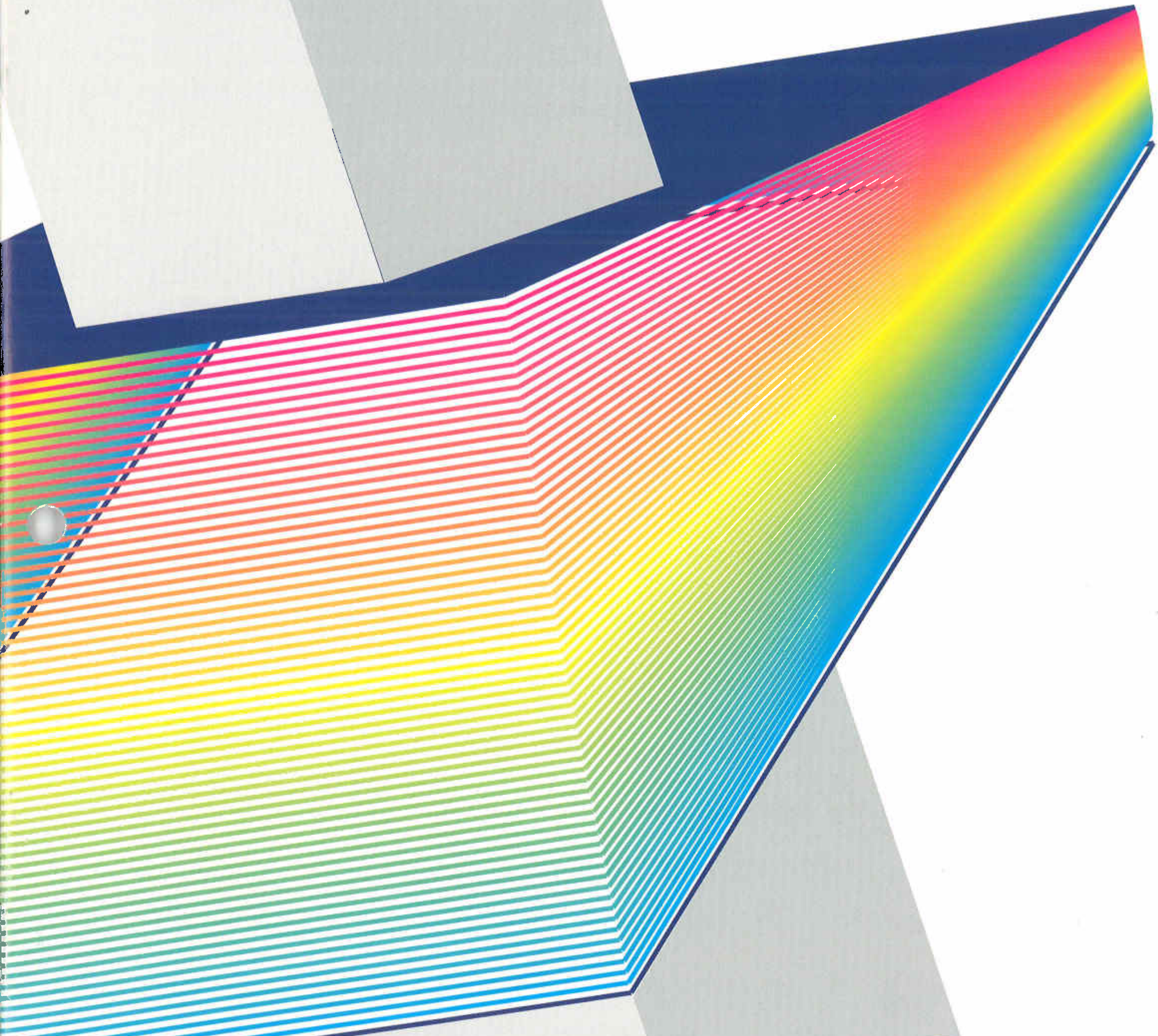
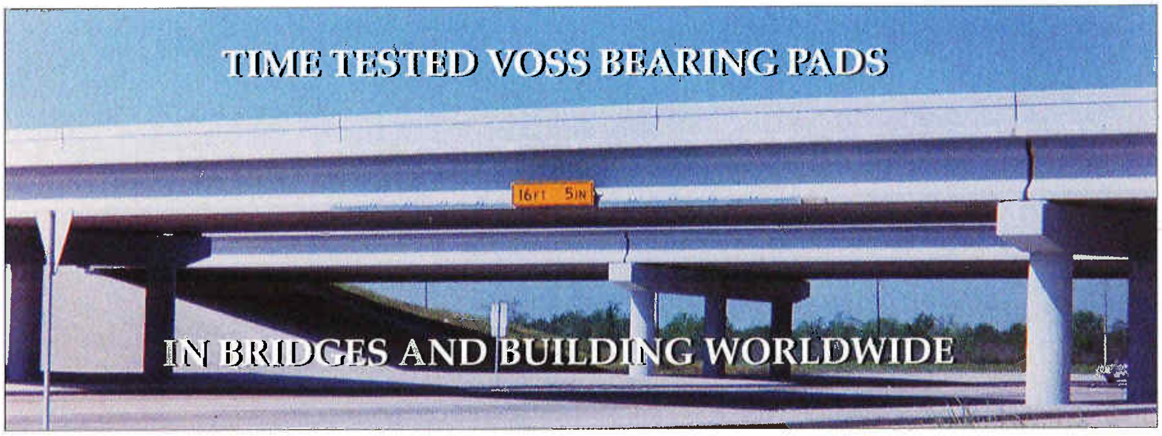
VOSS ENGINEERING • SORBTEX/FIBERLAST BEARING DESIGN MANUAL

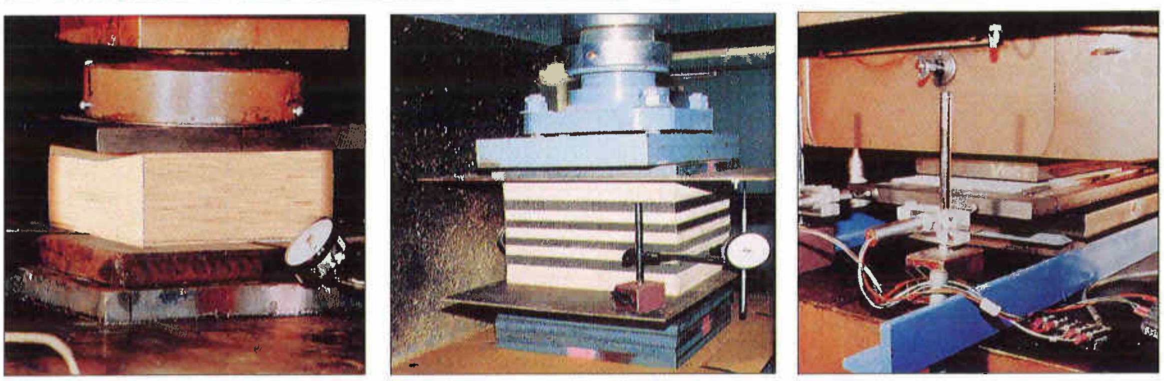
SORBTEX



FIBERLAST

THE RIGHT EXPANSION AND FIXED BEARING PAD SYSTEMS
FOR BUILDINGS, BRIDGES AND MOST LOAD BEARING STRUCTURES





EXAMPLES OF WJE COMPRESSION TESTS ON VOSS ENGINEERING EXPANSION BEARING PADS

Voss Engineering is proud to provide a complete line of the most extensively tested bearing pads in the industry.

Since 1961 Voss Engineering has been a leader in bearing pad materials research. Our extensive test programs have provided our clients with complete bearing design data for a variety of applications.

We have produced data describing the damping and shock transmissibility characteristics of Sorbtex preformed fabric pads. In 1988 Voss Engineering research produced the industry's most complete presentation of ROF bearing pad performance data with the introduction of the Fiberlast bearing pad catalog. Detailed research on compression, shear and creep provide design engineers with complete performance information for use in making bearing pad design decisions.

In 1990, Voss Engineering research developed a composite bearing pad for use in a highly specialized bridge design application where redundancy at critical locations was impractical. Safety considerations were met by designing 13 in x 13 in x 10 in thick composite bearing pads made of layers of Sorbtex and Fiberlast to provide customized impact absorption qualities. Today Voss Engineering continues its dedication to research by presenting this design manual of bearing pad systems for structural applications. The manual provides complete performance data for SORBTEX, FIBERLAST, and Voss Slide bearings.

Voss Engineering remains committed to providing leadership in research development and production of the finest bearing pads in the industry.

Bearing pads are commonly used in all types of standard construction, steel, precast and prestressed concrete bridges and buildings, as well as for machinery and equipment foundations. They are designed to:

- distribute vertical and horizontal loads over bearing areas to eliminate highly localized stresses and resulting structural damage
- allow horizontal and/or rotational movements at the bearing surfaces to reduce the effects of temperature, creep, shrinkage, and impact
- provide a longer bearing life than steel bearings which in the past have commonly failed due to corrosion
- isolate shock loads on structural members
- minimize vibrations between contacting surfaces.

Elastomeric bearing pads may be classified into two groups: plain pads (unreinforced) and reinforced pads. Plain pads are generally made in single layers from Neoprene© (chloroprene) such as NEOSORB™, Chloroprene formulated with other elastomers and natural rubber. Reinforced pads are made by several methods and materials, including steel reinforcement, fiberglass reinforcement, random oriented fibers (ROF) such as FIBERLAST™ and preformed cotton duck reinforced pads such as SORBTEX™.

SORBTEX bearing pads provide structural engineers and designers an alternative material for high load, small deflection applications. Made of layers of cotton and polyester fabric impregnated with oil resistant synthetic rubber, SORBTEX provides a high-quality alternative to comparable steel or fiberglass reinforced Chloroprene expansion bearings.

FIBERLAST bearing pads offer engineers and designers a new choice in ROF pads. With today's ever increasing structural needs and higher load requirements, a pad was needed that could meet these rigid demands and remain cost effective. FIBERLAST is such a product. Made of high-quality ozone resistant virgin elastomer combined with synthetic fibers, FIBERLAST pads have been extensively tested to demonstrate that their performance characteristics[1] are superior to comparable ROF or AASHTO grade unreinforced Neoprene© (Chloroprene) pads[2].

The 1988 FIBERLAST test program and published design manual[1] identified the need for an updated and comprehensive test program and a similar published design manual for larger-sized and thicker elastomeric pads for bridge construction and other heavy duty loadings. Such a test program was undertaken on SORBTEX and FIBERLAST for fixed and low-friction sliding bearings. This design manual presents the data and design recommendations for these different elastomeric bearing pad materials based upon the 1991 test program.

Details of The Structural Bearing Pad Test Program

An extensive laboratory test program was undertaken by Voss Engineering Company to evaluate the structural performance properties of various bearing pad systems. The tests were performed in 1991 by Wiss, Janney, Elstner Associates, Inc., Northbrook, Illinois. The tests were designed and performed by Gilbert T. Blake, Senior Engineer, and Joseph Zachorowski, Specialist. Donald W. Pfeifer, Vice President, served as a consultant on the project. Photographs of the various tests are shown on the inside front cover.

Prior to undertaking the laboratory testing, a literature review[1-10] was made to establish the state-of-the-art in structural design considerations for elastomeric pads. Significant factors identified in the literature which need to be considered in the design process are as follows:

- Stress-strain behavior of uniformly loaded bearing pads
- Creep properties of uniformly loaded bearing pads
- Stress-strain behavior of non-uniformly loaded bearing pads
- Horizontal shear resistance behavior and friction characteristics of uniformly loaded pads
- Coefficient of friction between bearing surfaces of low friction slide bearings.

In the test program, triplicate uniform compression tests were conducted between steel surfaces on SORBTEX pads with sizes of 8x8x 11/32 in., 8x8x1/2 in., 8x8x1 in., 8x8x3 in. and 7x14x2 in. Data reported in this manual also includes SORBTEX test data from previous tests on 13x13x10 in. bearings. Pad configurations tested included conventional SORBTEX, SORBTEX laminated to layers of polymer and Polytetrafluoroethylene (PTFE), and SORBTEX laminated to 1/4 in. thick steel plates recessed to contain a bonded layer of 1/8 in. thick PTFE.

Uniform compression tests were also conducted in triplicate on 8x8x3 in. and 7x14x2 in. specimens of FIBERLAST. The pads tested included FIBERLAST bonded to layers of polymer and PTFE and FIBERLAST bonded to 1/4 in. thick steel plate recessed to contain a bonded layer of 1/8 in. thick PTFE. Fig. 1 shows the various pads tested. Data reported in this manual also includes FIBERLAST test data from previous tests on 13x13x10 in. thick pads.

Nonuniform (rotation) compression tests at load angles of 0.015 and 0.025 radians were conducted on triplicate

ENGINEERING

specimens of SORBTEX and FIBERLAST with laminations of polymer and recessed steel with PTFE.

Low-friction expansion bearing pads generally use laminated top surfaces of PTFE as the low friction element. When bonded to elastomers, lateral pad deformations cause the PTFE to also stretch laterally under load. The test program included measurement of the lateral cold flow behavior of PTFE bonded to various substrates when under compressive loads.

Tests were conducted to determine the coefficient of friction between PTFE bonded to various substrates and polished stainless steel. These friction tests were conducted under uniform compressive stresses of about 500, 2000 and 3500 psi. Tests were also conducted to determine the sliding friction behavior between slide bearing surfaces of filled and unfilled PTFE bonded to conventional mild steel plates under uniform compressive stresses of 500, 2000, and 3500 psi.

Shear modulus tests, as described in ASTM D4014-87, Annex A1, were performed on specimens of SORBTEX as part of the test program. Apparent shear modulus tests were also conducted to determine the shear/slip characteristics of SORBTEX and FIBERLAST. These tests were conducted between concrete to concrete and steel to concrete surfaces at compressive stresses from 500 to 3000 psi for SORBTEX and 500 to 1500 psi for FIBERLAST.

Creep tests were made in triplicate using a constant compressive stress of 1500 psi on 4-1/4x4-1/4x1/2 in. pads of SORBTEX, FIBERLAST and NEOSORB. The 13.5 ton loads were maintained for 120 days using standard 50-ton creep frames in accordance with ASTM C512 methods.

SORBTEX BEARING PADS

SORBTEX Specifications

Made of high-quality cotton-polyester duck cloth that has been impregnated with oil resistant synthetic rubber and treated with mold and mildew inhibitors. Manufactured to the specifications of MIL-C-882E, 27 January 1989[9].

1. Hardness (Shore A) . . . . 90±5
2. Compression - Minimum Ultimate Strength . . . . 10,000 psi
3. a. Shear Modulus(G) . . . . 450 psi
   Based on tests conducted according to ASTM D 4014-87, Annex A1 at pure shear strain of 33 percent.
   b. Apparent Shear Modulus (G_A) . . . . 400, 850, 1150 & 1325 psi
   At compressive stresses of 500, 1000, 2000 and 3000 psi, Based on shear stress measurements made at 70°F to 80°F at a shear plus slip strain of 50 percent.
4. Permanent Set . . . . 2±1%
5. Volume swell per FED-STD-601(Ref.) . . . . 25% max
6. Dielectric Strength, ASTM D 149 (VDC/mil.) 155
7. Volume Resistivity, ASTM D 257 (ohm°cm x 10^{10}) 3.3
8. Thickness tolerance . . . . 5% of thickness
9. Plan Size Tolerance . . . . ±1/8 in.

For closer tolerances consult the factory

ALL PRODUCT IS CERTIFIED TO ABOVE SPECIFICATIONS BY VOSS ENGINEERING, INC., LINCOLNWOOD, ILLINOIS

PHYSICAL PROPERTIES OF PTFE

Virgin Unfilled PTFE	
Specific Gravity ASTM D 792	2.16
Tensile Strength at Break (psi) ASTM D 638	3000
Elongation at Break ASTM D 638	200%
Hardness Shore "D" ASTM D 2240	54
Deformation Under Load (% at 1200 psi) ASTM D 621	6.2%

Compression Design Characteristics

Structural bearing pad design procedures are usually based on service loads, excluding impact. The design procedures for elastomeric bearings contained in AASHTO Standard Specifications for Highway Bridges[2] presented here also reflect the latest research contained in the October, 1987 NCHRP Report 298[3] and recent work conducted by Roeder and Stanton[7].

The maximum compressive stress, σ_c, allowed by AASHTO, is determined from the equation

$$\sigma_c \le GS/\beta \qquad (1)$$

Where: σ_c = Average compressive stress caused by dead and live loads, excluding impact

G = Shear Modulus at 73°F, psi

S = Shape Factor

β = Modifying factor having a value of 1.0 for internal layers of reinforced bearings, 1.4 for cover layers and 1.8 for plain pads

This equation is based on limiting the amount of bulge in compressed elastomer material. Excessive bulging leads to pad cracking and ultimate failure. Shape factor, S, is a nondimensional relationship associated with the bulging caused by compressing a bearing pad. It is an important consideration in plain and reinforced pad design and is defined as the area of the pad divided by the area of the pad circumference:

$$S = \frac{LW}{2t(L+W)} \qquad (2)$$

Where: L or L_1 = loaded length of pad, in.

W or W_1 = loaded width of pad, in.

t = thickness of pad or layers, in.

AASHTO further limits the maximum uniform compressive stress to 1000 psi for steel reinforced pads or 800 psi for fabric reinforced bearings or plain pads. An increase of 10 percent is allowed where shear translation is prevented.

While these limitations are valid for normal elastomeric bearings made of AASHTO grade Chloroprene or Isoprene, testing indicates that SORBTEX pads have limited bulging at these

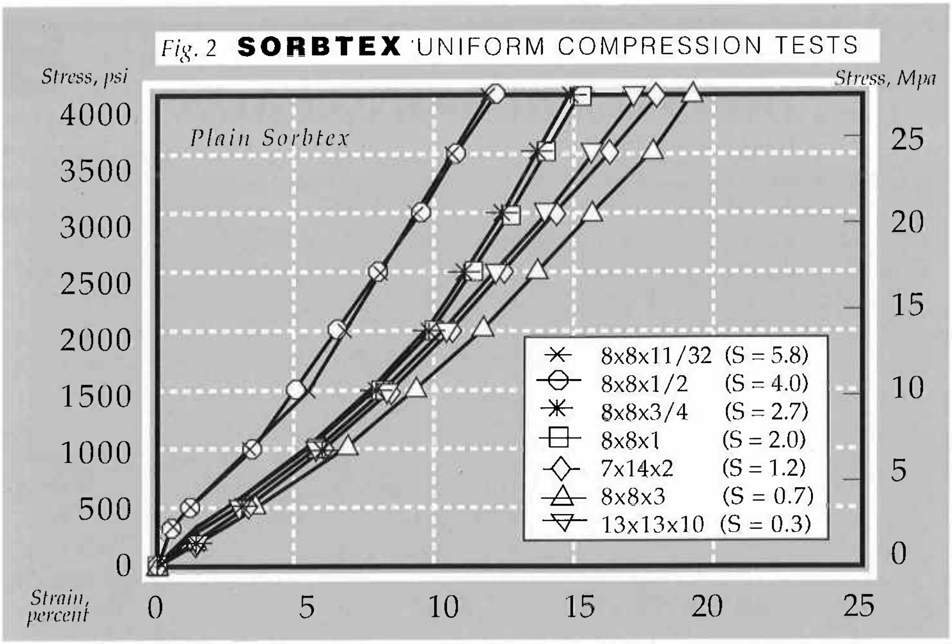


Fig. 2 **SORBTEX** UNIFORM COMPRESSION TESTS

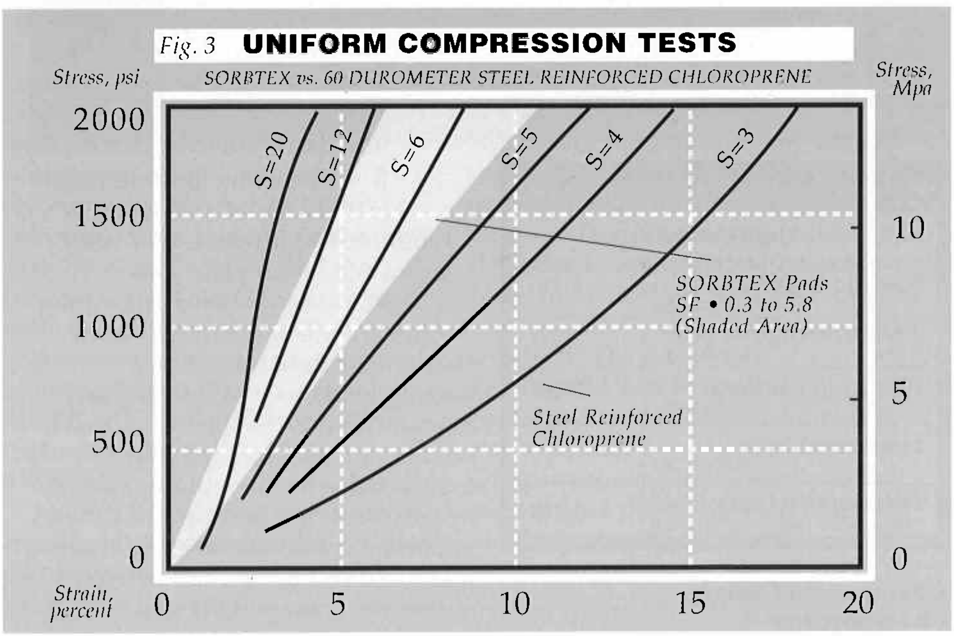


Fig. 3 **UNIFORM COMPRESSION TESTS**

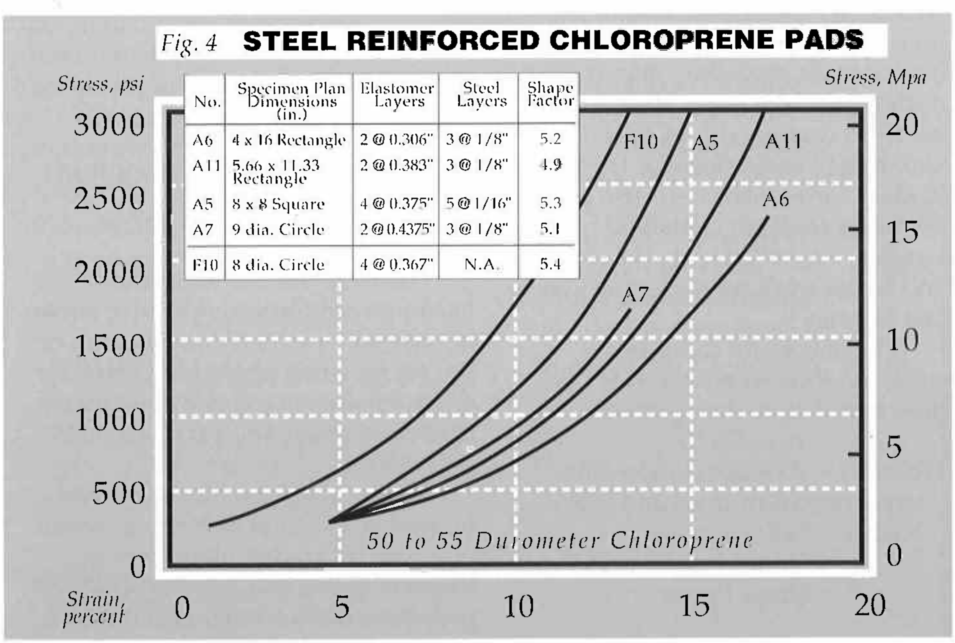


Fig. 4 **STEEL REINFORCED CHLOROPRENE PADS**

AASHTO maximum stress levels and do not suffer from cracking or delamination until much higher compressive stress levels are applied.

The compressive stress/strain curves for the uniformly loaded SORBTEX pads from the 1991 test program are shown in Fig. 2. These average curves, from triplicate specimens, are from pads with shape factors ranging from 0.3 to 5.8.

Figure 3 shows SORBTEX stress / strain curves for shape factors from 0.3 to 5.8 plotted for comparison purposes with 60 durometer AASHTO grade Neoprene® (Chloroprene) stress/strain curves[5] for shape factors from 3 to 20. These comparisons demonstrate a much lower sensitivity to bulging for SORBTEX when compared to Chloroprene which is very sensitive to bulging. Since SORBTEX is much less sensitive to the detrimental effects of bulging, the use of the AASHTO equation[1] and stress limits are not valid. For instance, the AASHTO equation for plain or fiber-reinforced pads would restrict the allowable stress for various tested shape factors as follows:

AASHTO Allowable Stress

Shape Factor	Stress, * psi
0.7	58
2	167
4	333
5.8	483
9.6	800

*Assume G = 150 psi and β = 1.8 in equation [1]

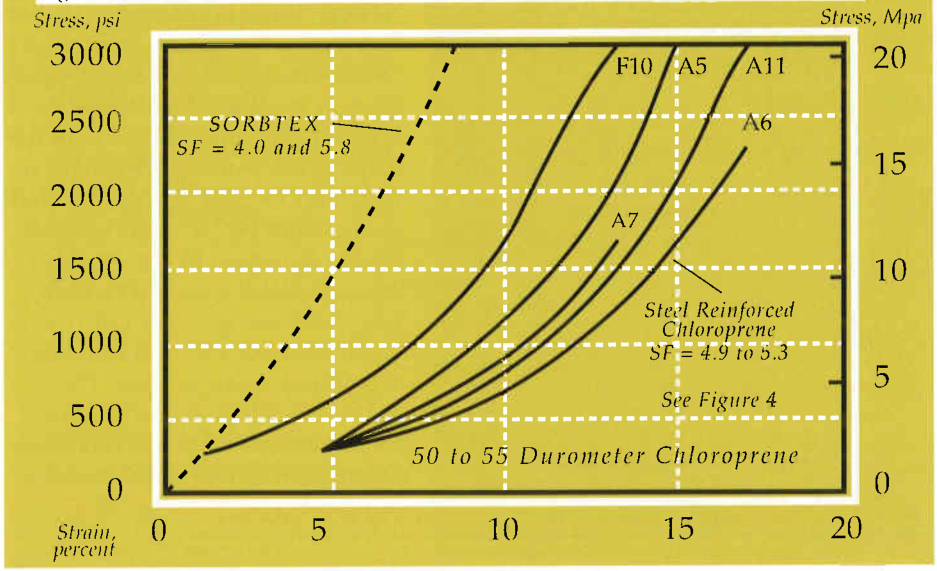
The data shown in Fig. 2 for SORBTEX shows that the SORBTEX pads having shape factors from 0.3 to 5.8 can easily support maximum stresses far above the 58 to 483 psi limits established by AASHTO for Cholorprene. In fact, SORBTEX pads have been designed for 2000 psi uniform stress levels for over 20 years, as discussed in the PCI Design Handbook [5].

Based upon the results of over 35 years of experience with SORBTEX pads in bridge and building applications and the results from the 1991 test program, an allowable maximum uniform compressive stress of 2500 psi is considered safe. This stress level will produce measured compressive strains of 7.5 to 13.3 percent for the wide range for tested shape factors as shown in Fig. 2. This ability to sustain higher stresses than steel reinforced Chloroprene pads is clearly shown in Fig. 3 where a 60 durometer reinforced Chloroprene pad with a shape factor of 5 at a stress of 800 psi produces a compressive strain of 5 percent, while the SORBTEX pad with a shape factor of about 5 will sustain 1500 psi at the identical 5 percent strain. At a shape factor of 4, the comparison is even more beneficial with the SORBTEX pad able to sustain 2300 psi at a strain of 7.3 percent, while the reinforced AASHTO Chloroprene pad can only sustain a stress of about 800 psi for the same 7.3 percent strain.

Since Chloroprene bulges significantly with durometers of 50, 60 and 70, as explained and shown in NCHRP Report 298[3], steel plates are used to reinforce and laminate thinner layers of Chloroprene to reduce the bulging problem. Stress/strain curves for five nominal 50 to 55 durometer differently shaped steel plate reinforced Chloroprene pads having shape factors of about 5 are shown in Fig. 4. These same stress/strain curves are shown in Fig. 5 with the SORBTEX stress/strain curve for the same nominal shape factor of about 5. These data further illustrate the greater load carrying capacity of SORBTEX when compared to steel plate reinforced AASHTO Chloroprene pads. A review of the data in Fig. 5 for steel plate reinforced Chloroprene pads working at a stress of 1000 psi indicates that the SORBTEX pad can sustain from about 2200 psi to above 3000 psi while allowing the same compressive strains of about 7 to 12 percent.

Uniform compression tests were conducted on typical SORBTEX expansion bearing pads laminated to PTFE, polymer with PTFE and steel with PTFE. The purpose of these tests was to determine if the compression stress/ strain behavior was influenced by the low-friction laminate. The test results are shown in Figs. 6 to 8. These tests on SORBTEX pads with shape factors of 0.7 to 2.0 indicate that the various low-friction SORBTEX pads can also be designed for 2500 psi uniform compressive stress. For these tests on triplicate specimens of 8 different laminated SORBTEX pads, the compressive strain at 2500 psi ranged

Fig. 5 **SORBTEX** vs STEEL REINFORCED CHLOROPRENE PADS



from 12.5 to 16.2 percent with an average compressive strain of 13.7 percent. This average strain for 13.7 percent compares quite favorably with the 12.5 percent average strain measured on the conventional SORBTEX pads having the same range in shape factor while also at 2500 psi. Therefore, the low-friction SORBTEX pads have very similar stress/strain curves when compared to the conventional SORBTEX pads.

Compressive Strain and Creep Behavior

Average instantaneous compressive strain is defined as follows:

$$\varepsilon_c = \frac{\Delta_c}{t} \qquad (3)$$

Where: ε_c = instantaneous compressive strain, in./in.
Δ_c = instantaneous compression shortening of pad, in.
t = original bearing pad thickness, in.

The total average compressive strain during the life of the pad is the sum of the initial compressive strain due to instantaneous dead and live loads, and the long-term compressive strain due to creep. Instantaneous compressive strains for the tested SORBTEX pads when loaded uniformly to 2500 psi range from about 7.5 to 13.3 percent and from about 5 to 8.8 percent for a uniform 1500 psi stress. Long-term creep data for SORBTEX pads uniformly loaded to 1500 psi with a shape factor of 2 are shown in Fig. A1 (on pg. 22). This creep data shows about 8 percent creep strain after 120 days of sustained loading. Thus, the creep strain for a 1500 psi sustained stress can vary from approximately 90 to 160 percent of the instantaneous compressive strain at a stress of 1500 psi. The total long- term compressive strain could range from 13 to 17 percent at a sustained stress of 1500 psi and from about 21 to 24 percent of the original pad thickness if loaded continuously at 2500 psi. Since bearing pads are generally under sustained working stresses due to dead load only, the total actual long-term compressive strain of the pads would probably be less than the 21 to 24 percent suggested range for a sustained 2500 psi stress level.

Nonuniformly Loaded Bearing Pads in Compression (Rotation)

Bearing pads are often loaded

Fig.6 **SORBTEX** UNIFORM COMPRESSION TESTS

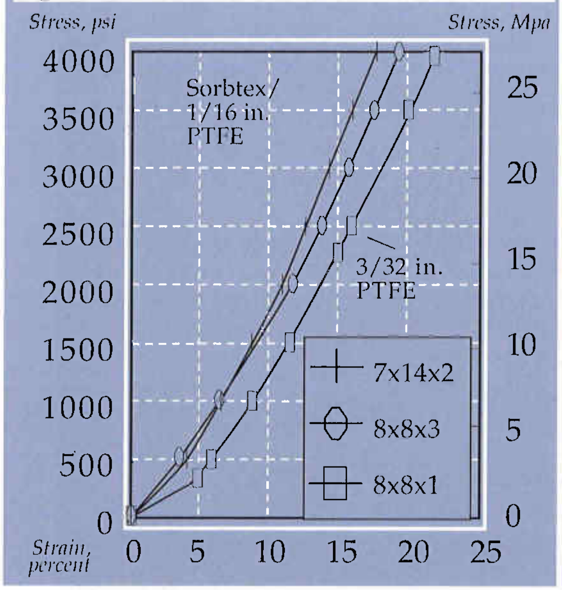


Fig.7 **SORBTEX** UNIFORM COMPRESSION TESTS

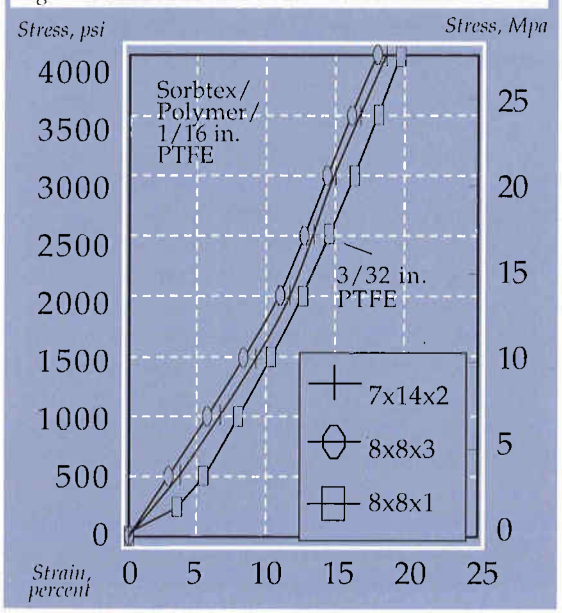
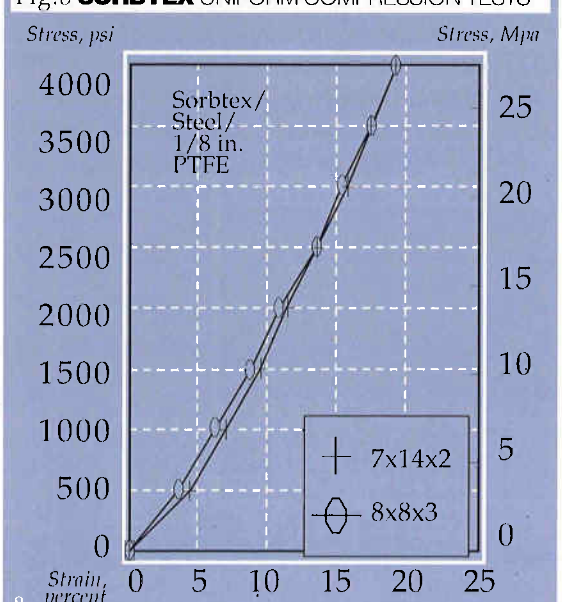


Fig.8 **SORBTEX** UNIFORM COMPRESSION TESTS



nonuniformly as shown in Fig. 9. The total angular difference, θ, between the two structural member bearing surface planes is referred to as rotation. Rotation is significant because it causes the load to be nonuniformly distributed over the bearing pad. Under some conditions, pads may be only partially loaded as shown in Fig. 10 or completely loaded as shown in Fig. 11. Non - uniform loading can cause high edge load stresses. For this reason, the amount of rotation must be accounted for in design. The AASHTO Bridge Specifications[10] limit the relative rotation between the top and bottom surfaces of the bearing by:

$$L\theta_L + W\theta_W \le 2\Delta_c \text{ for rectangular bearings} \quad (4a)$$

$$D\sqrt{\theta^2_L + \theta^2_W} \le 2\Delta_c \text{ for circular bearings} \quad (4b)$$

Where: L = Gross loaded length of rectangular bearing parallel to longitudinal axis of beam, in.

W = Gross loaded width of rectangular bearing perpendicular to longitudinal axis of beam, in.

θ_L = Relative rotation between top and bottom bearing surfaces about the transverse axis, radians

θ_W = Relative rotations between top and bottom bearing surfaces about the longitudinal axis, radians.

Δ_c = Instantaneous shortening of a uniformly loaded bearing, in.

D = Bearing pad dia., in.

t = thickness of pad or layers, in.

The recommended SORBTEX nonuniformly loaded service design stress is based upon a completely loaded surface as shown in Fig. 11 with a maximum strain of 12 percent at the most highly loaded edge for pads with thicknesses of 0.50 in. or greater.

Then for SORBTEX:

$$L\theta_L + W\theta_W \le 0.12t \quad (5)$$

And if either θ_L or θ_W = zero, then:

$$\theta_L \text{ or } \theta_W = \frac{0.12t}{L \text{ or } W} \quad (6)$$

The AASHTO definition for L or W assumes that the entire surface of the pad is loaded and that there is full contact on both the top and bottom loaded surfaces. There can be instances, particularly with large pads and large rotations, when there is not full load contact over the entire pad area. Since the entire pad area cannot be used for load calculations, these partially-loaded design cases are not considered in this manual.

ROF or plain unreinforced pad materials may not exhibit equivalent nonuniform load behavior unless their stress-strain behavior produced the same maximum 12 percent compressive strain at the most highly loaded edge at service loads.

Compressive deflection (strain) behavior is limited by AASHTO to the use of data obtained from AASHTO design aids such as Equations 3 and 4, results of testing, such as discussed in this manual, or by rational analysis.

The use of L or W (L_l or W_l) depends on which surface dimension is affected by the rotation, as shown in Fig 10. If rotations occur about both axes, the dimension with the greater angle is used for calculating pad size. Limiting rotation angles derived from Equation 6 for various SORBTEX pad thickness and dimension combinations are plotted in Fig. 12. These curves show the relationship between maximum usable pad dimensions L or W, pad thickness t, and rotation angle θ, for nonuniform loading conditions which provide full contact on the pad or 100 percent utilization of the pad area. Equation 6 is valid when one edge is fully loaded and the other edge load is zero.

Figure 12 can also be used to determine the proper pad thickness t, for efficient utilization of the pad by maximizing the actual loaded area of the pad under nonuniform loading conditions. As an example, from Fig. 12, for an assumed design rotation of 0.025 radians, the maximum L or W (L_l or W_l) dimension for a 1.5 in. thick pad will be 7.2 in. to achieve full contact pressure on the pad. However, these dimensions would increase to 9.6 in. if a 2 in. thick pad was selected. When the actual rotation conditions of a project are unknown and the designer wishes to assume an angular rotation of 0.025 radians, the Fig. 12 chart shows that 0.5 to 4.0 in. thick pads can provide usable fully-loaded dimensions L or W (L_1 or W_1) of 2.4

to 19.2 in., respectively.

There are two loading cases possible for fully loaded bearings under nonuniform loading conditions. The first case is when one edge is loaded to a maximum stress σ_{max} and the other edge stress is zero. This case produces the maximum pad length L_{max}, which can be found by rearranging Equation 6:

$$L_{max} \text{ or } W_{max} = \frac{0.12t}{\theta_L \text{ or } \theta_W} \quad (7)$$

The average stress, σ_{avg} for this case is one-half σ_{max}.

The other loading possibility is when both edges are loaded to significant stresses. For design purposes, the most highly loaded edge is allowed to increase from 2500 psi when $\theta = 0$ radians to 4000 psi when $\theta = 0.025$ radians. The pad length L_{min}, for this second condition represents the minimum fully loaded length for $\sigma_{avg} = 2500$ psi. Shorter lengths will result in excessive edge stresses. The minimum lengths for bearings loaded to significant levels at both edges were calculated using the following relationship derived from specimen geometry:

$$L_{min} \text{ or } W_{min} = \frac{5.76t}{24\theta_{(L or W)}+1} \quad (8)$$

These minimum pad lengths are plotted in Fig. 13.

Table 1, (pgs. 12, 13) is a tabulation of allowable average stresses between L_{min} and L_{max} for fully loaded bearings under nonuniform loads with rotations between 0 and 0.025 radians and pad thicknesses between 0.5 and 3.0 in.

These design load conditions and resulting stress/strain behavior allows for as much as 20 percent strain at the most highly stressed loaded edge of the nonuniformly loaded bearing pad while limiting the average strain to 10 percent or less at the center of gravity of the loaded area of the pad. No detrimental effects were apparent at these stress levels during load tests of 54 different pads.

As an example of the use of Table

Fig. 9

TYPICAL NONUNIFORM BEARING CREATED BY CONSTRUCTION TOLERANCES OF TWO CONCRETE STRUCTURAL MEMBERS

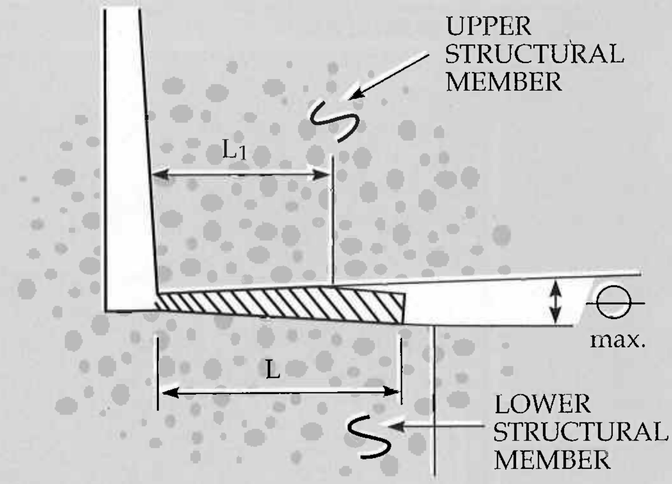
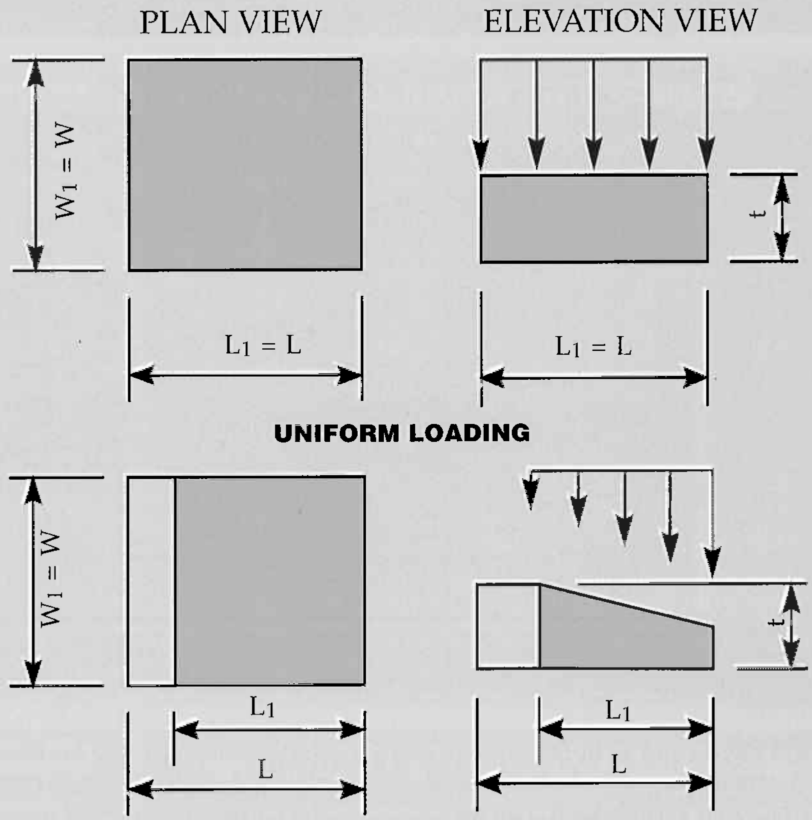


Fig. 10

DESIGN LOADING CONDITIONS

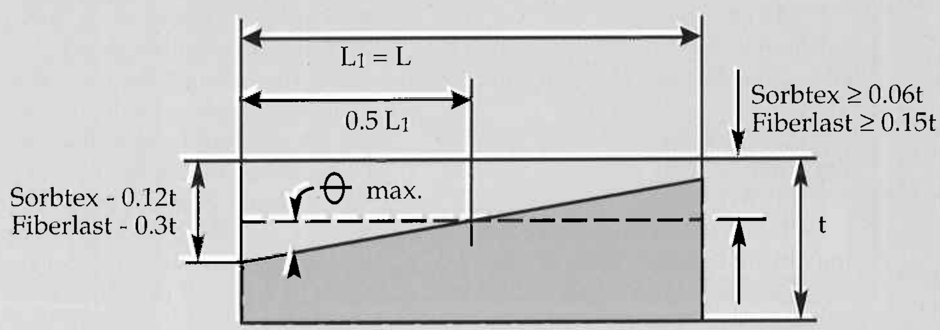


PARTIAL NONUNIFORM LOADING

L-L1 is not loaded and cannot be used for load calculations

Fig. 11

NONUNIFORMLY LOADED PAD UTILIZING FULL PAD AREA



FULL-CONTACT AREA CONDITION

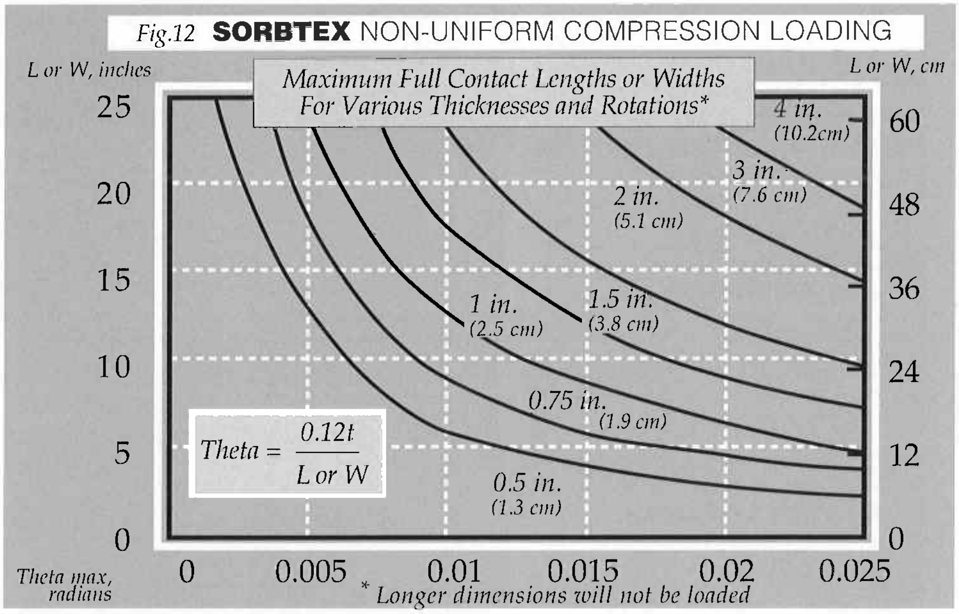


Fig.12 **SORBTEX** NON-UNIFORM COMPRESSION LOADING

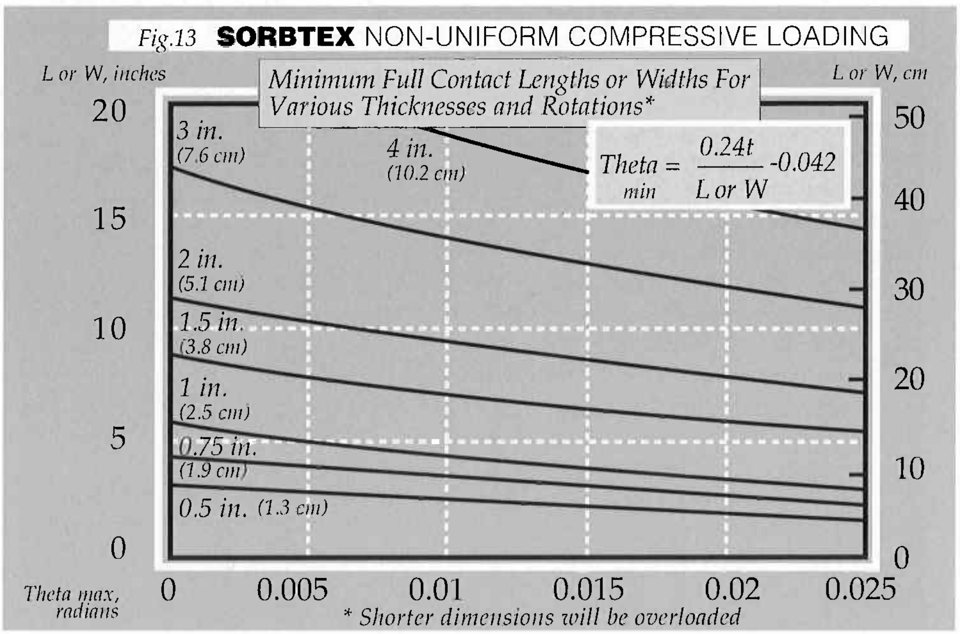


Fig.13 **SORBTEX** NON-UNIFORM COMPRESSIVE LOADING

1 and Fig. 12 and 13 or Equations 6 and 7, the total allowable design load, P (unfactored service load) can be calculated for pads under different load conditions. The calculation shown for a 10 in. by 10 in. x 1 in. pad, uniformly and nonuniformly loaded are as follows:

For θ max = 0.00 radians

$P = LW\sigma$

Where L = 10 in., W = 10 in., each edge is loaded to a stress of 2500 psi. Therefore, σ_{avg} = 2500 psi

P = 250,000 lbs.

For θ max = 0.015 radians

$P = L\,W\sigma_{avg}$

t = 1.0 in. is too small since the maximum loaded length at this rotation = 8 in. and 20 percent of the pad area is not loaded. By increasing the thickness to 1-1/2 in., the average allowable stress becomes 1983 psi and the pad is fully loaded.

P = 10 x 10 x 1983 = 198,300 lbs.

For θ max = 0.025 radians

Again, t = 1.0 in. is too small since the loaded length L_l = 4.8 in. and 52 percent of pad area is not loaded. Using t = 2.0 in. and Table 1, the average allowable stress is 2000 psi and the pad is fully loaded.

P = 10 x 10 x 2000 = 200,000 lbs.

Shorter bearings could also be used for the reviewed examples with only a small loss in load capacity. For instance, from Table 1, a 9 in. x 10 in. x 2 in. thick pad will sustain an average stress of 2125 psi and = 9 x 10 x 2125 = 191,250 lbs.

Severe rotations greater than 0.025 radians should be avoided since pad capacity decreases rapidly with decreasing loaded area. Severe rotations could cause the loaded edge stresses to increase beyond the capacity of the pad.

For θ max = 0.03 radians, t = 1.0 and P = 112,000 lbs.

L_l = The loaded length is 4.0 in. (60 percent of pad area is not loaded)

σ_{max} = 4300 psi which exceeds the maximum allowable edge stress of 4000 psi.

Figs. 14, 15 and 16 show SORBTEX average nonuniform compressive stress/strain behavior for plain SORBTEX and low-friction SORBTEX expansion pad lamination combinations with shape factors of 0.7 and 1.2 when loaded nonuniformly at 0.015 radians. Figs. 17, 18 and 19 show SORBTEX average stress/strain behavior for the same thicker and low shape factor pads when nonuniformly loaded at 0.025 radians. A statistical analysis of all of the uniform and nonuniform test data for pads with shape factors of 0.7 to 2.0 indicated similar stress/strain behavior between 0 and 12 percent edge strain.

Pad Recovery (Permanent Set)

After testing the SORBTEX bearing pads at compressive stresses of 4000 psi, the pads were monitored for 14 days to determine elastic recovery. The average recovery for all SORBTEX pads was 98 ± 1 percent.

Planar (Horizontal) Shear

Shear in a bearing pad is related to the relative planar deformation between the top and bottom surfaces. This horizontal deformation is caused by forces being applied by the loading member, the reaction or both. These forces can be the result of vehicle acceleration and braking, thermal effects, prestressing effects and other factors.

Recent studies presented in the NCHRP Report 298[3] have shown that bearing pads with combined horizontal shear and vertical compressive loadings have maximum shear efficiency when the shear plus slip strain is limited to about 50 percent of the pad thickness. Strains beyond 50 percent caused the pad edges to be overstrained. This results in the rolling over of the edges, which can cause localized high stresses and debonding of the fiber from the

Fig. 14 **SORBTEX** NONUNIFORM COMPRESSION TESTS

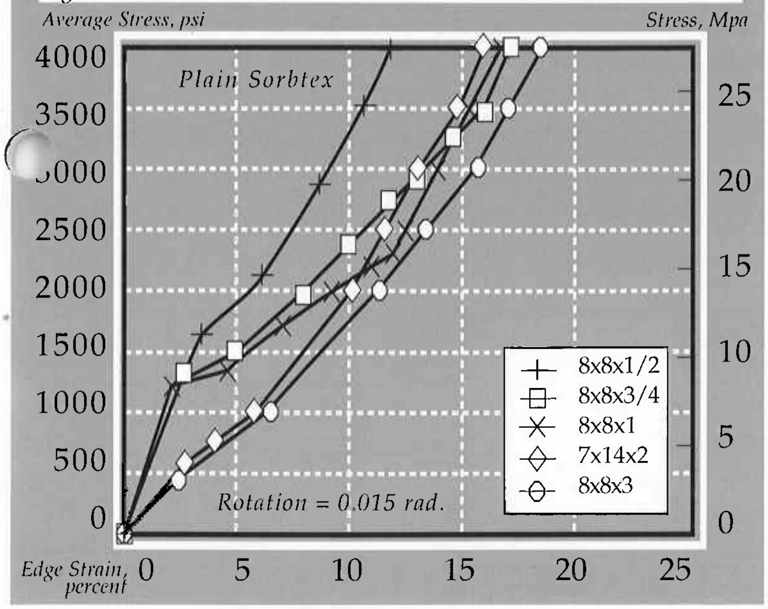


Fig. 17 **SORBTEX** NONUNIFORM COMPRESSION TESTS

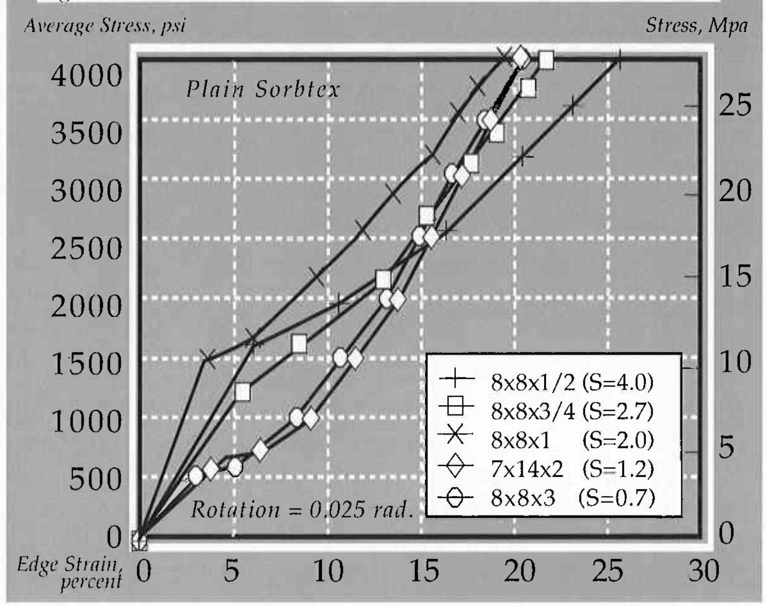


Fig. 15 **SORBTEX** NONUNIFORM COMPRESSION TESTS

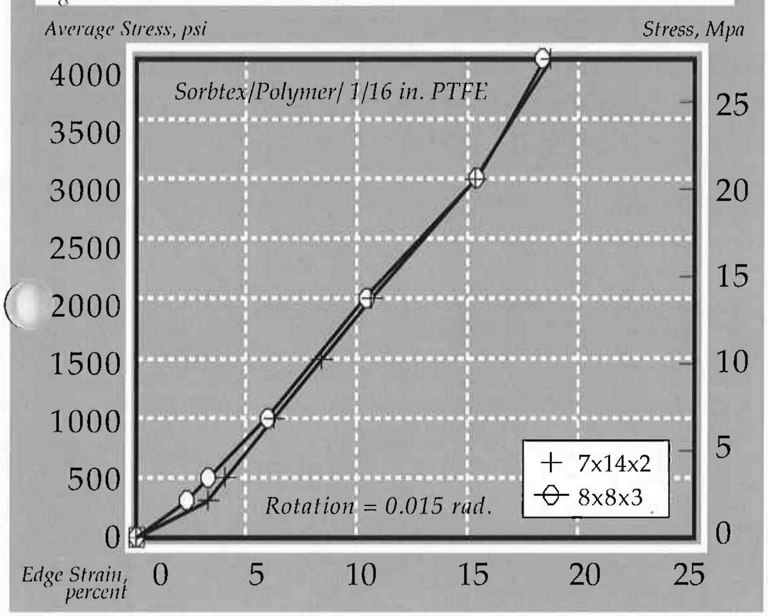


Fig. 18 **SORBTEX** NONUNIFORM COMPRESSION TESTS

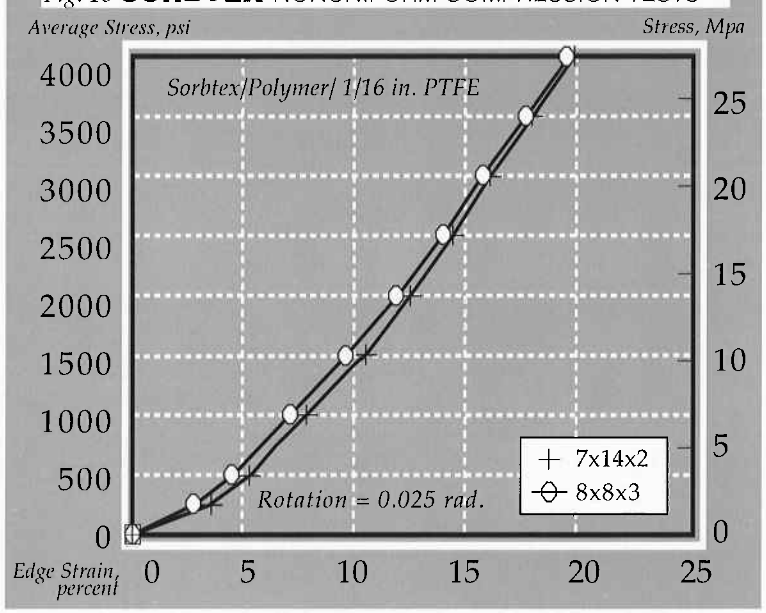


Fig. 16 **SORBTEX** NONUNIFORM COMPRESSION TESTS

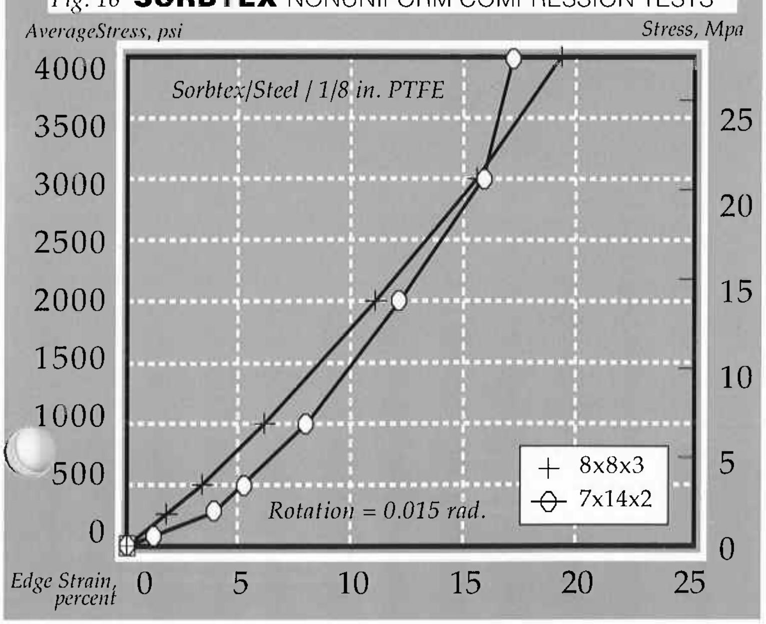
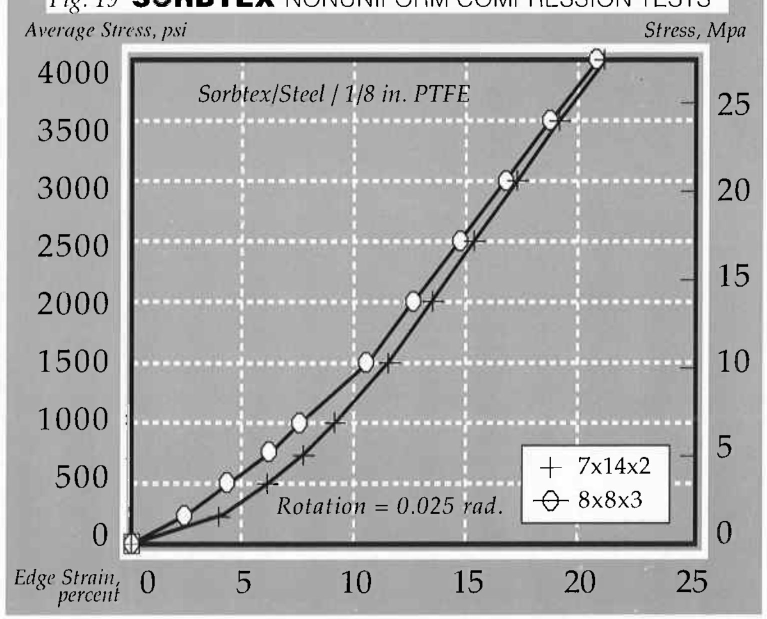


Fig. 19 **SORBTEX** NONUNIFORM COMPRESSION TESTS



SORBTEX ALLOWABLE AVERAGE COMPRESSIVE STRESS FOR NONUNIFORM LOADING ON PLAIN OR PTFE COATED BEARING PADS

STRESS, PSI FOR Θ = 0.005 RADIANS

$L_1(W_1)$	t = 0.5	$L_1(W_1)$	t = 0.75	$L_1(W_1)$	t = 1.0	$L_1(W_1)$	t = 1.5	$L_1(W_1)$	t = 2.0	$L_1(W_1)$	t = 3.0
2.6*	2500	-	-	-	-	-	-	-	-	-	-
4	2333	3.9*	2500	-	-	-	-	-	-	-	-
5	2217	5	2411	5.1*	2500	-	-	-	-	-	-
6	2100	6	2333	6	2440	-	-	-	-	-	-
7	1983	7	2255	7	2385	-	-	-	-	-	-
8	1867	8	2177	8	2325	7.7*	2500	-	-	-	-
9	1750	9	2100	9	2270	9	2450	-	-	-	-
10	1633	10	2022	10	2210	10	2411	10.3*	2500	-	-
11	1517	11	1944	11	2150	11	2372	11	2479	-	-
12**	1400	12	1866	12	2095	12	2333	12	2450	-	-
		13	1789	13	2035	13	2294	13	2421	-	-
		14	1711	14	1980	14	2256	14	2392	-	-
		15	1633	15	1920	15	2217	15	2363	15.4*	2500
		16	1555	16	1865	16	2178	16	2333	16	2498
		17	1478	17	1805	17	2139	17	2304	17	2469
		18**	1400	18	1745	18	2100	18	2275	18	2450
				19	1690	19	2061	19	2246	19	2431
				20	1633	20	2022	20	2217	20	2411
				21	1575	21	1983	21	2188	21	2392
				22	1517	22	1944	22	2158	22	2372
				23	1458	23	1906	23	2129	23	2353
				24**	1400	24	1867	24	2100	24	2333

STRESS, PSI FOR Θ = 0.010 RADIANS

$L_1(W_1)$	t = 0.5	$L_1(W_1)$	t = 0.75	$L_1(W_1)$	t = 1.0	$L_1(W_1)$	t = 1.5	$L_1(W_1)$	t = 2.0	$L_1(W_1)$	t = 3.0
2.3*	2500	-	-	-	-	-	-	-	-	-	-
3	2325	3.5*	2500	-		-	-	-	-	-	-
4	2067	4	2410		-	-	-	-	-	-	-
5	1808	5	2238	4.6*	2500	-	-	-	-	-	-
6**	1550	6	2066	6	2325	-	-	-	-	-	-
		7	1894	7	2196	7*	2500	-	-	-	-
		8	1722	8	2067	8	2411	-	-	-	-
		9**	1550	9	1938	9	2325	9.3*	2500	-	-
				10	1808	10	2239	10	2454	-	-
				11	1679	11	2153	11	2390	-	-
				12**	1550	12	2067	12	2325	-	-
						13	1981	13	2260	-	-
						14	1894	14	2196	13.9*	2500
						15	1808	15	2131	15	2454
						16	1722	16	2067	16	2411
						17	1636	17	2002	17	2368
						18**	1550	18	1938	18	2325
								19	1873	19	2282
								20	1808	20	2239
								21	1744	21	2196
								22	1679	22	2153
								23	1615	23	2110
								24**	1550	24	2067

Table 1 is a tabulation of allowable average stresses between L_{min} and L_{max} for fully loaded bearings under nonuniform loads with rotations between 0 and 0.025 radians and pad thicknesses between 0.5 and 3.0 in.

L_1 (W_1) = Length (or width) of fully loaded bearing, in.

t = Bearing pad thickness, in.

* Minimim pad Length, L_{min} (W_{min}). Shorter length or width will result in overstressed pads.

** Maximum pad length, L_{max} (W_{max}). Longer length or width will not be utilized.

STRESS, PSI FOR Θ = 0.015 RADIANS

$L_1(W_1)$	t = 0.5	$L_1(W_1)$	t= 0.75	$L_1(W_1)$	t = 1.0	$L_1(W_1)$	t = 1.5	$L_1(W_1)$	t = 2.0	$L_1(W_1)$	t = 3.0
2.1*	2500	-	-	-	-	-	-	-	-	-	-
3	2125	3.2*	2500	-	-	-	-	-	-	-	-
4**	1700	4	2267	4.6*	2500	-	-	-	-	-	-
		5	1983	5	2338	-	-	-	-	-	-
		6**	1700	6	2125	6.4*	2500	-	-	-	-
				7	1913	7	2408	-	-	-	-
				8**	1700	8	2267	8.5*	2500	-	-
						9	2125	9	2444	-	-
						10	1983	10	2338	-	-
						11	1842	11	2131	-	-
						12**	1700	12	2125	-	-
								13	2019	12.7*	2500
								14	1913	14	2408
								15	1806	15	2338
								16**	1700	16	2267
										17	2196
										18	2125
										19	2054
										20	1983
										21	1913
										22	1842
										23	1771
										24**	1700

STRESS, PSI FOR Θ = 0.020 RADIANS

$L_1(W_1)$	t = 0.5	$L_1(W_1)$	t= 0.75	$L_1(W_1)$	t = 1.0	$L_1(W_1)$	t = 1.5	$L_1(W_1)$	t = 2.0	$L_1(W_1)$	t = 3.0
1.9*	2500	-	-	-	-	-	-	-	-	-	-
3**	1850	2.9*	2500	-	-	-	-	-	-	-	-
		4.5**	1850	3.9*	2500	-	-	-	-	-	-
				5	2158	-	-	-	-	-	-
				6**	1850	5.8*	2500	-	-	-	-
						7	2261	-	-	-	-
						8	2056	7.8*	2500	-	-
						9**	1850	9	2313	-	-
								10	2158	-	-
								11	2004	-	-
								12**	1850	11.7*	2500
										13	2364
										14	2261
										15	2158
										16	2056
										17	1953
										18**	1850

STRESS, PSI FOR Θ = 0.025 RADIANS

$L_1(W_1)$	t = 0.5	$L_1(W_1)$	t= 0.75	$L_1(W_1)$	t = 1.0	$L_1(W_1)$	t = 1.5	$L_1(W_1)$	t = 2.0	$L_1(W_1)$	t = 3.0
1.8*	2500	-	-	-	-	-	-	-	-	-	-
2.4**	2000	2.7*	2500	-	-	-	-	-	-	-	-
		3.6**	2000	3.6*	2500	-	-	-	-	-	-
				4.8**	2000	5.4*	2500	-	-	-	-
						6	2333	-	-	-	-
						7.2**	2000**	7.2*	2500	-	-
								8	2333	-	-
								9	2125	-	-
								9.6**	2000*	-	-
										10.8*	2500
										12	2333
										13	2194
										14	2056
										14.4**	2000

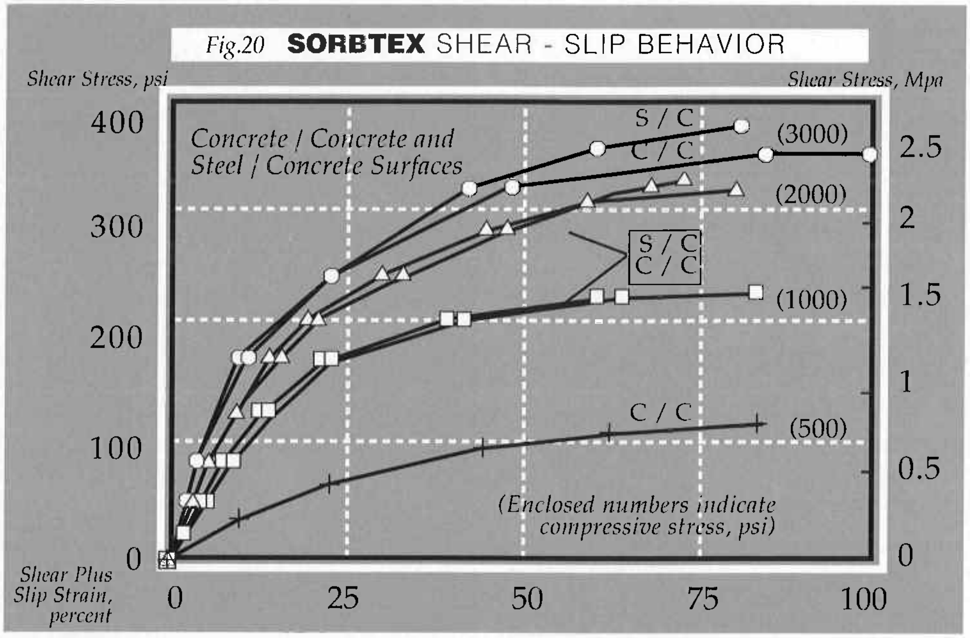


Fig.20 **SORBTEX** SHEAR - SLIP BEHAVIOR

elastomeric matrix. Although 70 percent shear plus slip strain has been recommended as a limit by PCI[4] and others, the NCHRP and AASHTO shear specifications limit deformation to 50 percent of the pad thickness. The maximum allowable shear stress, τ_s can be expressed by this relationship:

$$\tau_s = \varepsilon_s G_A \qquad (9)$$

Where: τ_s = maximum allowable shear stress, psi
ε_s = maximum shear strain of 0.50 in./in.
G_A = apparent shear modulus at shear plus slip strain of 0.50 in./in., psi

SORBTEX has been tested in shear. Fig. 20 shows the horizontal shear characteristics of SORBTEX when tested under various compressive loads and two surface conditions. These 18 tests show that the apparent shear modulus, G_A, is relatively sensitive to the compressive stress variation from 500 to 3000 psi, but insensitive to the bearing surface conditions. The G_A values at 50 percent shear plus slip strain ranged from about 400 to 1325 psi.

Friction Properties of Low Friction SORBTEX Expansion Pads

Tests were conducted on SORBTEX / recessed steel / PTFE expansion pads interfaced with a polished stainless steel to determine the friction properties between the mating surfaces as shown in the back cover. For all specimens, 1/16 in. or 1/8 in. thick, unfilled PTFE surfaces were tested against 14 gage, Type 304 stainless steel with a surface finish of about 18 microinches root- mean square (rms). This surface roughness is approximately equivalent to an average surface finish (R_a) of about 16 microinches. Friction tests were conducted at nominal compressive stresses of 500, 2000 and 3500 psi. The results of the tests are shown in Fig. A2 (on pg. 22) and tabulated along with the AASHTO minimum design requirements in the following table:

SORBTEX/Unfilled PTFE on Stainless Steel

Friction Coefficients

Performance	Bearing Pressure, psi		
	500	2000	3500
SORBTEX	0.03	0.02	0.02
AASHTO[2]	0.08	0.06	0.04

The SORBTEX coefficient of friction values listed above are provided to reflect the typical performance of the materials described and are not intended to be a design value recommendation. Voss Engineering, Inc. recommends at a minimum, AASHTO design values be used for the structure design.

In addition to the friction requirements, AASHTO also requires that the average bearing pressure on the PTFE sliding surfaces due to all loads shall not exceed 3500 psi for recessed unfilled PTFE and 2000 psi for PTFE not recessed. This AASHTO requirement lowers the allowable compression stress for SORBTEX/ PTFE and SORBTEX/ polymer/PTFE systems to 2000 psi. The average allowable compressive stress for expansion bearings designed with SORBTEX/ recessed steel/PTFE is 2500 psi.

AASHTO also requires that edge load pressure due to all loads and rotation shall not exceed 5000 psi. Using the recommended allowable average stresses, all configurations of SORBTEX expansion pads tested in the 1991 series meet this requirement.

Stability

Failure in highly-loaded, thick and narrow bearing pads is often caused by buckling rather than bulging and splitting. To ensure maximum stability, the AASHTO specifications recommend that the pad thickness, t, should relate to pad length, L, width, W or diameter, D as follows:

$$t \leq \frac{L}{3}, \frac{W}{3} \text{ or } \frac{D}{4} \qquad (10)$$

for steel reinforced Chloroprene pads

Because of the high shear resistance of SORBTEX experience and testing has shown that the additions of steel shims is not beneficial to stability. To maintain stability in SORBTEX pads, it is recommended that:

$$t \leq \frac{\text{smallest pad plan dimension}}{1.5} \qquad (11)$$

ENGINEERING

BEARING INSTALLATION

Expansion and slide bearing assemblies generally consist of upper and lower components. The upper component contains a support element such as a steel plate and a contact element such as a sheet of stainless steel or layer of PTFE. The lower component usually consists of a steel support element, an ROF elastomeric or preformed fabric pad and a contact assembly. The contact assembly can be a bonded layer of PTFE, bonded laminations of polymer and PTFE or a bonded steel plate recessed to contain a layer of PTFE. These assemblies can be installed in concrete to concrete, steel to steel and concrete to steel construction.

Fig. 34, 35 and 36 illustrate some typical methods of bearing assembly attachment. Fig. 35 shows methods of attaching bearings in concrete to concrete construction while Fig. 34 shows methods used for steel to steel attachment. Some installations require bearings which limit movement to one direction. Examples of two such designs are shown in Fig. 36. Combinations of these methods and others can be used for steel to concrete applications.

Upper Bearing Assembly

Upper bearing pad support elements are usually fabricated from ASTM Type A36 steel. Stainless steel contact surfaces when used, are made from ASTM A240 or Type 304 stainless steel and shall be at least 14 gage (0.064 in.) with a surface finish less than 16.5 microinches R_a (20 microinches, root-mean-square.) In addition to the surface roughness requirement, other PTFE contact surfaces shall have minimum Brinell Hardness of 125 (~70 Rockwell B).

Stainless steel contact surfaces should be continuously welded to the support element to prevent infiltration of moisture between the sheet and plate. The bearing area of the contact surface should be sufficiently larger than the contact area of the lower element to allow for relative movement between the elements. Contact areas of both upper and lower elements should be protected from dirt, abrasion etc. during installation. Wherever possible, the contact surfaces shall be oriented so that sliding movements will cause dirt and dust accumulation to fall from the mating surface.

Lower Bearing Assembly

The lower bearing assembly usually rests on a steel plate cast in concrete or is attached to a steel structural element. Support elements of the bearing are usually ASTM Type A36 steel, welded or bolted to the steel plate or structural element. The bearing pad/contact surface element can be either unrestrained free standing, restrained free standing, or bonded to the support element, if used.

If welding is used to attach elements with bonded PTFE surfaces, provisions must be made to ensure that the temperature in the bond area does not exceed 300°F (150°C).

When designing retainers for the lower assembly, consideration must be given to bulge and long-term creep shortening characteristics of the bearing pad. Retainers must be positioned so that there is sufficient vertical and horizontal clearances between the pad and the retainer to allow for pad lateral expansion and long-term creep shortening.

All exposed carbon steel should be painted to retard corrosion.

Lateral Cold Flow of PTFE With Laminated Expansion Bearing Pads

As elastomeric pads compress from applied vertical loads, the pads expand laterally. When the elastomeric material is laminated to a low-friction PTFE system, the PTFE material also expands laterally unless a special polymeric material separates the elastomeric pad from the PTFE material. This cold flow within the PTFE can create long-term durability problems, particularly when the PTFE does not recover its lateral cold flow strain. During the test program, the lateral cold flow characteristics of PTFE bonded to plain SORBTEX, to SORBTEX with a polymer, to FIBERLAST and to FIBERLAST with a polymer were measured. The results of these uniform compression tests are shown in Fig. A4 (on Pag 22). The test data indicate that the polymer layer dramatically reduces the lateral cold flow behavior of the PTFE when bonded to SORBTEX or FIBERLAST.

The design engineer should consider the expected lateral strain in the design bearing when considering the use of a polymer substrate. If the edge strain of a FIBERLAST / Polymer / PTFE pad under rotation exceeds about 15 percent, a piece of 10 gage stainless steel should be used in place of the polymer.

References

1. Fiberlast--The Omni Direction Bearing Pad of Tomorrow, Voss Engineering, Inc., Chicago, Illinois, 1989, 14 pages

2. Standard Specifications for Highway Bridges, Division 1, Section 14 and 15; Division 2, Sections 25 and 27, American Association of State Highway and Transportation Officials (AASHTO), Fourteenth Edition, 1989

3. National Cooperative Highway Research Program Report 298, "Performance of Elastomeric Bearings, Transportation Research Board, October, 1987

4. Pfeifer, D. W. and Iverson, J. F., "Bearing Pads for Precast Concrete Buildings," PCI Journal, September/October, 1985

5. "PCI Design Handbook-Precast and Prestressed Concrete," Prestressed Concrete Institute,Third Edition, 1985

6. National Cooperative Highway Research Project Report 248, "Elastomeric Bearings-Design,Construction and Materials," Transportation Research Board, August, 1982

7. Roeder, C. W. and Stanton, J.F., "State-of-the Art Elastomeric Bridge Bearing Design," ACI Structural Journal, Vol. 88, No. 1, January-February, 1991

8. Iverson, James K. and Pfeifer, Donald W., "Criteria for Design of Bearing Pads," Technical Report No. 4, Prestresseed Concrete Institute, June, 1985

9. Military Specification MIL-C-882E, 27 January 1989," Cloth, Duck, Cotton or Cotton-Polyester Blend, Synthetic Rubber Impregnated and Laminated, Oil Resistant."

10. Interim Specifications - Bridges - 1990, American Association of State Highway and Transportation Officials

Voss

ENGINEERING

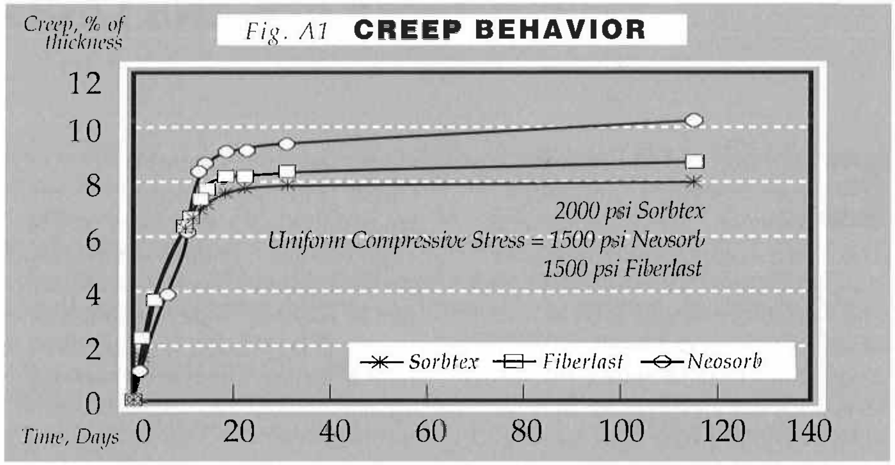


Fig. A1 **CREEP BEHAVIOR**

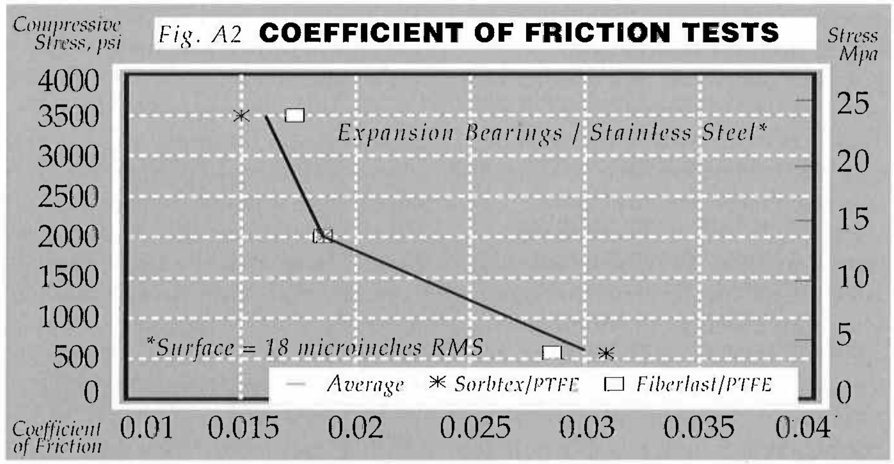


Fig. A2 **COEFFICIENT OF FRICTION TESTS**

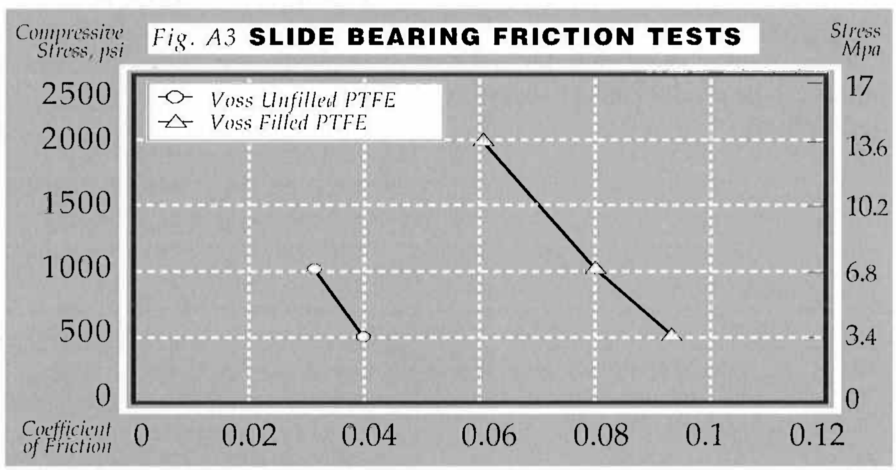


Fig. A3 **SLIDE BEARING FRICTION TESTS**

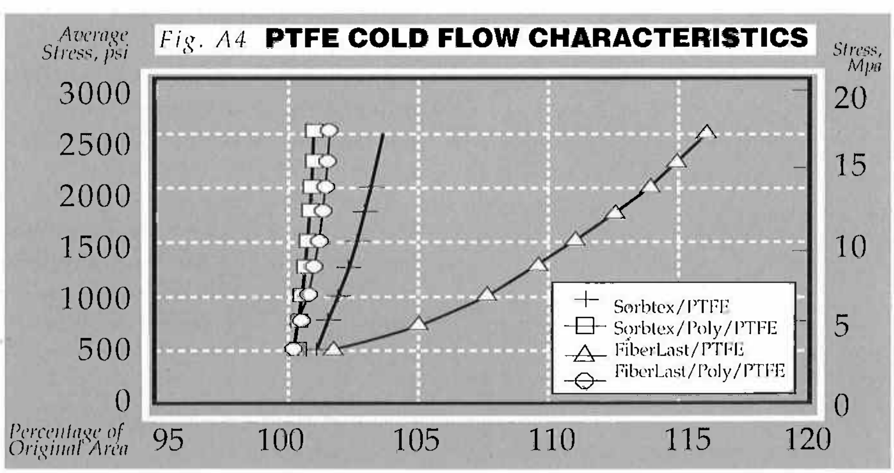


Fig. A4 **PTFE COLD FLOW CHARACTERISTICS**

DESIGNED & PRODUCED BY J. UHLIR DESIGN, HARVARD, IL

EXPANSION BEARING CONCEPTUAL DESIGN DETAILS

Fig.34 **STEEL TO STEEL**

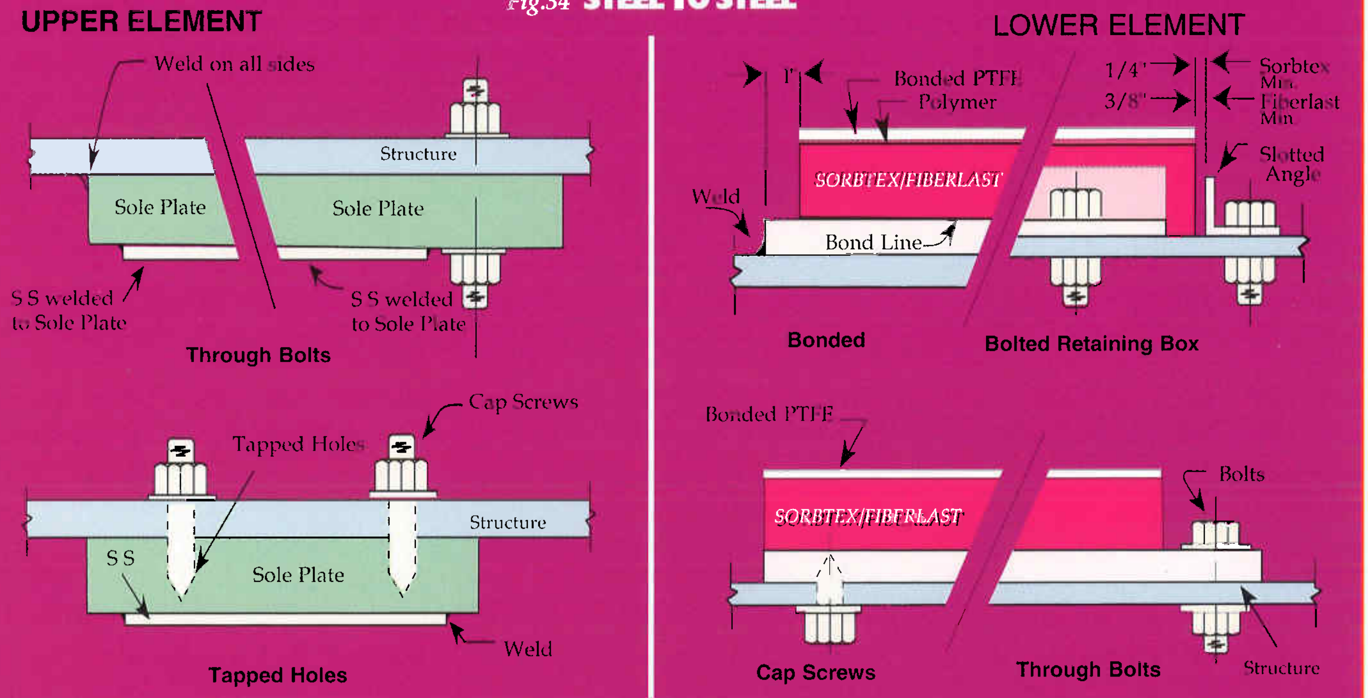


Fig.35 **CONCRETE TO CONCRETE**

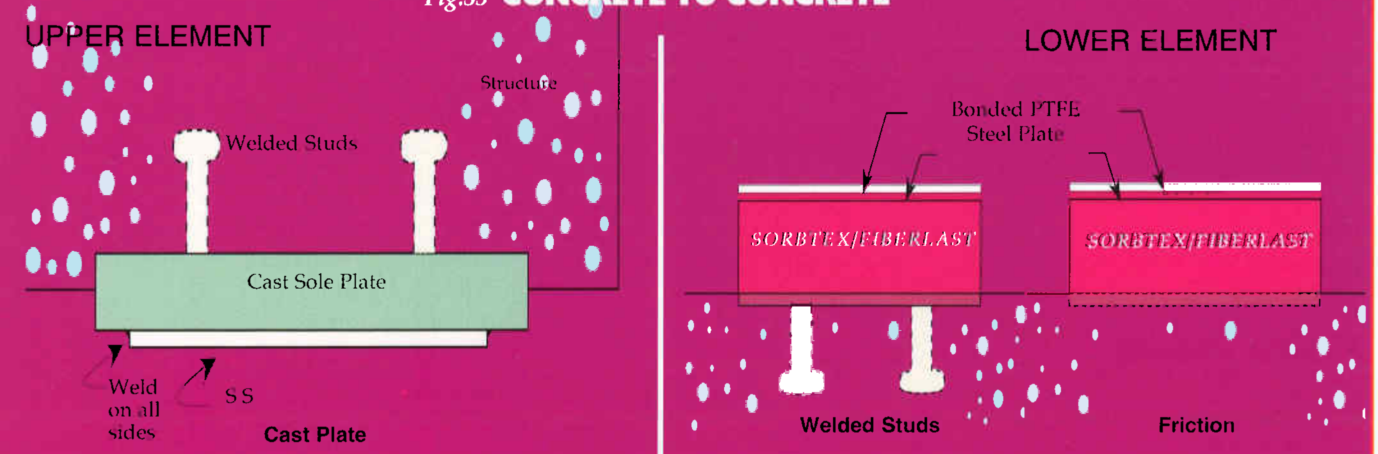


Fig.36 **LATERAL RESTRAINT**