Performance of Sliding Bridge Bearings

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ABSTRACT

An experimental program to evaluate the performance of sliding bridge bearings is described. Tests were conducted in a fixture specially constructed to simulate actual field conditions. Vertical load, up to 250 kips, was applied through a roller nest to the top flange of a 33-in.-deep girder directly over the test bearing. A closed-loop hydraulic testing system was used to apply the horizontal (friction) force. Data were accumulated and processed in real time using a microcomputer-based data acquisition system. Results are presented for three types of tetrafluoroethylene (TFE) elements on two steel surfaces with two backing types, and for new and used self-lubricating bronze expansion bearings. Comparison of results with published design recommendations shows that the recommendations are not conservative for certain TFE-type bearings but are adequate for self-lubricating bronze expansion bearings.

The purpose of this study was to determine experimentally the effective coefficient of friction of two classes of sliding bridge bearings--tetrafluoroethylene (TFE) and self-lubricating bronze expansion bearings. Both new bearings and bearings removed after approximately 20 years of service were used in the testing program.

From previous research (1) it was known that few studies of the behavior of complete bearing assemblies have been conducted and that specification provisions have been based on classic values of coefficients of friction between sliding parts without regard to effects of manufacturing tolerances or environmental effects. This study was an attempt to assess these effects and to provide guidelines to establish accurate estimates of horizontal force requirements for the type of bearings tested. The TFE bearing tests were conducted under sponsorship of the Research Division of the Oklahoma Department of Transportation (ODOT) and the self-lubricating bronze expansion bearing tests under the sponsorship of the Engineering Department Materials Division, the Port Authority of New York and New Jersey.

For the purpose of this study the effective coefficient of friction, μ_{eff}, is defined as

$$\mu_{eff} = F/N \quad (1)$$

where F is horizontal force to overcome the resistance to allow motion and N is normal force applied to the bearing. The value of F was determined experimentally for the entire assembly for an applied normal force, N, from which μ_{eff} is calculated.

BACKGROUND

Few experimental studies of full-scale bridge bearings using simulated field conditions were found in the course of a thorough literature review (1). Specification requirements seem to have been developed from classic values of friction coefficients or from test setups normally used for quality control (small specimens loaded using standard testing machines). Only two significant papers on TFE bearings were found and none on self-lubricating bearings.

Jacobson (2) has conducted experimental work to investigate the potential use of TFE as a sliding surface. He concludes that TFE bearings are suitable for use in highway bridges but recommends that only unfilled TFE be used for bridge bearings. A substantial increase in the coefficient of friction for filled TFE was found after 7,000 cycles of testing. The use of 15-25 percent glass filler resulted in a 35-50 percent increase in the values for the coefficient of friction under applied normal loads between 200 and 800 psi. He also tested several fabric-backed specimens with filled TFE surfaces that failed by delamination of the fabric pad. He concludes that the fabric-backed materials are suitable only when used in conjunction with unfilled TFE.

Taylor (3) has found that the coefficient of friction of polymerized tetrafluoroethylene (PTFE) is influenced by a number of parameters, including pressure across sliding surfaces, rate of movement, presence or absence of lubrication, previous loading and movement history, and temperature. Most of the tests were made on unlubricated and unfilled PTFE. The maximum value of the coefficient of friction of all unlubricated bearings occurred during the first cycle of movement. The coefficient of friction decreased with higher compressive stress across the bearing, but increased slightly at lower temperature. He discusses the theory of the real area of intimate contact between the PTFE and slider, and the shear force required to break the junctions in these areas.

For unspecified reasons, in Recommended Design Loads or Bridges (4), the following recommendations to replace the last paragraph of Article 1.2.13 of the AASHTO specification (5) are made:

> The longitudinal force due to friction at expansion bearings or shear resistance at elastomeric bearings shall also be provided for in the design as follows. For sliding type bearings, this force shall be based on the following percentages of the dead load supported:
>
> | Bearing Type | Average Static Friction Coefficient |
> |---|---|
> | Steel bearing on steel | 0.2 |
> | Steel bearing on self-lubricating bronze plate | 0.1 |
> | Polytetrafluorethylene (PTFE) on polytetrafluorethylene or stainless steel | 0.06 |
>
> For rocker type bearings, this force shall be based on a 20% friction coefficient on the pin, and shall be reduced in

proportion to the radii of the pin and the rocker ... (4,p.1173).

SCOPE OF STUDY

The results of two series of tests on sliding bridge bearings are reported. Tests of typical TFE bearings were conducted to determine the effects of varying amounts of glass fiber, size of contact area, type of backing element, and nonparallel conditions on the effective coefficient of friction. All tests were done at room temperature (approximately 70°F) and no lubrication was used. In addition, tests of both new and used self-lubricating bronze expansion bearings were conducted. Both flat plate and curved plate bearings were tested at room temperature.

To achieve confidence in the experimental results, several increments of normal load were used and at least three tests were conducted at each load level for each bearing.

TEST DETAILS

To determine the experimental coefficient of friction of bridge bearings, a test setup that simulates an actual bridge was built as shown in Figures 1 and 2. The normal force is applied with a 750,000-lb-capacity hydraulic ram and the horizontal force with a 55,000-lb-capacity closed-loop hydraulic testing system. The data are recorded using a microcomputer system.

The test setup was erected inside the Fears Structural Engineering Laboratory on the laboratory reaction floor. The floor is a concrete slab 30 ft x 60 ft x 3 ft 6 in. deep with four W36x150 steel beams embedded in the concrete. The slab weighs 1 million lb and is capable of reacting 320,000 lb in any one location. The setup was erected directly over two of the embedded W36 beams spaced 8 ft apart. The setup consisted of three parts: (a) an H-frame (Figure 1) that was designed for 250,000 lb maximum vertical reaction and that supported the hydraulic ram, (b) a triangular frame (Figure 2) that was designed for 55,000 lb maximum horizontal reaction and that supported the closed-loop hydraulic testing system, and (c) a W33x130 15-ft-long girder, which simulated the actual bridge girder.

The vertical load chain consisted of the H-frame, hydraulic ram, load cell, swivel head, roller nest with a known effective coefficient of friction, a steel plate with a highly polished surface, the simulated bridge girder, the test bearing, a steel reaction plate, and the reaction floor, as shown in Figure 1. The horizontal load chain consisted of the triangular frame, the actuator of the closed-loop hydraulic testing system, the load cell, a loading linkage to prevent out-of-plane forces, and the simulated girder, as shown in Figure 2. Lateral brace mechanisms were used to stabilize the girder against out-of-plane rotations and a pipe roller was used to support the unloaded end of the bridge girder.

Instrumentation consisted of the two calibrated load cells, a horizontal displacement transducer, an analog-to-digital signal converter, and a microprocessor. The applied normal force was measured using the calibrated 300,000-lb-capacity load cell; the horizontal force was measured using the calibrated 100,000-lb-capacity load cell; and the horizontal movement (girder movement) was measured using a calibrated transducer that is part of the closed-loop hydraulic testing system.

The analog signals from the three instruments were digitized using a 16-channel differential input AC/DC converter with direct interface to the micro-

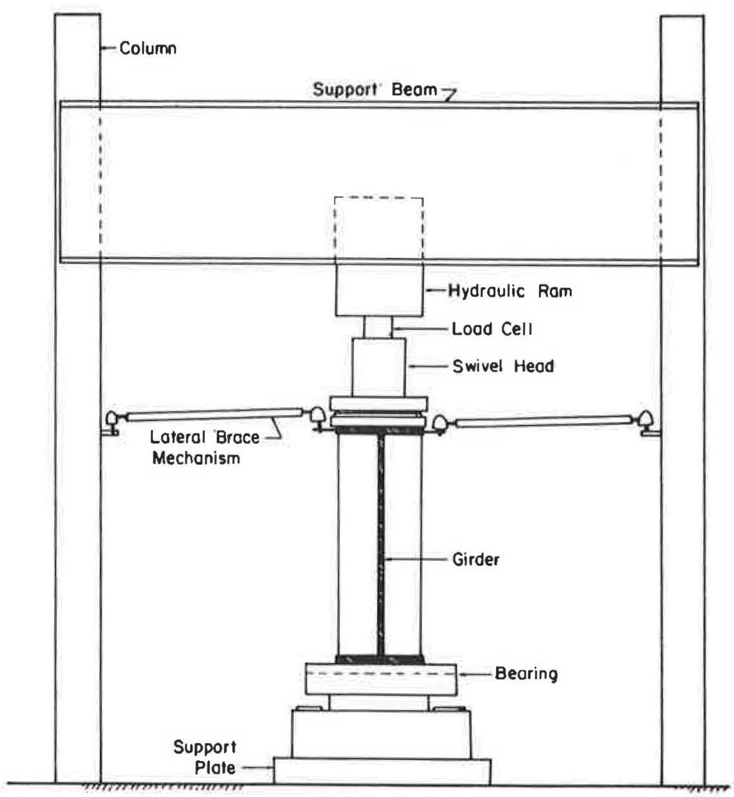

FIGURE 1 Vertical load chain.

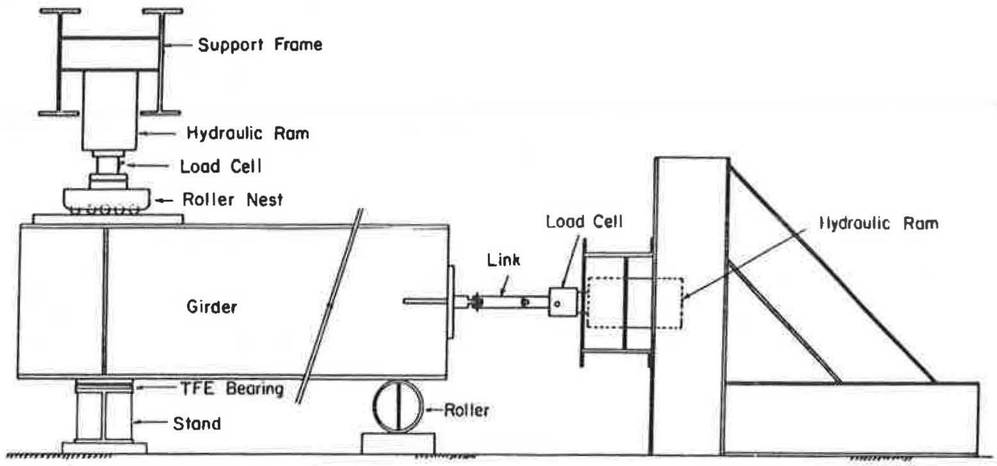

FIGURE 2 Side view of test setup.

processor. The microprocessor was used to reduce and plot the data in real time. In this manner, changes in normal force due to uncontrollable vertical movement in the vertical force chain were accounted for, and the instantaneous relationship of the two force and one displacement variables was known.

The microprocessor was programmed to account for the coefficient of friction of the roller nest, for the effects of the weight of the girder and other test setup parts not accounted for by the load cell in the vertical load chain, and for uplift effects caused by the horizontal force couple. In Figure 2 it can be seen that a force couple results from the application of the horizontal force and the resisting force at the bearing sliding surface. This couple tends to reduce the applied normal force at the bearing.

Tests of each TFE bearing assembly were conducted at nominal contact pressures ranging from 200 to 6,000 psi depending on the configuration. Tests of the self-lubricating bearings were conducted at nominal load increments of 25 kips starting at 175 kips and decreasing to 50 kips. A second test series was then conducted at 175 kips. At each normal force level three tests were conducted.

Approximately 100 data sets (each set consisted of two force readings and one displacement reading) were recorded for each test. The effective coefficient of friction was automatically calculated by the microprocessor taking into account the initial force on the bearing due to the weight of the system, the horizontal force-couple effect, and the effective coefficient of friction of the roller nest. The graphics capabilities of the microprocessor system were used to plot results. Typical plots for TFE and self-lubricating expansion bearing tests are shown in Figure 3. Normal forces vary from the nominal load increments because of uncontrollable vertical movement as the girder is pulled. These changes are recorded by the microprocessor. The normal force corresponding to the maximum horizontal force is used to calculate the effective coefficient of friction for the test. The initial linear displacement is caused by elastic deformation of the test fixtures and does not affect test results.

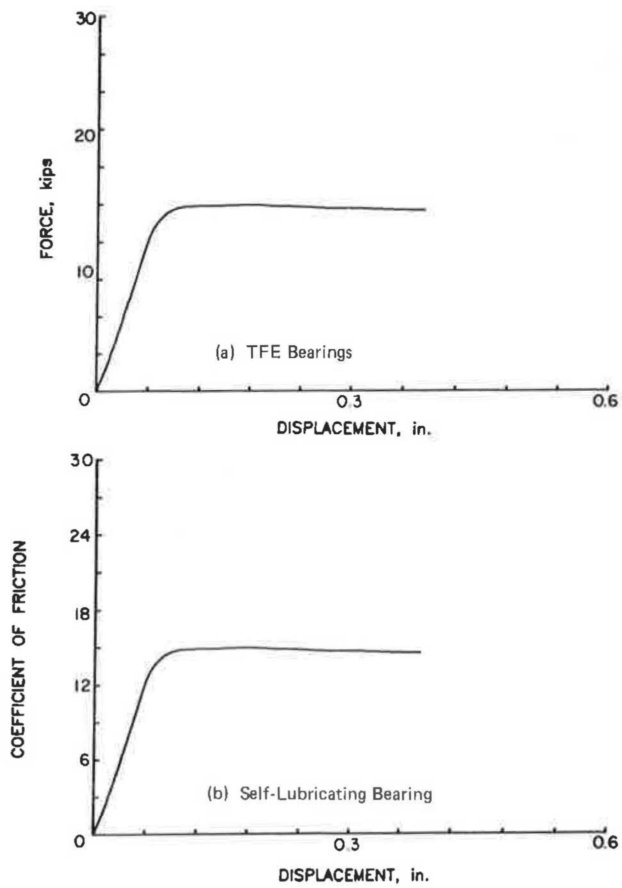

FIGURE 3 Typical horizontal movement versus friction force plots.

TEST RESULTS FOR TFE EXPANSION BEARINGS

In this study, three types of TFE elements (unfilled, 25 percent glass filled by weight, and woven unfilled and glass-filled fibers), two steel surfaces (stainless steel and mirror-finish stainless), and two backings (carbon steel plate and 70 Durometer elastomeric material vulcanized to a steel plate) were tested in appropriate combinations. Table 1 gives the seven element types and Table 2 gives the eight combinations tested. In each test the bottom element was tack welded to the stand (Figure 2) and the top element was tack welded to the girder so that movement could occur only between the element surfaces. The interface was moved at least 0.15 in. horizontally in a direction parallel

TABLE 1 TFE Test Elements

Element No.	Description
1	3/32" Glass filled* TFE bonded to 1/4" A-3 carbon steel
2	3/32" Glass filled* TFE, mechanically locked to 1/4" carbon steel
3	1/4" Mirror finish stainless steel
4	3/32" Glass filled* TFE bonded to #10 gage carbon steel hot vulcanized to 3/4" 70 Durometer AASHTO grade neoprene
5	1/16" Unfilled TFE bonded to 1/4" carbon steel
6	Unfilled TFE fibers and glass fibers woven and bonded to 1/4" carbon steel
7	1/8" Stainless steel

*Glass filled 25% by weight

TABLE 2 TFE Test Element Combinations

Test Series	Top Element	Bottom Element
I	Glass Filled TFE (#1)	Glass Filled TFE (#1)
II	Mirror Finish Stainless Steel (#3)	Glass Filled TFE (#1)
III	Glass Filled TFE (#2)	Mirror Finish Stainless Steel (#3)
III-A	Unfilled TFE (#3)	Mirror Finish Stainless Steel (#3)
IV-N	Glass Filled TFE (#1)	Glass Filled TFE w/Neoprene Backing (#4)
V	Woven TFE (#6)	Mirror Finish Stainless Steel (#3)
VI-N	Stainless Steel (#7)	Glass Filled TFE (#1)
VII-N	Unfilled TFE (#5)	Glass Filled TFE (#1)

N - nonparallel

to the short side of the elements at a speed of 1 in. per minute.

Tests were conducted in either parallel or nonparallel conditions. For the former, the girder and rigid stand were leveled as accurately as possible. For the nonparallel condition, the girder was shimed so that a 1/32 in. per foot (0.15 degree) slope was induced. Contact area between elements was varied for Test Combination I (glass-filled TFE versus glassfilled TFE) only. Table 3 gives the complete variation of test parameters. All tests were done at room temperature (approximately 70°F) on new elements (0 cycle). The effect of dirt or sand in the interface was not investigated.

Effect of Contact Area and Contact Pressure

To determine the effect of contact area on the effective coefficient of friction, a series of tests was conducted using Test Combination I, glass-filled TFE versus glass-filled TFE. Contact area was varied from 20 in.^{2} (Tests I-20) to 100 in.^{2} (Tests I-100) and contact pressure was varied from 250 to 2,000 psi. The average coefficient of friction from at least three tests for each combination of area and pressure is shown plotted in Figure 4.

It is clear from Figure 4 that contact area has little effect on the effective coefficient of friction. However, the effective coefficient of friction for this combination was found to decrease with increasing contact pressure. At low contact pressure, 250 psi, the effective coefficient of friction is approximately 10 percent, decreasing sharply to approximately 8.25 percent at 500 psi and then at a slower uniform rate to approximately 6.75 percent at 2,000 psi. Because of these results only contact pressure was varied in subsequent testing.

TABLE 3 Summary of Test Combinations

Series	Top Element	Bottom Element	Dimension (in)	Contact Area (in^2)	Parallel*
I-20	#1	#1	3 x 6.6	20	no
I-40	#1	#1	5 x 8	40	no
I-60	#1	#1	6 x 10	60	no
I-100	#1	#1	8.7 x 11.5	100	no
I	#1	#1	2.93 x 7	20.5	yes
I-N	#1	#1	2.93 x 7	20.5	no
II	#3	#1	5 x 8.91	44.55	yes
II-N	#3	#1	5 x 8.91	44.55	no
III	#2	#3	5.45 x 9.4 4.2 x 7.6	51.8 31.90	yes
III-A	#5	#3	5 x 9	45	yes
IV-N	#1	#4	5 x 8.91	44.55	no
V	#6	#3	4.9 x 9	44.1	yes
VI-N	#7	#1	6 x 10	60	no
VII-N	#5	#1	4.9 x 9	44.10	no

*Yes - Parallel Interface
No - Nonparallel (1/32" per 12" slope) Interface (N)

Results for Glass-Filled TFE Versus Glass-Filled TFE

Twenty-two tests were conducted using glass-filled TFE elements, top and bottom. The contact area for all tests was 20.5 in.^{2} and the contact pressure was varied from nominally 200 psi to 2,000 psi. The effective coefficient of friction was found to de-

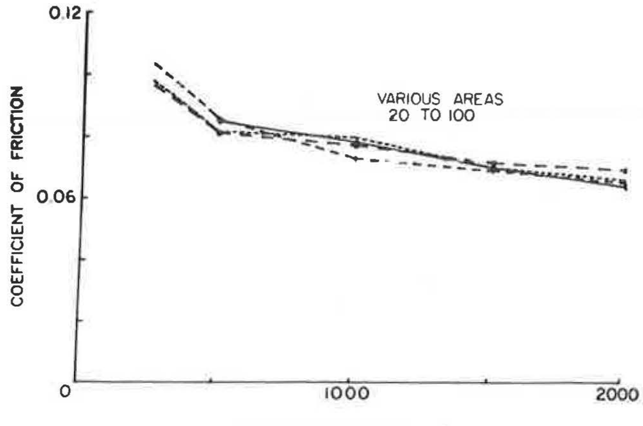

FIGURE 4 Coefficient of friction versus vertical pressure with variation of contact area (Series I).

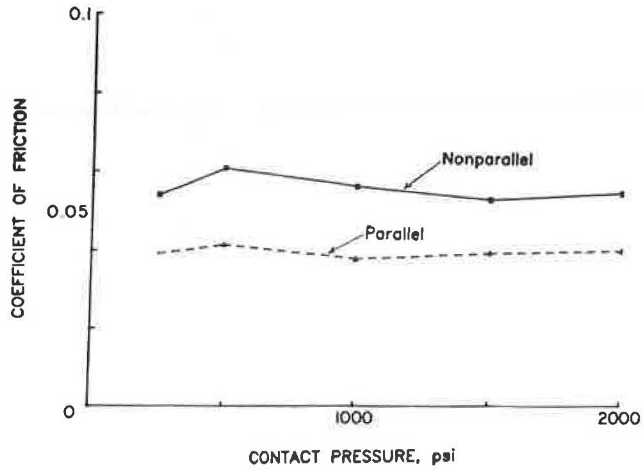

FIGURE 6 Coefficient of friction versus contact pressure, mirror-finish stainless steel versus glass-filled TFE (Series II).

crease abruptly from 5.5 to 3.6 percent between 500 and 1,000 psi and then to increase gradually to 3.9 percent at 2,000 psi as shown in Figure 5, Test Series I (parallel).

Test Series I was repeated with nonparallel interfaces with the results shown in Figure 5. Both the magnitude and relationship to contact pressure of the effective coefficient of friction were influenced by the nonparallel interface. When the nonparallel interface was used, the effective coefficient of friction increased approximately 50 percent.

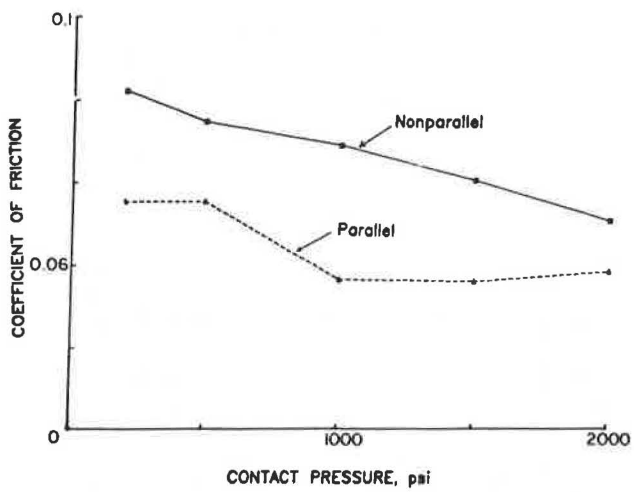

FIGURE 5 Coefficient of friction versus contact pressure, glass-filled TFE versus glass-filled TFE (Series I).

Test with Mirror-Finish Stainless Steel

Test Series II, III, III-A, and V were conducted with one TFE element and one mirror-finish stainless steel element. Glass-filled TFE was used for Series II and III, unfilled TFE for Series III-A, and woven TFE for Series V. Both parallel and nonparallel interfaces were used in Test Series II and III.

Figure 6, Series II test results, shows the effect of nonparallel interfaces on the effective coefficient of friction. The average increase is approximately 40 percent for a slope of 1/32 in. per foot. From Figure 6 it is clear that contact pressure has little effect on the coefficient of friction of glass-filled TFE sliding on mirror-finish stainless steel.

Test Series III varied from Series II only in that the mirror-finish stainless steel element was placed on the bottom and glass-filled TFE mechanically locked to a 1/4-in.-thick steel plate was used for the upper element. This type of TFE element has a significantly higher allowable contact pressure than does glass-filled TFE bonded to carbon steel plates, 6,000 psi versus 2,000 psi. Only the parallel condition was tested. For this series, the effective coefficient of friction decreased slightly with increasing contact pressure from approximately 4 percent at 1,000 psi to 3 percent at 6,000 psi.

Test Series III-A was identical to Series III except that the top element was unfilled TFE bonded to 1/4-in.-thick carbon steel. The allowable contact pressure for this combination was 5,000 psi. A significant decrease in the effective coefficient of friction, compared to Series III, was found. The effective coefficient of friction using the unfilled TFE element is approximately 64 percent of that for the glass-filled TFE element. Little effect was found when the contact pressure was varied from 1,000 to 5,000 psi (2.6-2.2 percent).

Unfilled TFE fibers and glass fibers woven and bonded to 1/4-in.-thick carbon steel were used as the top element in Test Series V. The bottom element was mirror-finished stainless steel. The allowable contact pressure for this combination was 2,000 psi. The effective coefficient of friction was found to be essentially the same as that for unfilled TFE versus mirror-finish stainless steel, Series III-A.

Miscellaneous TFE Tests

Test Series IV-N was conducted using glass-filled TFE bonded to 1/4-in.-thick carbon steel as the top element and glass-filled TFE bonded to No. 10 gauge carbon steel hot vulcanized to 3/4-in.-thick 70 Durometer AASHTO grade neoprene as the bottom element. This combination was tested in the nonparallel condition with a limiting contact pressure of 500 psi. The effective coefficient of friction varied from 9.2 to 6.8 percent when the contact pressure was varied from nominally 250 psi to 500 psi.

Test Series VI-N used an unfinished stainless steel top element and a glass-filled TFE bottom ele-

TABLE 4 Summary of TFE Expansion Bearing Test Results

Test No.	Elements	Parallel	Average Effective Coefficient of Friction				
			250 psi	500 psi	1000 psi	1500 psi	2000 psi
I-60-N	Glass Filled TFE vs Glass Filled TFE	no	0.096	0.081	0.077	0.072	0.070
I	Glass Filled TFE vs Glass Filled TFE	yes	0.055	0.055	0.037	0.036	0.039
I-N	Glass Filled TFE vs Glass Filled TFE	no	0.082	0.075	0.069	0.061	0.051
II	Glass Filled TFE vs Mirror Finish Stainless Steel	yes	0.039	0.041	0.038	0.039	0.040
II-N	Glass Filled TFE vs Mirror Finish Stainless Steel	no	0.054	0.061	0.056	0.053	0.055
III	G.F. Mechanically Locked TFE vs Mirror Finish Stainless Steel	yes	-	-	0.040	-	0.042[1]
III-A	Unfilled TFE vs Mirror Finish Stainless Steel	yes	-	-	0.026	-	0.024[2]
IV-N	Glass Filled TFE vs Glass Filled TFE with Neoprene	no	0.092	0.068	-	-	-
V	Woven TFE and Glass vs Mirror Finish Stainless Steel	yes	0.025	0.022	0.026	0.020	0.020
VI-N	Glass Filled TFE vs Stainless Steel	no	0.123	0.102	0.082	0.077	0.075
VII-N	Unfilled TFE vs Glass Filled TFE	no	0.069	0.062	0.059	0.053	0.056

*Minimum of 3 tests.
1. Tested to 6000 psi: 0.040 @ 3000 psi, 0.031 @ 4000 psi, 0.030 @ 5000 psi, 0.031 @ 6000 psi
2. Tested to 5000 psi: 0.024 @ 3000 psi, 0.021 @ 4000 psi, 0.022 @ 5000 psi

ment. The series was conducted in the nonparallel condition and the contact pressure was limited to 2,000 psi. The effective coefficient of friction was found to be higher than that for any other combination, as high as 12.3 percent, and was found to vary considerably with contact pressure, 12.3 percent at 275 psi to 7.5 percent at 2,000 psi.

Test Series VII-N was conducted with an unfilled TFE top element and a glass-filled TFE bottom element in the nonparallel condition with a limiting contact pressure of 2,000 psi. The effective coefficient of friction varied from 6.9 percent at 250 psi to 5.3 percent at 1,500 psi to 5.6 percent at 2,000 psi.

Summary of TFE Tests

A summary of all TFE expansion bearing tests is given in Table 4. The average effective coefficient of friction from at least three tests for each contact pressure in the range 250-2,000 psi is shown. The highest values were found for the lowest contact pressure and the lowest for the highest contact pressure. Values varied from 12.3 to 2.0 percent.

A comparison of the results for the four most commonly used element combinations is shown in Figure 7: glass-filled TFE versus stainless steel, glass-filled TFE versus glass-filled TFE, glass-filled TFE versus mirror-finish stainless steel, and unfilled TFE versus mirror-finish stainless steel. The effective coefficient of friction decreases with increasing contact pressure for all combinations. The highest values were obtained for glass-filled TFE versus stainless steel and the lowest for unfilled TFE versus mirror-finish stainless steel. For contact pressure greater than 500 psi, the effective coefficient of friction does not vary with contact pressure. Note that Figure 7 shows results for parallel and nonparallel conditions.

In all of the tests, the lowest effective coefficient of friction was found for the combination of

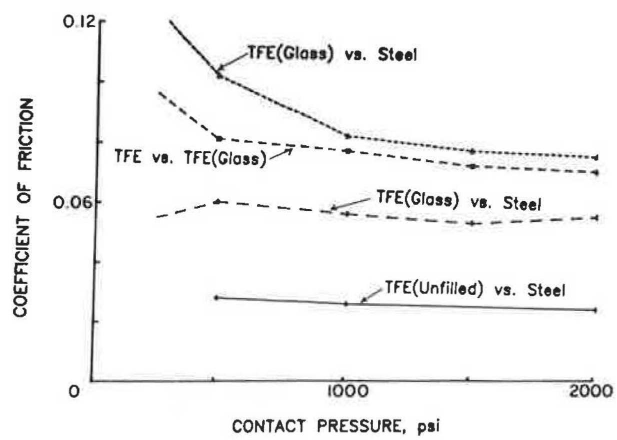

FIGURE 7 Comparison of results for various TFE elements.

unfilled TFE fibers and glass fibers woven and bonded to carbon steel versus mirror-finish stainless steel. However, when tests using the nonparallel condition were attempted, the woven element tended to dig into the opposite element causing damage and a very high effective coefficient of friction. Consequently, this combination is not recommended unless a perfectly parallel interface can be guaranteed.

TFE bearings backed with rubber (neoprene) are commonly recommended for nonparallel surfaces. Test Series IV-N was conducted using 3/32-in.-thick glass-filled TFE bonded to No. 10 gauge carbon steel that in turn was hot vulcanized to 3/4-in.-thick 70 Durometer AASHTC grade neoprene versus 3/32-in.-thick glass-filled TFE bonded to 1/4-in.-thick carbon steel. The bearing was tested at 250, 500, and 700 psi contact pressure. At 700 psi, the allowable contact pressure, the neoprene failed with a substantial increase in effective coefficient of friction. A possible cause was poor-quality neoprene.

TEST RESULTS FOR SELF-LUBRICATING BRONZE EXPANSION BEARINGS

Two types of bearings were used in this portion of the study (6): flat plate and curved plate. Details are shown in Figure 8. Each bearing consists of three parts: a machined steel base plate, a machined bronze plate, and a machined steel sole plate. The bronze plate contains recesses on both sides that are filled with a solid lubricant applied under heat and pressure. The recesses are arranged in a geometric pattern so that overlap in the direction of movement is achieved. The total area of the recesses is approximately 50 percent of the total surface area of the bronze plate.

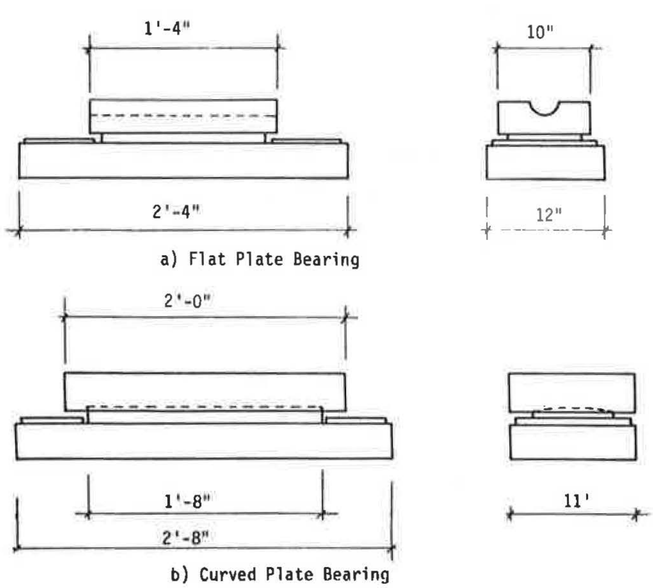

FIGURE 8 Self-lubricating bronze expansion bearings used in testing.

The flat plate bearing used in the testing program is only part of the entire bearing assembly. A separate pin and upper bearing plate are normally provided to permit rotation at the bearing location. Longitudinal expansion is accommodated through movement of the bronze plate. Because of the configuration of the test setup used in this research, the lack of rotation capability in the flat bearings did not affect test results. The curved plate bearing provides allowance for both expansion and rotation.

One new and two used bearings of each type were tested for a range of normal forces. The four used bearings were removed from a bridge after 20 years of service. The two new bearings were manufactured to specifications identical to those of the used bearings.

All bearings were initially tested at a nominal normal force of 175 kips. Subsequent tests were conducted in decreasing increments of nominally 25 kips to 50 kips. A final test at 175 kips was then conducted At each normal force level three tests were conducted. For the first two tests, the bridge girder was carefully positioned so that the centerline of the sole plate was directly over the centerline of the bearing plate. The girder was then pulled approximately 0.35 in. toward the horizontal reaction frame. For the third test, the centerline of the sole plate was positioned 1 in. beyond the centerline of the bearing plate and then the girder was pulled toward the horizontal reaction frame. Travel was again approximately 0.35 in. To check this procedure, in two tests the centerline of the sole plate was positioned 1 in. beyond the centerline of the bearing plate and the girder pulled 2 in. toward the horizontal reaction frame. The original procedure was found to be adequate.

Results of the 123 tests are summarized in Tables 5, 6, and 7 and are discussed in the following paragraphs. A more complete description of the test results is found in Mazroi et al. (6).

Curved Plate Bearing Test Results

For the new curved plate bearing, the maximum effective coefficient of friction was obtained in the first test (nominal normal force of 175 kips). The effective coefficient of friction then decreased with decreasing load until 75 kips normal force, whereupon the values increased slightly. For the used curved plate bearing No. 1, a somewhat similar pattern was found; however, the effective coefficient of friction values for this bearing were lower than those for the new bearing. For the used curved plate bearing No. 2, the effective coefficient of friction values decreased until the nominal normal force was decreased to 100 kips and then increased. The highest value obtained in any test was 0.1232 (new bearing, Test 1) and the lowest was 0.0561 (curved plate bearing No. 1, Test 4) (Table 5). The average value for all tests was 0.0905 with a standard deviation of 0.0171 (Table 6).

Flat Plate Bearing Test Results

The maximum effective coefficient of friction for this bearing type was from the first test of flat plate bearing No. 2. For all three bearings, the effective coefficient of friction decreased with decreasing normal force until 100 ± 25 kips was reached and then the coefficient increased slightly. The highest value obtained in any test was 0.1772 (flat plate bearing No. 2, Test 1) and the lowest

TABLE 5 Highest, Average, and Lowest Results of Expansion Bearing Tests

	Effective Coefficient of Friction		
Bearing	Highest	Average	Lowest
Curved Plate			
New	0.1232	0.0946	0.0831
No. 1	0.1023	0.0711	0.0561
No. 2	0.1206	0.1052	0.0907
All	0.1232	0.0905	0.0561
Flat Plate			
New	0.1334	0.0961	0.0869
No. 1	0.1150	0.1004	0.0867
No. 2	0.1772	0.0833	0.0643
All	0.1772	0.0933	0.0643
All Tests	0.1772	0.0919	0.0561

TABLE 6 Summary of Expansion Bearing Test Results

Bearing	Average Effective Coefficient of Friction	Standard Deviation	Coefficient of Variation	Least Square Method	
				Slope	Intercept
Curved Plate					
New	0.0946	0.0090	0.000077	0.1001	-0.636
No. 1	0.0711	0.0115	0.000125	0.0754	-0.523
No. 2	0.1052	0.0094	0.000084	0.0931	1.231
All	0.0905	0.0171	0.000089		
Flat Plate					
New	0.0961	0.01083	0.000110	0.1094	-1.425
No. 1	0.1004	0.00877	0.000073	0.1093	-0.944
No. 2	0.0833	0.02510	0.000599	0.1232	-4.166
All	0.0933	0.01785	0.000313		
All Tests	0.0919	0.01747	0.000303		

TABLE 7 Summary of Expansion Bearing Test Results Excluding First Test of Each Bearing

Bearing	Average Effective Coefficient of Friction	Standard Deviation	Coefficient of Variation
Curved Plate			
New	0.0934	0.00666	0.000042
No. 1	0.0695	0.00905	0.000078
No. 2	0.1052	0.00966	0.000088
All	0.0895	0.01682	0.000278
Flat Plate			
New	0.0942	0.00641	0.000039
No. 1	0.0996	0.00830	0.000065
No. 2	0.0784	0.01223	0.000142
All	0.0907	0.01288	0.000163

was 0.0643 (flat plate bearing No. 2, Test 11) (Table 5). Both the high and the low values occurred with bearing No. 2. The average value for all tests was 0.0933 with a standard deviation of 0.01785 (Table 6).

Summary of Self-Lubricating Bearing Tests

For all tests the highest effective coefficient of friction found was 0.1772 and the lowest was 0.0561. The average value for all flat plate bearings was 0.0905, for all curved plate bearings 0.0933, and for all bearings 0.0919. The corresponding standard deviations are 0.0171, 0.01785, and 0.01747. Hence, the expected effective coefficient of friction for all bearings 95 percent of the time is approximately 0.09 ± 0.02.

The effective coefficient of friction for the first test of each bearing was, in general, higher than that for the remaining tests. Table 7 gives average values, standard deviations, and coefficients of variation for the test results excluding the first test of each bearing. From this data the expected effective coefficient of friction 95 percent of the time is approximately 0.09 ± 0.01. Insignificant difference was found between old and new bearings.

SUMMARY

From test results of various TFE expansion bearing configurations, the effective coefficient of friction was found to be less consistent when both elements were TFE, as opposed to one element being mirror-finish stainless steel. The highest values of effective coefficient of friction were obtained for glass-filled TFE versus stainless steel (7.5-12.3 percent) and the lowest for unfilled TFE fibers and glass fibers woven versus mirror-finished stainless steel (2.1-2.6 percent). Tests using a nonparallel condition showed that the effective coefficient of friction increases about 50 percent for only 1/32 in. per foot (0.15 degree) slope.

The effective coefficient of friction, in general, was found to decrease with increasing contact pressure. However, the change was found to be very small when the contact pressure was 50 percent or greater of the maximum contact pressure, except for Series I-N (glass-filled TFE versus glass-filled TFE with nonparallel interfaces) where the coefficient of friction continued to decrease and Series V (unfilled TFE fibers and glass-filled fibers woven versus mirror-finish stainless steel) where little change was found as the contact pressure was varied.

The results of this study show that the recommendation in Recommended Design Loads for Bridges (4), that the design longitudinal force due to friction at sliding expansion bearings composed of TFE on TFE or stainless steel should be based on a coefficient of friction of 0.06, is not conservative for all combinations of elements used in this study. Of the combinations tested, (a) glass-filled TFE versus glass-filled TFE, (b) glass-filled TFE versus mirror-finish stainless steel, (c) glass-filled TFE mechanically locked to steel plate versus mirror-finish stainless steel, (d) unfilled TFE versus mirror-finish stainless steel, and (e) unfilled TFE fibers and glass fibers woven and bonded to carbon steel plate versus mirror-finish stainless steel satisfied the design recommendation for all contact pressures. The criterion was also satisfied with unfilled TFE versus glass-filled TFE for contact pressures of 1,000 psi and greater. The design assumption was satisfied for nonparallel conditions using (a) glass-filled TFE versus mirror-finish stainless steel and (b) unfilled TFE versus glass-filled TFE for contact pressure of 1,000 psi and more. The design recommendation was not satisfied for (a) nonparallel tests of glass-filled TFE versus glass-filled TFE, (b) nonparallel tests of glass-filled TFE versus stainless steel, and (c) nonparallel tests of unfilled TFE versus glass-filled TFE for contact pressures less than 1,000 psi. Thus, it is concluded that the suggested design assumption (4) must be used with caution.

Recommended Design Loads for Bridges (4) also recommends that the design coefficient of friction for steel bearing on self-lubricating bronze plate be taken as 0.1. For both the new and used self-lubricating bronze expansion bearings tested, the effective coefficient of friction was found to be 0.09 ± 0.02 with a confidence interval of 95 percent for all tests. Hence, the recommendation is judged to be adequate.

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