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Long-Term Performance Of Elastomeric Bridge Bearings

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LONG-TERM PERFORMANCE OF ELASTOMERIC BRIDGE BEARINGS:

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Final Report on a Study
Conducted in Cooperation with
The U.S. Department of Transportation
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ABSTRACT

This report summarizes effects of long-term service on steel-laminated elastomeric bearings placed on twin structures carrying the NY 400 Aurora Expressway over Conrail and NY 16 in Erie County. Expansion-joint bearings replaced as part of rehabilitation project on these bridges were recovered for evaluation. Generally, they were found to be in good condition. NYSDOT's current accelerated-test procedures were evaluated by comparing mean ratings of 1969 acceptance testing for these bearings after simulated aging, with results of the same tests in 1996 on as-received samples after their removal from these bridges. Included in this study is analysis of mean ratings of the 1969 acceptance-test results compared to similar tests repeated to judge effects of the years in service. Finally, the recovered bearings underwent acceptance testing for conformance with current specification tests. Bearings used in this project had problematic design, construction, and materials properties, but performed very well in service and were relatively insensitive to these deficiencies.

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I. INTRODUCTION (1)

The function of a bridge bearing is to restrain and isolate a load-bearing surface from its support while accommodating movement due to thermal expansion and contraction, shrinkage, creep, and live-load deflections. Such movements may occur as translation, rotation, or compression. Conventional bridge bearings are designed to maintain a specified vertical load while allowing horizontal movements due to thermal expansion and contraction (Fig. 1). Elastomeric bearings are economical, effective, and require no maintenance. They are simply solid pads of elastomeric material, or a steel plate laminated between elastomer layers, with no moving parts. Bearings deflect in shear to accommodate expansion, contraction, and end rotation of the bridge structure (Fig. 2). They need no lubrication or cleaning, and do not seize.

A. Background (2,3)

DeLeuw, Cather & Associates supervised original design and construction for the Aurora Expressway (FASH 68-7). Contract III, FASH 68-7 was let on 2/15/68 and awarded to Tri-Delta Construction Corporation and Stimm Associates Incorporated on 3/26/68 for a total bid of $18,773,554.40. A

Figure 1. Bearing locations.

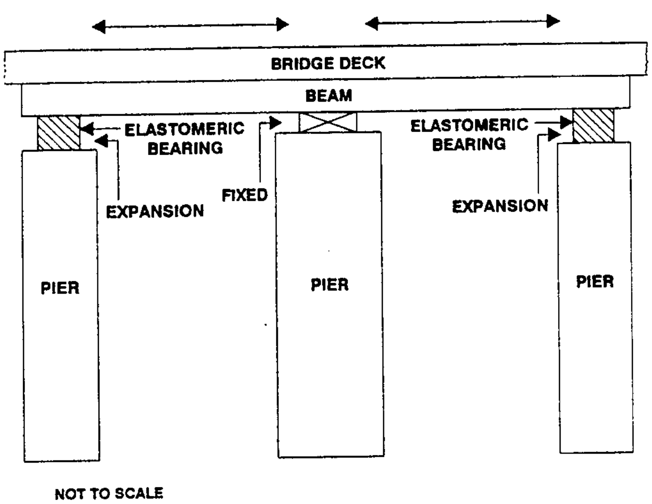
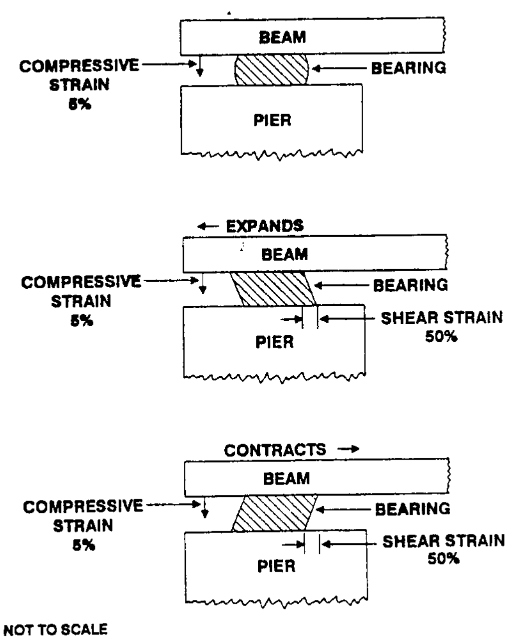


Figure 2. Bearing deflection to accommodate deck movement.



contract item that assumed far greater importance than might have seemed warranted by its initial cost was "115E, Bridge Bearings (Elastomeric)." Bid price for this item was $70 for each of 514 bearings, for a total cost of $35,980.00. All these bearings were used in two parallel adjacent structures 20SA and 20NA (BINs 105458-1 and -2, respectively) carrying NY 400 over Conrail and NY 16 in Erie County in NYSDOT's administrative Region 5.

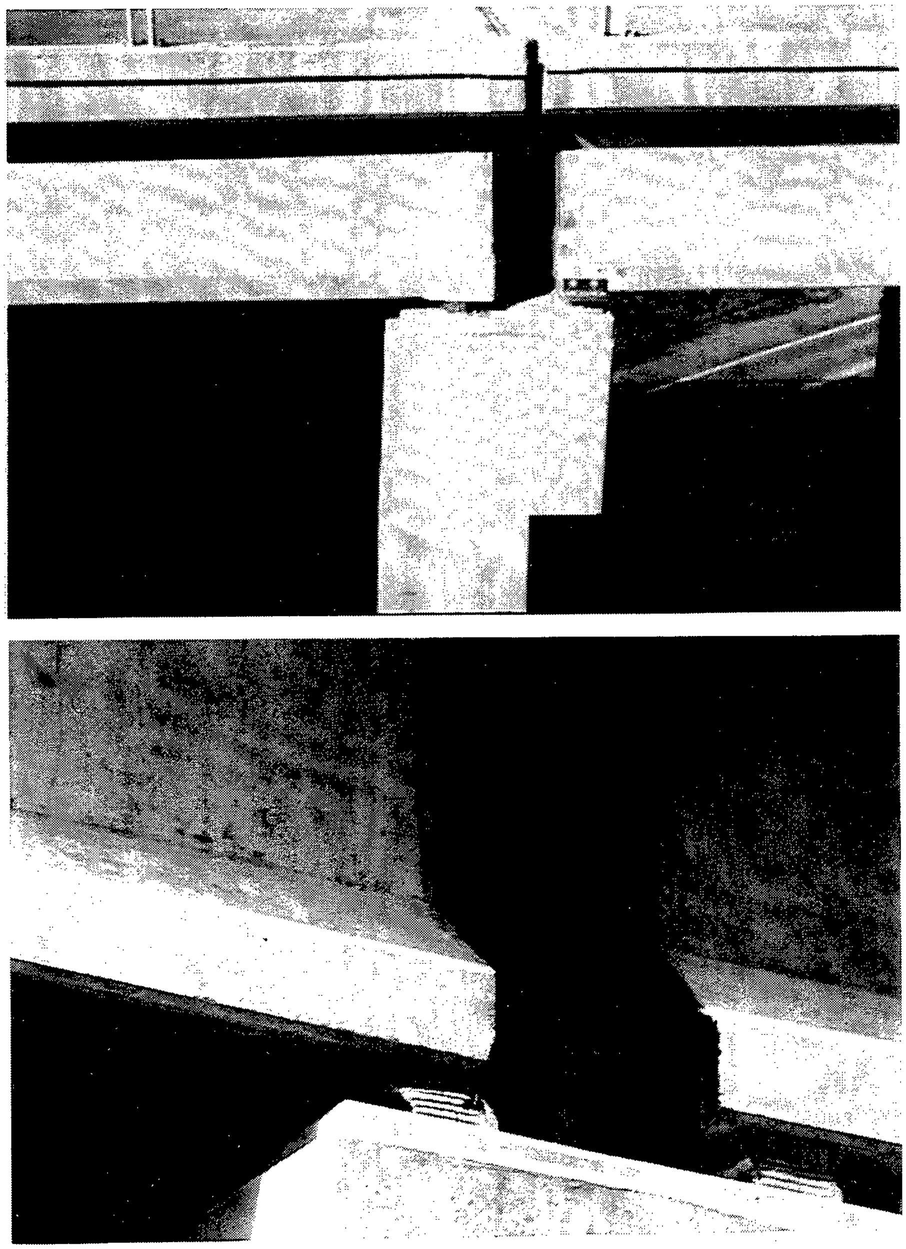
The design called for a concrete deck, supported by prestressed concrete beams resting on steel-laminated elastomeric neoprene bearings. Each structure is composed of 17 pretensioned concrete-girder spans with nominal lengths of 100 ft and an average curb-to-curb width of 39 ft. (For consistency with original contract documents and test results, all quantities are given here in US customary units.) The prestressed-concrete beams were designed to act as simple spans under dead load, and are continuous for three spans under live load. This was accomplished by pouring slabs continuously over the piers and diaphragms. The grades are approximately 3-1/3 percent both northbound and southbound.

Bearings were purchased for contract use by Interpace (a subcontractor) from the Continental Rubber Works. Their dimensions were 24 by 7-1/2 by 5-1/2 in. The first bearings shipped were rejected as under normal required height, and not being suitably marked with contract identification. Subsequent lots failed to meet compression-deflection requirements of Materials Specification M6E. The bearings developed approximately 1-percent more deflection than the 7 percent allowed by M6E at a static load equivalent to 800 psi. An implicit assumption in M6E was that the design shape factor exceed 5. These bearings failed to meet the specification because of a change in design (Shape Factor = 3.8) rather than incorporating poor or deficient material. An appropriate rebate was offered for the short and soft bearings, was accepted by the Department, and the bearings were used.

These bearings were the subject of an investigation by the Materials Bureau in the 1969 construction season. Placing concrete beams on the elastomeric bearings produced an immediate compressive load of 75 kips, and the grade caused the bearings to shear from 0 to 1/4 in. During roughly the next eight months, shear increased to 1/2 to 1 in. After the slab was cast on the beams, shear increased to as much as 3 in. (Fig. 3). This shear was caused by the beam's grade, in combination with lack of a notch (bird's mouth or dap) in the bottom of the beam, and was not due to seasonal temperature change. If the notch had been present, the beam's load would have been transmitted vertically to the bearing. Given the grade and lack of a notch, the vertical load created a horizontal force component that contributed to bearing shear. Shear was well beyond that expected, raising concern over long-term effects on the bearings. Consequently, it was decided to suspend work on the project.

To evaluate the effect of excessive shear on these bearings, several of those most sheared were removed from the structure and sent to the Materials Bureau. Numerous tests were performed, with the objective of determining whether the bearings in question had suffered permanent damage as a result of the large-scale distortions constantly imposed after pouring of the deck slabs. It was concluded that the bearings were still serviceable, and the structure underwent some modifications to fix one end of each span in place. The remaining bearings were left in place, and substitutes were manufactured to replace those that had been sent to the Materials Bureau.

Figure 3. Bearings in place, showing shear distortion.



Three corrective measures were directed by NYSDOT:

1. Further movement of the structure was prevented by inserting hardwood-block wedges in all beam or beam-and-slab assemblies.

2. Beams were reset in their locations on the southbound side where no slabs had yet been cast. For the northbound bridge, jacking was required because the slabs had already been cast.

3. Future movement was prevented by constructing a shear key, permanently fixing each three-span segment in place at one pier.

Sample bearings were retained by the Materials Bureau for further study. Two were stored in an unstressed condition, and two others were held in specially fabricated shear jigs under 7.25×10^4 psf compressive stress and 50-percent shear deflection (Fig. 4). The bearings and test jigs were sent to DuPont for examination in December 1984. Their test data showed that aging had very little effect on physical and dynamic properties of the 16-year-old bearings (4).

B. Bearing Evaluation

1. Bearing Removal

Bearings in these structures observed periodically over the years showed no evidence of physical damage in spite of the high shear strain to which they were initially subjected. NYSDOT Region 5, however, has been concerned over possible instability of the structures due to the high height-to-width ratio of the bearings and their extreme displacement. Contract D253061 let in December 1989, provided for rehabilitation of BINs 105458-1 and -2. At the Region's request, this project included removal and replacement of expansion bearings in these structures (Fig. 5).

Because of their historical and engineering significance, the Structures Division elected to save the most-distressed bearings for possible study. Of 126 expansion bearings being replaced under this 1989 contract, Item 05565.4902 required that 49 be shipped to the NYSDOT main office laboratories in wooden boxes. (The contract specified that the contactor was to dispose of the remaining 77 bearings.)

In September 1990, the authors visited the bridges to observe jacking of the joints and to prepare transport of the bearings removed back to Albany for testing. On-site evaluation of bearing condition led to a decision to salvage all bearings for testing -- 62 were retrieved then, and another 61 were subsequently removed from the site. After 22 years in service, many of the manufacturer's original markings were still visible. The bearings generally retained their original rectangular shape, but exhibited distorted contours when unloaded, especially on the outer edges. Conditions of representative bearings are shown in Figure 6. Diagonal and thickness dimensions indicated varying

Figure 4. Bearings removed during reconstruction, placed in jigs for testing.

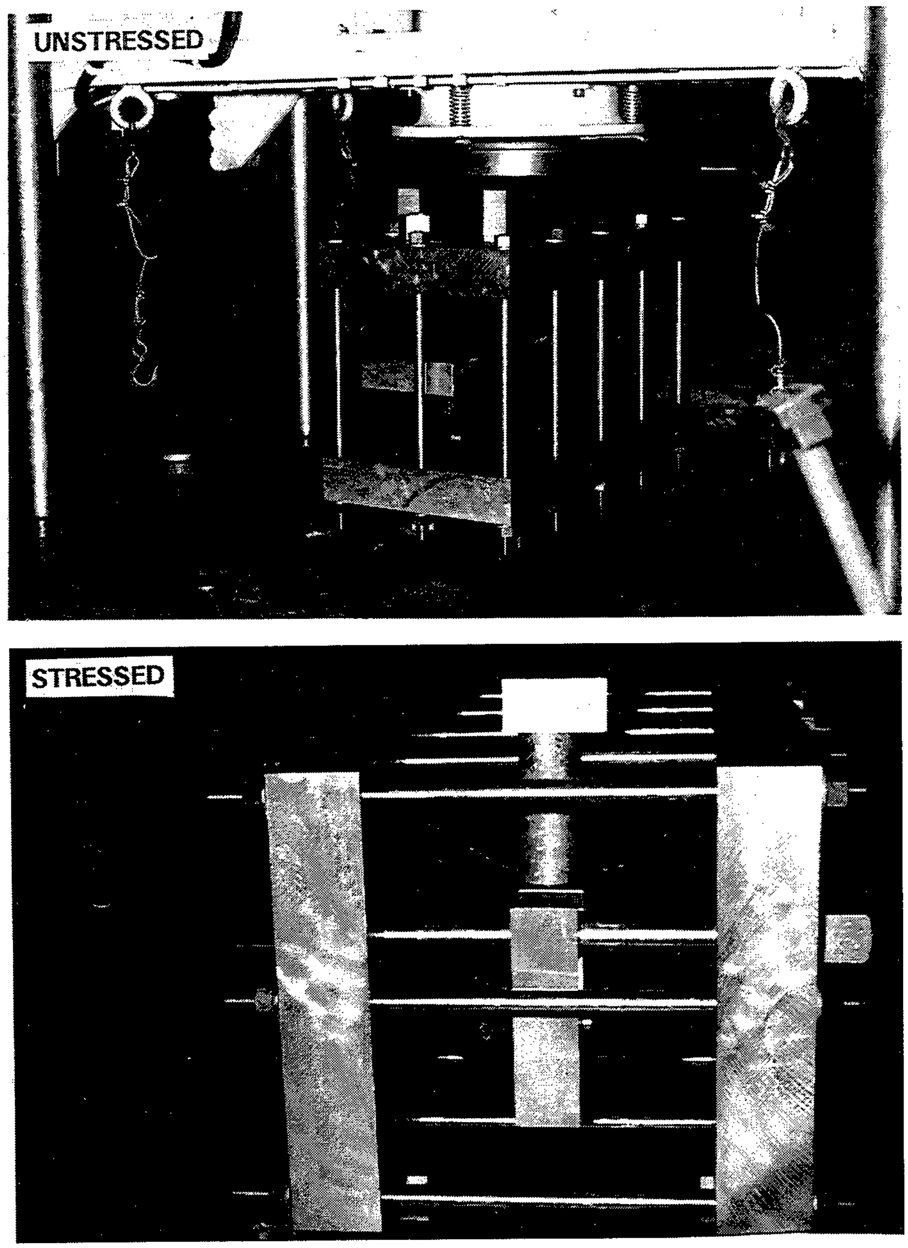


Figure 5. Removed bearing (top) and replacement bearing (bottom).

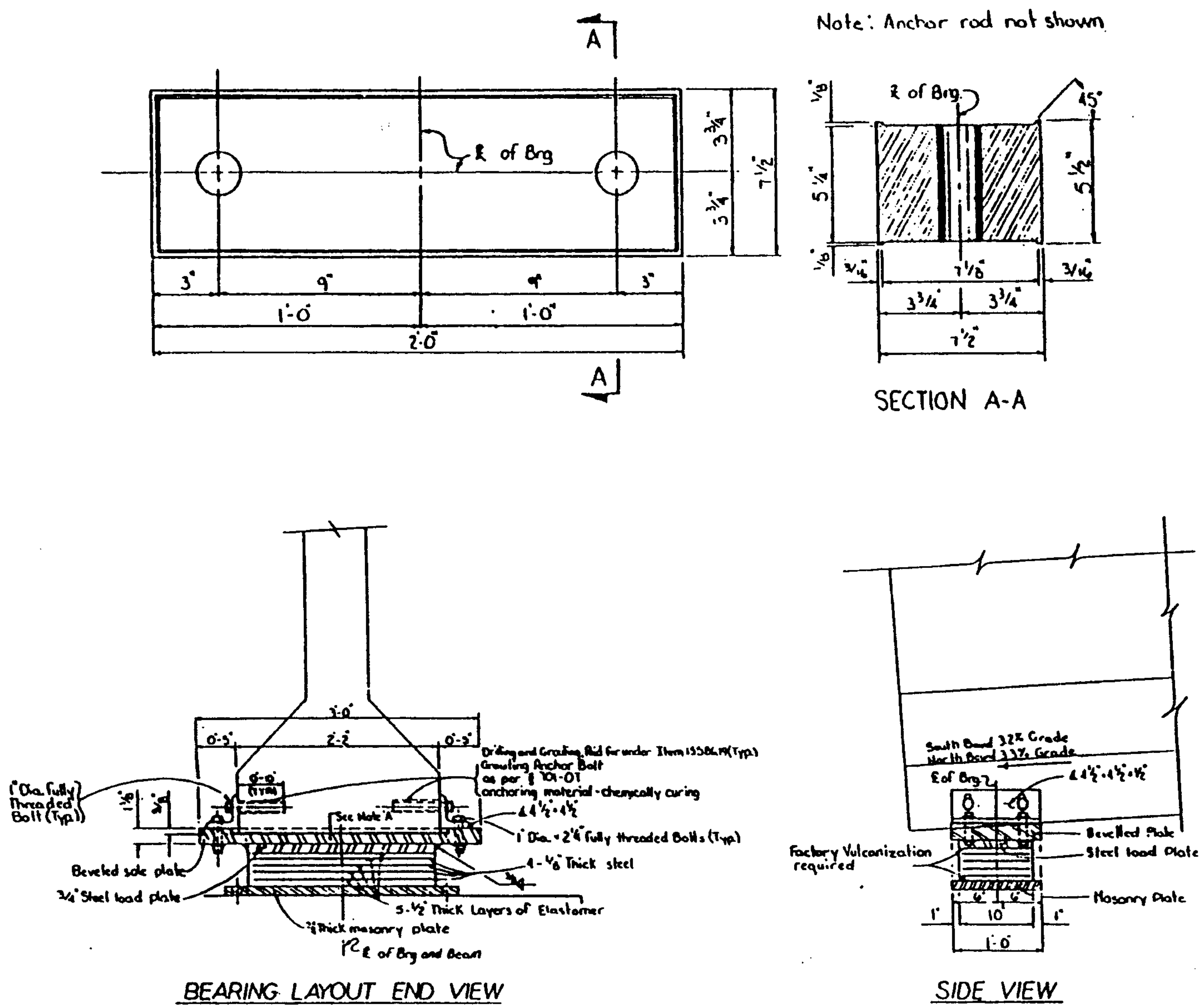
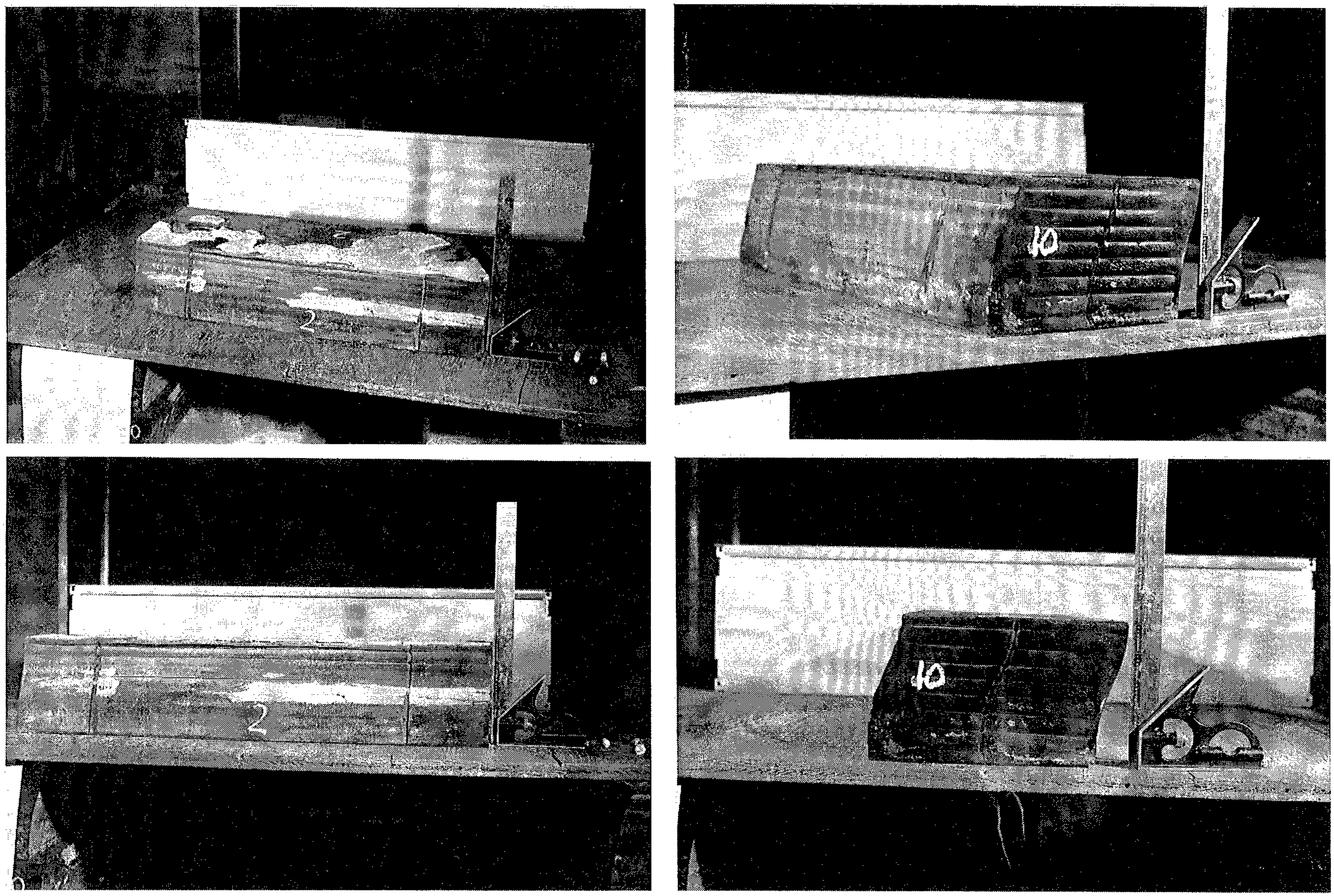


Figure 6. Recovered bearings in good condition (left) and showing permanent set (right).



amounts of permanent set in each bearing. Bearing numbers were painted on for identification and testing purposes. Field notes are given in Appendix A.

2. Elastomeric Bearing Test Parameters (5,6)

Physical material properties of elastomers change under stress over time. They are affected by temperature and are strain-rate sensitive. Most elastomers are produced in large batches, and then blended to achieve desired material properties. Standard manufacturer's tests yielding data about elastomer compounds are useful for their quality control, but will not predict actual performance, particularly in cold weather. Most advertised material properties are determined by short-term tests at fixed strain rates, at laboratory temperatures.

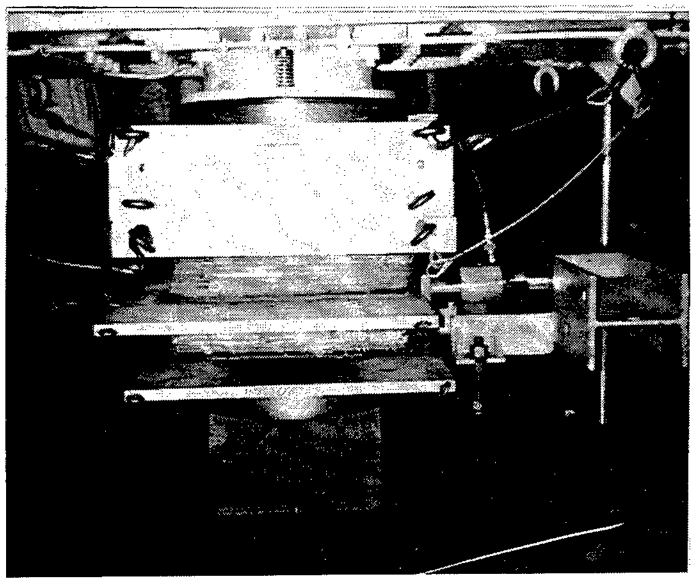
Elastomer longevity has been estimated largely through accelerated laboratory testing intended to determine long-term creep behavior and propensity for environmental stress-cracking. Effects of environmental exposure depend on material composition, including polymer type, grade, and additives; manufacturing process; and final-product physical structure.

Changing conditions and elastomer aging are modeled by various tests in an attempt to predict behavior in the field. Current acceptance tests and limits specified by the NYSDOT Materials Bureau are as follows:

Tensile Strength	2030 psi min
Ultimate Elongation	400% min
Aged % Δ Tensile	-15% max
Aged % Δ Elongation	-40% max
Compression Set (Neoprene)	35% max
Shore A Durometer 50 Hardness	50 ± 10
Aged Δ Hardness	+15 max
Compression Deflection Slope	0.002 to 0.01 max
Cold Temperature Shear	50 psi max
Adhesion	40 lb/in. min
Oil Swell	120% max

Bearings deflect in shear to accommodate expansion and contraction of the bridge structure. In the case of the bearings retrieved from the Aurora Expressway, they were tested opposite the permanent set. Compression/deflection tests determine whether they were manufactured correctly, in accord with designed loadings. Compression-deflection quality-assurance data are modified by NYSDOT from the normal specification format to a slope to produce single-number representations of the data. Compression results are reported as percent deflection (% ERT, where "ERT" is the effective rubber thickness). Compression results are not to exceed 5-percent deflection at 500 psi or 8-percent deflection at 800 psi. Corrected deflections at 500 and 800 psi equal the slope multiplied by 500 and 800, respectively. ERT of a bearing is critical and determines the amount of horizontal movement the bearing will permit.

Figure 7. Setup for cold-temperature testing.



Compression-set tests measure a bearing's permanent set (or creep) in compression. Creep is the additional deformation occurring with time in a bearing under stress (5), and occurs in neoprene to some degree at any stress level. Creep measurement is expressed in percent of original deformation. It occurs initially at a relatively high rate and then proceeds at a progressively reducing rate. If the period is very long or stress is very high, creep may enter a failure phase where the rate increases rapidly until actual fracture occurs.

Two terms are commonly used to describe low-temperature properties of neoprene. "Thermal stiffening" is the change occurring as temperature of the neoprene is lowered. Stiffening is measured by change in hardness of the vulcanizate after being subjected to some predetermined low temperature for a given period. "Crystallization" is realignment of polymer molecules that results in a stiffer, harder vulcanizate than would be expected from the effect of lower temperature alone. Specifications calling for a compression-set test at low temperature are meant to measure resistance of a neoprene compound to crystallization, which should not be confused with the brittleness generally occurring at a temperature much lower than required for crystallization. Cold-temperature shear testing models a bearing's response to such conditions (Fig. 7) by measuring horizontal deflection.

Shape factor reflects the bearing's vertical deflection characteristics and is defined as the ratio of surface area or plan area between plates of one loaded face to the area free to bulge around the perimeter of one of the bearing's internal elastomeric layers. Shape has only minor effects in shear and in tension, but shape of a piece (as distinguished from its size) may affect unit compressive stiffness and strength. Bearings with a low shape factor would be expected to show greater deflection under a given load than those with a higher shape factor made from the same stock. No consistent relationship has been found between shape factor and compressive modulus.

Reinforcement between neoprene layers in bearings increases their shape factor and reduces deflection. Steel plates are the most common reinforcement. Tensile strength of the reinforcing material, not the base elastomer, largely determines the ultimate compressive strength. Hardness of the bearing's elastomeric material is a relative measure of its modulus in both compression and shear. Generally, as hardness increases, modulus increases and deflection decreases. Adhesion testing measures slippage of the elastomer against the steel plates in steel-laminated bearings. Oil swell is a screening mechanism for natural rubber versus neoprene. Material properties of the neoprene -- tensile strength, elongation, and Shore A Durometer 50 hardness -- are measured in the original condition and after simulated aging to model performance in the field.

II. RESULTS AND DISCUSSION

The recovered bearings were tested when convenient during the regular Materials Bureau bearing-test schedule over the next few construction seasons, with the average results summarized in Table 1. (Raw data for all tests are given in Appendix B Tables 2 and 3.) Percentage changes (%) in hardness, tensile strength, and elongation are values taken after simulated aging, less the unaged values, divided by the unaged values. Bearings were grouped by lot where identification was possible. Mean values are reported for all test parameters. A number of compression/deflection and cold-temperature shear tests on the recovered bearings were stopped because their permanent set would have damaged the swivel head on the test equipment.

A. Original Aged Acceptance versus As-Received, Recovered Condition

As a method of checking validity of the simulated aging tests, a Student's t comparison of the means (7) was performed at the 99-percent confidence level to determine uniformity of values for three material properties. The null hypothesis in each case is that sample means are the same, and the alternative is that they were not (two-sided alternative).

Aged Shore A Durometer 50 hardness from the original acceptance tests averaged 53 (with a standard deviation of 2.0) for all bearing lots, compared to as-received hardness for the recovered bearings of 63 (with a standard deviation of 4.6). Based on Student's t-test, mean hardness differed significantly between the accelerated test and bearings in service 22 years. Average values of hardness also did not meet current specifications.

Table 1. Summary of acceptance testing.

	Comp-Defl Slope	Comp Set, %	Original Shore A Duro 50 Hardness	Aged Δ Hardness	Tensile Strength, psi	Aged % Δ Tensile Strength	Elong, %	Aged % Δ Elong	Oil Swell, %	Cold-Temp Shear, psi	Adhesion, lb/in.
Current Standard	0.01000 max)	(35% max)	(50±10)	(+15 max)	(2030 psi max)	(-15% max)	(400% min)	(-40% max)	(120% max)	(50 psi max)	(40 lb/in. min)
1969 ACCEPTANCE TESTS											
N	96	--	7	7	7	7	7	7	8	26	--
Avg	0.01025	--	47	6	2303	-5	781	-10	63	24	--
Std Dev	0.00114	--	1.1	2.0	328	14.1	54	13.8	26.2	8.0	--
1992-95 ACCEPTANCE TESTS											
N	37	18	18	18	18	18	18	18	18	28	48
Avg	0.00711	39	61	5	2255	-4	626	-9	78	35	60
Std Dev	0.00133	11.6	3.0	2.2	164	7.3	34	9.8	7.4	8.1	1.5

Aged tensile strength from the original testing averaged 2209 psi (with a standard deviation of 516) for all bearing lots, compared to as-received tensile strength for the recovered bearings of 2212 psi (with a standard deviation of 209). Based on Student's t-test, there is no significant difference in mean tensile strength between the accelerated test and bearings in service 22 years.

Aged elongation from the original testing averaged 700 percent (with a standard deviation of 106) for all bearing lots, compared to an as-received elongation for the recovered bearings of 603 percent (with a standard deviation of 57). Based on Student's t-test, mean elongation did not differ significantly between the accelerated test and bearings in service 22 years.

These test results support the accelerated testing specified for bearing acceptance by the Materials Bureau. In-service performance of the tested bearings indicated that the materials properties tested seemed correct for modeling that performance.

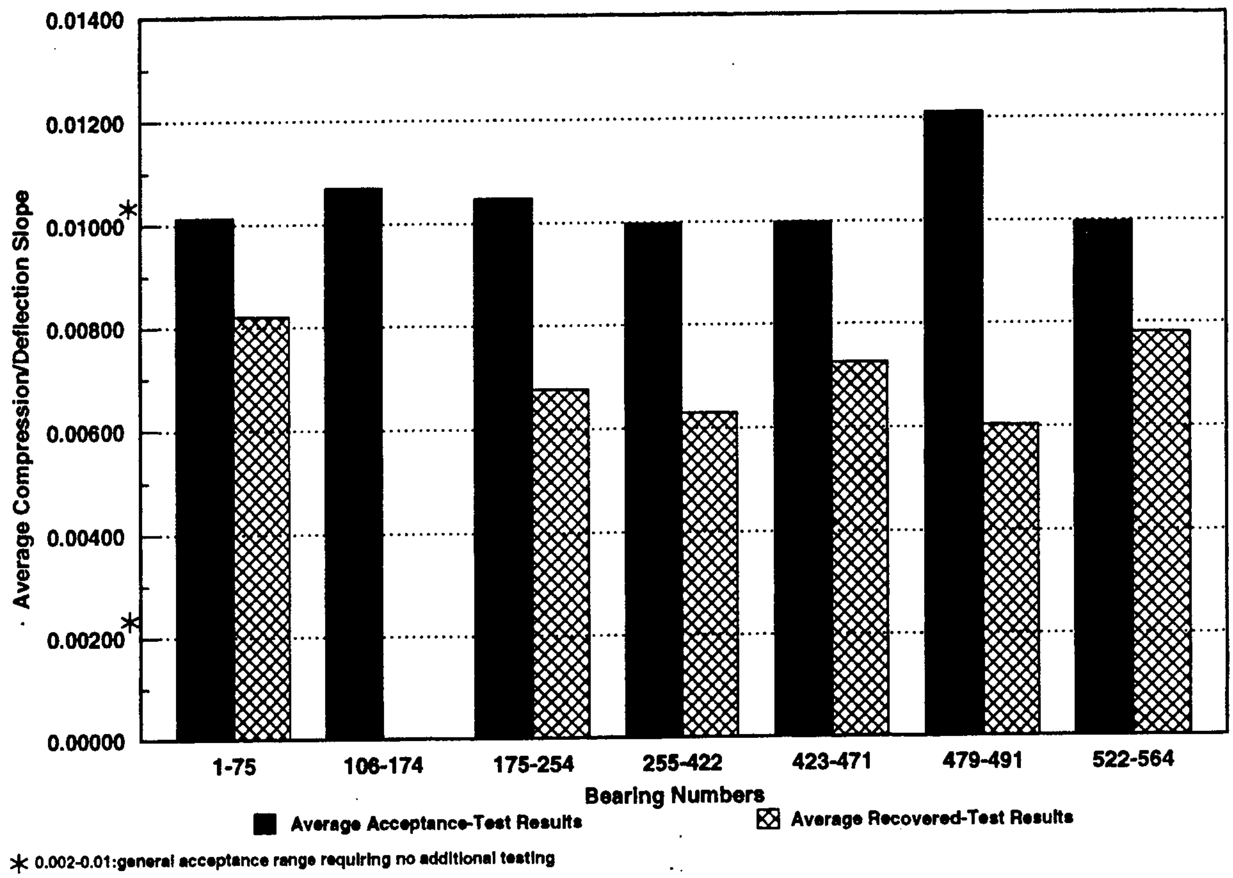
B. Recovered Pads versus Original Test Results

It is well known that dynamic properties of rubber vulcanizates are influenced by their previous strain histories (5). To measure the extent of that effect and the changed condition of the bearings after service, recovered pads were evaluated for conformance of test results in their as-received condition to original acceptance-test results. Comparing original acceptance-test results (Table 2 in Appendix B) to recovered-bearing test results (Table 3 in Appendix B), effects of 22 years service can be seen in general changes in values for all test parameters. A few materials properties were occasionally out of specification.

The 31-percent decrease in compression/deflection slope reflects the creep produced by the loading condition to which the bearings were subjected. New, softer bearings can produce a higher dynamic spring rate than aged, harder compounds when tested under conditions of equal compressive static stress. Bearing performance in compression/deflection testing is shown in Figure 8. The 17-percent increase in as-received hardness corresponds to a 25-percent increase in aged hardness. The 2-percent decrease in as-received tensile strength corresponds to a 2-percent decrease in aged tensile strength. The 20-percent decrease in as-received elongation corresponds to a 20-percent decrease in aged elongation. Compression/deflection and cold-temperature shear-test results still fall within standard design parameters, indicating that the bearings were performing as designed when loaded in compression and shear. Adhesion results were excellent after 22 years in service. All test results are generally within current specifications.

Due to the inherent properties of an elastomeric material, compressive creep increases with increasing hardness. Performance over time as reported here validates the selection and engineering of dynamic mechanical properties of neoprene for use in elastomeric bearings for bridge applications.

Figure 8. Results from bearing acceptance tests and used bearing tests.



C. Recovered Pads versus Current Specifications

To evaluate condition of the bearings after service, recovered pads were subjected to current acceptance tests. This is useful in comparing properties of removed bearings to those currently being installed in bridges. As seen in Appendix B Table 3, most test results after 22 years of service meet current acceptance specifications. A few materials properties were occasionally out-of-specification. Average values of Shore A Durometer 50 hardness and compression set barely failed to meet current specifications. Of 247 tests run on 52 bearings, only 22 or 8.9 percent of the results did not meet current standards.

These test results illustrate how creep is directly related to amount of time under load. The majority of creep occurred dramatically in a relatively short period after initial loading, stabilizing in the long term.

D. Bearings Tested Both Times

For additional information, two bearings were recovered that had test records from the original acceptance testing, and similar tests were run after service:

No. 185: the compression/deflection slope changed from 0.01062 to 0.00657 -- a decrease of 0.00405 or 38 percent.

No. 481: the compression/deflection slope changed from 0.01851 (out-of-spec) to 0.00763 -- a decrease of 0.01088 or 59 percent. Cold-temperature shear decreased from 31 to 17 psi -- a decrease of 45 percent.

No conclusions can be drawn from this comparison, due to the small number of bearings tested.

III. CONCLUSIONS AND RECOMMENDATIONS

This study has proved useful in identifying tasks for further research to provide a sound basis for informed judgments in developing future specification/testing requirements. Properties influencing bearing performance were modeled by acceptance testing. The relationship between each property and specific performance characteristics needs to be more fully understood.

The following conclusions can be drawn:

1. Neoprene's resistance to shear, weather aging, compression set, oil, and ozone ensures a long service life and no maintenance needed in bridge bearing applications. This is borne out by bearing performance in the acceptance tests after 22 years in service.

2. The value of NYSDOT's rigorous materials specifications and the aging-test process for elastomeric properties is verified by bearing performance in the testing after service, compared to initial aged-test results.

3. Initial compressive deflection to which the bearings were subjected and subsequent performance reinforce the need for proper bearing design (shape factor) in maintaining effective rubber thickness to deflect shear stresses, as well as properly specified material properties.

Based on this study's work and these conclusions, the following recommendations are suggested:

1. Conduct, support, and monitor additional research to develop tests addressing performance requirements for various types of bearings in civil-engineering applications, under various loading conditions.

2. Performance over time as reported here substantiates continued use of neoprene in elastomeric bearings by the Department for bridge applications.

ACKNOWLEDGMENTS

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APPENDIX A. FIELD NOTES

AURORA EXPRESSWAY BEARING PADS - FASH 68-7
NORTHBOUND

NOTES:
1. In comments: TOP is either side that holes are in, FACE is either remaining long side, END is either short side.
2. An * after the Original # means the entire # was located on the pad.
3. In the dimensions: Diagonal was across the face from opposing top corners, height was at an end, both measured in inches.
4. Location # (Loc. #) were labeled on pads as they were removed from piers.
5. ER&DB # were assigned in the order that they were examined.

ER&DB #	PIER ID	ORIG. #	LOC. #	DIMENSIONS Diag.	Hgt.	COMMENTS
37				9.7	5.1	Holes misaligned - Gouges in other top @ both end edges - Pad near 1 hole appears burned
39				9.5	5.2	OK
40				9.6	5.1	OK
49				9.4	5.2	Holes slightly misaligned - Damaged face/end edge
59				9.4	5.3	Small gouge in top
20	NF			9.6	5.2	1 hole misaligned - Worn top/face edge & 1 corner
22	NF			9.9	4.7	Holes misaligned - Other end is 5.1 high - Worn @ top/face edge - Pad near 1 hole appears slightly burned
24	NF			9.5	5.2	OK
27	NF			9.5	5.1	Holes misaligned - Cut in 1 face - Worn @ top/face edge
28	NF			9.5	5.2	OK
29	NF			9.4	5.2	OK
35	NF			9.4	5.0	Holes misaligned - Worn @ top/face & top/end edges
36	NF			9.4	5.2	Slight warp top/face edge
19	NF	351*	4	9.6	5.1	OK
33	NF	448*	6	9.5	5.2	Worn @ top/face edge
25	NF	439*	7	9.7	5.2	Worn on 1 top @ ends
30	NF	352*	10	9.5	5.2	Rows of nicks in 1 top - Gouges in other top @ end edges
23	NF	377*	11	9.6	5.2	Holes misaligned - Worn @ top/face edge
34	NF	358*	13	9.5	5.2	Holes misaligned
62	NC	538*	1	9.4	5.3	3 gouges in 1 top - Metal showing @ end center
57	NC	489*	3	9.5	5.2	OK
58	NC	532*	4	9.4	5.3	Sm. gouge in top/end edge
48	NC	531*	5	9.4	5.3	Sm. gouge in top/end edge
32	NC	533	6	9.5	5.2	Sm. gouge in top/end edge
61	NC	440*	7	9.5	5.1	Sm. gouge in top
47	NC	481*	9	9.3	5.2	OK
50	NC	281*	11	9.6	5.2	Slight bend in top @ 1 end
26	NC	552*	12	9.4	5.2	Slight bend in tops
60	NC	366*	14	9.6	5.0	OK

ER&DB #	PIER ID	ORIG. #	LOC. #	DIMENSIONS Diag.	Hgt.	COMMENTS
3	NI			9.8	5.2	Holes misaligned - Area @ holes distorted - 1 end split
4	NI			9.7	5.1	Holes misaligned - Area @ holes distorted - Both ends split
9	NI			10.0	5.1	Holes misaligned - Area @ holes distorted
10	NI			9.8	5.0	Holes misaligned - 1 end split
14	NI			9.9	5.0	Holes misaligned - Area @ holes distorted
2	NI	161*	1	10.0	5.0	Holes misaligned - 1 end split - PCC on 1 top
5	NI	143*	4	9.9	5.1	Holes misaligned - Area @ holes distorted
8	NI	185*	5	9.6	5.1	Area @ holes distorted
7	NI	203*	7	9.7	5.2	Holes misaligned - Area @ holes distorted
6	NI	217*	9	9.7	5.1	Holes misaligned - Area @ holes distorted
43	NI	145*	10	9.9	5.2	Holes misaligned - End/face edge damaged - Pad near both holes appears burned
11	NI	187*	11	9.8	5.1	Area @ holes distorted - 1 end split
12	NI	219*	12	9.9	5.1	Holes misaligned - Area @ holes distorted - Both ends split
46	NL	137*	1	9.8	5.1	OK
53	NL	154*	2	10.0	5.2	Holes misaligned - Tear in top from hole to end then along edge - Pad near holes appears burned
54	NL	197*	3	9.8	5.1	Holes misaligned - Pad near 1 hole appears burned
55	NL	165*	4	9.9	5.2	Holes misaligned
44	NL	113*	5	9.8	5.1	Holes misaligned
31	NL	168	6	10.0	5.1	Holes misaligned
41	NL	156*	7	10.0	5.1	OK
51	NL	167	8	10.3	5.1	Holes misaligned - Top/face edge warped - Pin still in 1 hole
45	NL	149*	9	10.1	5.1	Holes misaligned - 1 face split
42	NL	159*	10	10.1	5.1	Holes slightly misaligned
52	NL	125	11	10.1	5.1	Holes misaligned
56	NL	121*	12	9.4	5.3	Holes misaligned
38	NL	123*	13	10.3	5.2	Holes misaligned
1	NL	119*	14	10.7	4.9	Holes misaligned - 1 face split w/ metal showing
16	NO	3	1	9.9	4.9	Holes misaligned
21	NO	6*	2	9.6	5.0	Holes misaligned - Worn @ top corner to metal
63	NO	4*	3	9.9	5.0	Holes slightly misaligned
15	NO	22*	4	10.1	5.0	Holes misaligned - Worn @ top corner
17	NO	61*	5	10.8	4.8	Holes misaligned badly
13	NO	51*	6	10.5	4.9	Holes misaligned badly
18	NO	54	7	10.2	4.9	Holes misaligned

AURORA EXPRESSWAY BEARING PADS - FASH 68-7
SOUTHBOUND

ER&DB #	PIER ID	ORIG. #	LOC. #	DIMENSIONS Diag.	Hgt.	COMMENTS
S9	SC			9.5	5.2	OK
S7	SC	433	1	9.7	5.2	Bent along top w/ gouge in top corner
S20	SC	471	2	9.6	5.1	OK
S8	SC	436	3	9.6	5.1	Worn top corner
S12	SC	311	4	9.5	5.2	OK
S18	SC	262	5	9.4	5.1	Rip @ 1 hole
S10	SC	305	6	9.5	5.0	Badly bent along top
S17	SC	537*	8	9.6	5.2	OK
S50	SC	562	10	9.5	5.3	OK
S19	SC	524	11	9.5	5.3	Slight bulge on 1 face opposite hole
S11	SC	549*	13	9.7	5.3	Gouge between rolls on face
S16	SC	525	14	9.5	5.3	OK
S1	SF	383*	2	9.6	5.1	OK
S15	SF	324	3	9.6	5.2	OK
S14	SF	343	4	9.8	5.0	Slight damage @ 1 hole
S3	SF	304	5	9.7	5.3	OK
S13	SF	302	6	9.6	5.1	OK - 1 face has 2 man-made L-shaped cuts that were patched
S39	SF	442*	9	9.6	5.2	Holes misaligned
S41	SF	430*	10	9.6	5.1	Holes misaligned
S4	SF	438*	11	9.7	5.2	OK
S31	SF	275*	12	9.6	5.2	OK
S55	SF	443	14	9.6	5.1	OK
S54	SI	69*	3	9.9	4.9	Holes misaligned
S53	SI	342*	4	9.7	5.1	OK
S44	SI	265*	5	9.7	5.1	OK
S51	SI	13*	6	10.0	4.9	Holes misaligned
S56	SI	231	9	10.0	5.1	OK
S60	SI	107*	10	9.8	5.0	Holes misaligned
S47	SI	158*	11	9.7	5.1	Holes misaligned - Slits on 1 face @ corners
S57	SI	142*	12	9.7	5.1	OK
S58	SI	172*	14	9.9	5.0	Holes misaligned

All these pads except S57 were marked as if they came off Pier SF - located to Pier SI by original numbers.

ER&DB #	PIER ID	ORIG. #	LOC. #	Diag.	Hgt.	COMMENTS
S42			1	9.5	5.1	Slight tear on 1 face @ corner
S52			1	9.7	5.0	OK
S38			7	10.1	4.8	Holes misaligned
S49			7	9.6	5.1	Damaged face/end edge - top worn
S59			8	9.7	5.1	Holes misaligned
S5			8	9.7	5.2	Slight damage on 1 face in corner
S2			13	9.7	5.2	OK
S34			13	9.9	5.1	OK

These pads were all marked as if they came off Pier SF but could be off either Pier SI or Pier SF

ER&DB #	PIER ID	ORIG. #	LOC. #	DIMENSIONS Diag.	Hgt.	COMMENTS
S30	SL	252	1	9.6	5.0	Slight split on 1 face
S32	SL	209	2	9.7	5.0	Damage on 1 face @ 2 corners
S46	SL	213*	3	9.7	5.2	1 end appears burned
S24	SL	206	4	9.6	4.9	Top/face edge badly distorted
S27	SL	228*	5	9.8	5.1	Slightly damaged corner on 1 face
S21	SL	210*	6	9.7	5.1	OK
S36	SL	204	7	9.8	4.9	1 hole misaligned
S43	SL	128	8	10.0	4.8	OK
S23	SL	114	9	9.8	5.2	OK - 1 face has a man-made L-shaped cut that was patched
S37	SL	111	10	10.0	5.0	Holes misaligned - 1 face appears burned - 1 face has 2 man-made L-shaped cuts that were patched
S48	SL	118	11	10.0	5.1	Holes misaligned
S22	SL	108	12	9.8	5.1	OK
S45	SL	122	13	9.8	5.2	Holes misaligned - Slits on 1 face @ corners
S29	SL	124	14	9.7	5.2	1 hole misaligned - Both faces are split
S40	SO	71	1	9.5	4.9	Holes misaligned - Top scarred badly
S28	SO	58*	2	9.5	4.8	OK
S6	SO	17	3	9.6	5.0	Top corner worn to metal
S35	SO	73	4	9.6	4.9	OK
S26	SO	49*	5	9.6	5.0	OK
S25	SO	52*	6	9.5	4.9	OK
S33	SO	47	7	9.8	4.9	OK

APPENDIX B. LABORATORY TEST RESULTS

Table 2. Summary of 1969 bearing acceptance tests.

A. COMPRESSION-DEFLECTION (CD) TESTS

Acceptance Test 69-001		Acceptance Test 69-002		Acceptance Test 69-005		Acceptance Test 69-006		Acceptance Test 69-009		Acceptance Test 69-024		Acceptance Test 69-027	
Bearing No.	CD Slope	Bearing No.	CD Slope	Bearing No.	CD Slope	Bearing No.	CD Slope	Bearing No.	CD Slope	Bearing No.	CD Slope	Bearing No.	CD Slope
107	0.01047	177	0.00995	1	0.01017	255	0.01006	423	0.0098	481	0.01851	522	0.00708
117	0.01047	180	0.01081	7	0.01044	260	0.00998	429	0.00991	488	0.0116	526	0.01093
127	0.01059	185	0.01062	14	0.00889	266	0.00938	432	0.0104	491	0.00622	530	0.00991
129	0.01074	191	0.01085	20	0.00931	270	0.00976	437	0.00998			535	0.0101
133	0.0108	196	0.01074	27	0.01047	274	0.01044	439	--			540	0.01032
139	0.0103	203	0.01051	31	0.00938	280	0.00931	441	0.01025			548	0.0104
143	0.0106	207	0.01074	36	0.00916	285	0.01021	445	0.01002			552	0.01085
153	0.01044	211	0.01074	41	0.01085	292	0.01006	451	0.00957			558	0.00998
155	0.0113	216	0.01021	46	0.01021	296	0.00931	455	0.00991			564	0.01006
161	0.01074	221	0.01025	50	0.01062	301	0.00968	460	0.01014				
166	0.0103	224	0.01047	55	0.01017	306	0.01255	467	0.00983				
170	0.0112	229	0.01111	60	0.01055	309	0.01021						
171	0.01089	232	0.01044	66	0.01032	314	0.00972						
174	0.011	240	0.01032	70	0.0107	320	0.00852						
		246	0.01028	75	0.01062	327	0.00964						
		254	0.00972			338	0.01025						
						345	0.01002						
						355	0.01036						
						356	0.00942						
						360	0.00987						
						371	0.00964						
						378	--						
						380	0.01055						
						386	0.01055						
						390	0.01025						
						400	0.00998						
						406	0.01025						
						411	0.0098						
						416	0.00957						
						421	0.0101						
Avg	0.0107		0.01048		0.01012		0.00997		0.00998		0.01211		0.00996
Std Dev	0.00032		0.00036		0.00062		0.00066		0.00024		0.00616		0.00114

B. MATERIALS PROPERTIES TESTS

Bearing No.	Shore A Duro 50 Hardness	Aged Δ Hardness	Tensile Strength, psi	Aged Δ Hardness	Elong, %	Aged % Δ Elong	Oil Swell, %	Cold-Temp-Shear, psi
Acceptance Test 69-001								
107	--	-	--	--	--	--	--	29
127	46	9	1630	-26	800	-40	104	15
133	--	-	--	--	--	--	--	15
161	--	-	--	--	--	--	--	31
Avg	--	-	--	--	--	--	--	22
Std Dev	--	-	--	--	--	--	--	9
Acceptance Test 69-002								
211	--	-	--	--	--	--	--	30
216	--	-	--	--	--	--	--	18
221	47	5	2550	-3	810	-7	76	16
254	--	-	--	--	--	--	--	32
Avg	--	-	--	--	--	--	--	24
Std Dev	--	-	--	--	--	--	--	8
Acceptance Test 69-005								
7	--	-	--	--	--	--	--	24
27	--	-	--	--	--	--	--	32
31	47	7	2380	16	880	-7	76	19
66	--	-	--	--	--	--	--	43
Avg	--	-	--	--	--	--	--	30
Std Dev	--	-	--	--	--	--	--	11
Acceptance Test 69-006								
429	--	-	--	--	--	--	--	28
439	48	4	2311	4	720	1	58	14
441	--	-	--	--	--	--	--	--
Avg	--	-	--	--	--	--	--	21
Acceptance Test 69-009								
481	--	-	--	--	--	--	--	31
491	47	7	2180	-10	750	-5	34	18
Avg	--	-	--	--	--	--	--	24
Acceptance Test 69-024								
530	--	-	--	--	--	--	--	25
540	46	3	2570	-18	770	-12	28	13
Avg	--	-	--	--	--	--	--	19
Acceptance Test 69-027								
255	--	-	--	--	--	--	--	29
260	--	-	--	--	--	--	--	30
266	49	6	2500	1	740	-1	68	18
274	--	-	--	--	--	--	--	15
306	--	-	--	--	--	--	--	30
314	--	-	--	--	--	--	--	17
345	--	-	--	--	--	--	--	14
378	--	-	--	--	--	--	--	30
Avg	--	-	--	--	--	--	--	23
Std Dev	--	-	--	--	--	--	--	7

Table 3. Summary of 1992-95 retesting of recovered bearings.

A. COMPRESSION-DEFLECTION (CD) TESTS

Bearing Range 106-174		Bearing Range 175-254		Bearing Range 1-75		Bearing Range 255-422		Bearing Range 423-471		Bearing Range 479-491		Bearing Range 522-564	
Bearing No.	CD Slope	Bearing No.	CD Slope	Bearing No.	CD Slope	Bearing No.	CD Slope	Bearing No.	CD Slope	Bearing No.	CD Slope	Bearing No.	CD Slope
107	--	185	0.00657	5*	--	262	0.00661	436	0.00706	481	0.00763	524	0.00766
119	--	203*	--	6*	--	275	0.00593	438	0.00725	489	0.00443	531	0.00721
143	--	206*	--	13	--	281	0.00623	439	0.00785			532	0.00728
161	--	209	0.00586	17*	--	302*	--	442	0.00668			533	0.00751
165*	--	210	0.00959	22	--	305	0.00668	448	0.00743			537	0.00801
		213	0.00589	43	0.0071	311	0.00646					538*	--
		228	0.00589	49	0.00536	351	0.00702					549	0.00831
				51*	--	352	0.00473					550	0.00801
				52	0.01216	383	0.00665					552	0.00846
				58*	--								
				61	--								
Avg			0.00676		0.00821		0.00629		0.00725		0.00603		0.00781
Std Dev			0.00161		0.00353		0.00071		0.00043		0.00226		0.00046

*Test stopped due to excessive permanent set in bearing; when loaded, the swivel head on the test apparatus bottomed out.

B. MATERIALS PROPERTIES TESTS

Bearing No.	Comp Set, %	Original Shore A Duro 50 Hardness	Aged Δ Hardness	Tensile Strength, psi	Aged % Δ Tensile Strength	Elong, %	Aged % Δ Elong	Oil Swell, %	Cold-Temp Shear, psi	Adhesion, lb/in.
Bearing Range 106-174										
107	40	57	1	2580	-3	689	1	--	--	51
119										
143	64	60	5	2120	0	610	-4	70	--	--
161	28	69	5	2360	-1	576	-8	88	--	60+
165*	39	59	8	2170	-9	624	-8	73	--	60+
Avg	43	61	5	2308	-3	625	-5	77	--	58
Std Dev	15.2	5.3	2.9	209	4	47	4.3	9.6	--	4.5
Bearing Range 175-254										
185	--	--	-	--	--	--	--	--	29	60+
203*	--	--	-	--	--	--	--	--	29	60+
206*	--	--	-	--	--	--	--	--	45	60+
209	--	--	-	--	--	--	--	--	41	60+
210	--	--	-	--	--	--	--	--	26	60+
213	--	--	-	--	--	--	--	--	--	60+
228	49	66	2	2290	-23	643	-32	--	--	60+
Avg	--	--	-	--	--	--	--	--	34	60+
Std Dev	--	--	-	--	--	--	--	--	8.4	0
Bearing Range 1-75										
5*										
6*	35	58	8	2290	14	593	2	76	--	60+
13	--	--	-	--	--	--	--	--	--	60+
17*										
22	--	--	-	--	--	--	--	--	--	55
43	--	--	-	--	--	--	--	--	29	--
51*	24	62	5	2460	-7	643	-27	78	--	60+
52	--	--	-	--	--	--	--	--	28	60+
58*	--	--	-	--	--	--	--	--	--	60+
61	64	60	6	2420	0	695	-18	73	--	60+
Avg	41	60	6	2390	2	644	-14	76	--	59
Std Dev	--	--	-	--	--	--	--	--	--	1.9
Bearing Range 255-422										
262	--	--	-	--	--	--	--	--	37	60+
275	33	60	5	2220	-5	615	-13	--	29	60+
281	37	61	7	2270	-3	576	0	--	45	60+
302*	33	62	5	2470	-5	633	-7	--	41	60+
305	--	--	-	--	--	--	--	--	41	60+
311	39	59	4	2100	-5	628	-12	--	--	60+
351	--	--	-	--	--	--	--	--	33	60+
352	--	--	-	--	--	--	--	--	36	60+
383	26	62	8	2320	3	598	-4	78	--	60+
Avg	34	61	6	2276	-3	610	-8	--	37	60+
Std Dev	5	1.3	1.6	136	3.5	23.3	4.5	--	3.3	0
Bearing Range 423-471										
436	--	--	-	--	--	--	--	--	37	60+
438	--	--	-	--	--	--	--	--	26	60+
439	--	--	-	--	--	--	--	--	33	60+
442	49	62	8	2160	-9	598	-22	--	--	60+
448	--	--	-	--	--	--	--	--	40	60+
Avg	--	--	-	--	--	--	--	--	34	60+
Std Dev	--	--	-	--	--	--	--	--	6	0
Bearing Range 479-491										
481	--	--	-	--	--	--	--	--	17	60+
489	42	61	3	1946	-12	609	-7	--	--	60+
Bearing Range 522-564										
524	--	--	-	--	--	--	--	--	37	60+
531	37	58	4	2020	-4	658	-4	--	40	60+
532	--	--	-	--	--	--	--	--	36	60+
533	--	--	-	--	--	--	--	--	32	60+
537	--	--	-	--	--	--	--	--	28	60+
538*	39	59	4	2180	-7	638	-6	--	--	60+
549	24	57	8	2210	-2	641	4	91	--	60+
550	--	--	-	--	--	--	--	--	--	50
552	--	--	-	--	--	--	--	--	17	60+
Avg	33	58	5	2137	-4	646	-2	--	34	60+
Std Dev	8.1	1	2.3	102	2.5	10.8	5.3	--	10.3	0
Bearing Range Unknown										
Unk	--	--	-	--	--	--	--	--	--	60+
Unk	--	--	-	--	--	--	--	--	44	60+
Unk	--	--	-	--	--	--	--	--	32	60+
Unk	--	--	-	--	--	--	--	--	44	60+
Unk	--	--	-	--	--	--	--	--	45	60+
Unk	--	--	-	--	--	--	--	--	37	60+
Avg	--	--	-	--	--	--	--	--	40	60+
Std Dev	--	--	-	--	--	--	--	--	5.7	0