Seismic Response of Standard Thermal Expansion Bridge Bearings

James M. Kelly and **Dimitrios Konstantinidis**
Earthquake Engineering Research Center, University of California, Berkeley

ABSTRACT

Elastomeric bridge bearings have a history of use in the USA of close to 50 years. They are capable of carrying large vertical loads and allowing horizontal movement with low lateral force due to the extreme flexibility of the elastomeric material. They require little maintenance, have no moving parts, have good longevity and are very economical.

The elastomer in bridge bearings is usually either polyisoprene (Natural Rubber) or polychloroprene (Neoprene). Thermal expansion bearings are designed for a variety of deformations produced by thermal expansion of the bridge superstructure, shrinkage due to aging or prestress, misalignment or beam rotation through a process of shear deformation, the material being essentially incompressible. Under currently accepted design practice, the maximum shear strain developed in the elastomer due to all sources of deformation is not more than about 50%. On the other hand, seismic isolation bearings for bridges and buildings are designed for much larger shear strains, and it is known that under shear loading the shear strain at failure can exceed 400%. This raises the question that bridge-bearing specifications may be excessively conservative.

It is the purpose of this report to describe a series of experimental studies of the seismic behavior of three types of standard thermal expansion bearings for bridges. The experimental program has used the CALTRANS Seismic Response Modification Device (SRMD) Testing System at the University of California at San Diego. The three types covered by the test program are

1) Steel-Reinforced Elastomeric Bearings,
2) PTFE-Elastomeric Bearings, and
3) PTFE-Spherical Bearings.

The test program includes wide-range dynamic tests at velocities and displacements that could be experienced by these bearings but for which they have not been designed.

Only the results of the test program on the elastomeric pads are described in this report.

INTRODUCTION

This report will describe the testing of a set of six elastomeric bridge bearing pads manufactured to Caltrans requirements by Scougal Rubber Corp. These pads are designed and used solely as thermal expansion bearings but the purpose of the research work is to determine the response of such pads if they are subjected to seismic loading. Many bridge structures are provided with seismic isolation bearings specifically designed for that purpose and considerably more expensive

than the thermal expansion pads. They are also much more difficult to manufacture since they are made to more stringent requirements, and they are considerably heavier.

The primary weight in an isolator is due to the steel reinforcing plates, which are used to provide the vertical stiffness of the rubber-steel composite element. A typical rubber isolator has two large end-plates (25mm) and 20 thin reinforcing plates (3mm). The high cost of producing the isolators results from the labor involved in preparing the steel plates and laying-up of the rubber sheets and steel plates for vulcanization bonding in a mold. The steel plates are cut, sand-blasted, acid-cleaned, and then coated with bonding compound. Next, the compounded rubber sheets with the interleaved steel plates are put into a mold and heated under pressure for several hours to complete the manufacturing process. The purpose of this research is to suggest that both the weight and the cost of isolators can be reduced by using thinner steel reinforcing plates, no end-plates and no bonding to the support surfaces. Since the demands on the bonds are reduced, a simpler and less expensive manufacturing process can be used.

The manufacturing process for conventional isolators has to be done very carefully because the testing requirements in the current codes for seismic isolation require that the isolators be tested prior to use for very extreme loading conditions. The bond between the rubber and the steel reinforcement and between the rubber and the end plates must be very good for the bearing to survive these tests. The effect of a large shear displacement of the isolator is to generate an unbalanced moment which must be equilibrated by tensile stresses. The compression load is carried through the overlap region between top and bottom surfaces and the unbalanced moment is carried by tension stresses in the regions outside the overlap.

Thermal expansion bridge bearings in contrast to seismic bearings are much less expensive. The in-service demands on these bearings are, of course, much lower, but the tests reported herein have shown that even if displacements of seismic-demand magnitude are applied to them they can deform without damage. The primary reason for this is the fact that the top and bottom surfaces can roll off the support surfaces and no tension stresses are produced. The unbalanced moments are resisted by the vertical load through offset of the force resultants on the top and bottom surfaces (see Figure 1).

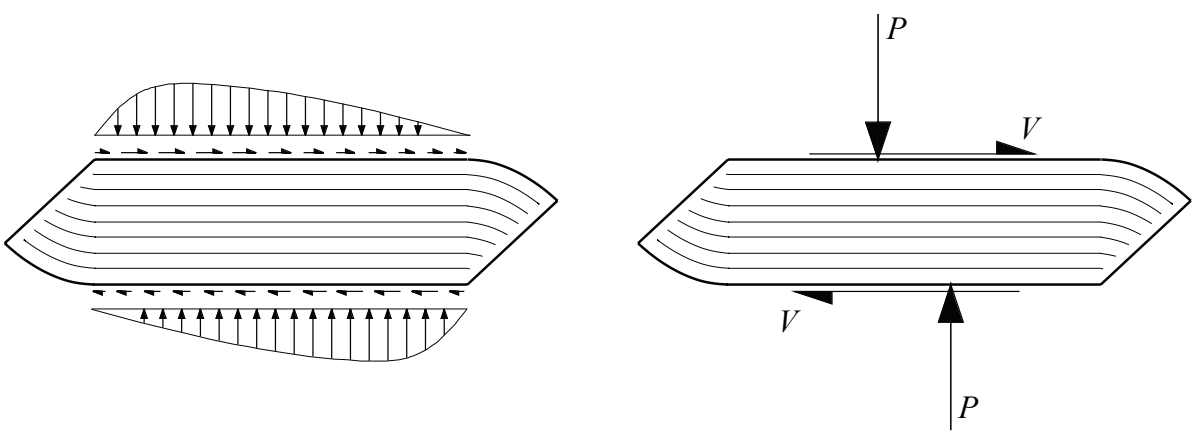

Figure 1. *Left*: Normal and shear stress distributions on the top and bottom faces of the unbonded bearing in its deformed shape. *Right*: The moment created by the offset of the resultant compressive loads, *P*, balances the moment created by the shear, *V*.

Table 1. Geometric characteristics of the steel-laminated elastomeric pads.

Bearing designation	Rubber height [mm (in.)]	No. of steel shims	Total height [mm (in.)]	Width [mm (in.)]	Depth [mm (in.)]
S-48	48 (1.89)	4	55.6 (2.19)	375 (14.76)	575 (22.64)
S-120	120 (4.72)	10	139.0 (5.47)	375 (14.76)	575 (22.64)
S-204	204 (8.03)	17	236.3 (9.30)	375 (14.76)	575 (22.64)

The bearings as tested in this test series survived very large shear strains, comparable to those expected of conventional seismic isolators under seismic loading. However their cost is in the hundreds of dollars as compared to the cost of conventional seismic isolators for bridges in the thousands of dollars.

BEARING DESIGNS AND RUBBER PROPERTIES

A set of three pairs of plain elastomeric pads were designed for the test program, all having the same plan dimensions 375mm by 575mm with rubber thicknesses varying from 48mm through 120mm to 204mm. The rubber compound was Neoprene (polychloroprene) with a hardness of 55 (shore). Each intermediate rubber layer was 12mm thick while the top and bottom rubber layers were 6mm thick. The bearings were laminated with 14-ga (1.9mm) A1011 steel shims. Table 1 shows detailed geometric properties of the bearings. These designs were forwarded to Scougal

Table 2. Material Certificate of Compliance provided by Scougal Rubber.

MATERIAL: 2-526 55 DUROMETER NEOPRENE
LOT: 18846A & 18846B

ASTM	PHYSICAL PROPERTIES	REQUIRED	RESULTS
D2240	- Hardness, Durometer +/- 5 Maximum	55	57
D412	- Tensile Strength, Psi Minimum	2250	3187
D412	- Elongation at Break, % Minimum	350	611
D573	OVEN AGED - 70 hours @ 212 F		
	- Hardness, Durometer Change Maximum	15	5
	- Tensile, % Change Maximum	-15	4
	- Elongation, % Change Maximum	-40	-15
D395	COMPRESSION SET		
	- Method B, 22 hours @ 212 F % Maximum	25	11
D624	TEAR STRENGTH		
	- Cured at 280 F, psi minimum	180	283
D4014	SHEAR MODULUS		
	- Tested @ 73° F, 98 - 120 PSI	109	117
D429	ADHESION		
	- Method B - Bond during vulcanization		
	- Pounds / inch minimum	40	72
D1149	OZONE 100 pphm in air by volume		
	- 20% strain, 104 +/- 3.6 F @ 100 hours	No Cracks	No Cracks
	- Mounting procedure D518, Proc. A		
D2137	LOW TEMPERATURE BRITTLENESS		
	- Method A, Grade 3 @ -40 C	No Failures	No Failures
D4014	BEARING COMPRESSION TEST		
	- Test @ 1.5 times max. design load	PASS	PASS

Rubber Corporation for assessment and bid. The resulting bearings were obtained from the manufacturer for a price of $3954 on November 2nd and forwarded to the SMRD Test Facility at the University of California at San Diego.

The material test properties of the elastomer are given in Table 2.

ULTIMATE DISPLACEMENT OF UNBONDED BEARINGS

The highly favorable response of an isolator which is not bonded to the top or bottom plates is due to the elimination of tension in the elastomer. In a bonded bearing under the simultaneous action of shear and compression, the presence of an unbalanced moment at both top and bottom surfaces produces a distribution of tensile stresses in the triangular region outside the overlap between top and bottom. The compression load is carried through the overlap area, and the triangular regions created by the shear displacement provide the tensile stresses to balance the moment. These tensile stresses must be sustained by the elastomer and also by the bonding between the elastomer and the steel reinforcement plates. The provision of these bonding requirements is the main reason for the high cost of current designs of isolator bearings for buildings. With the elimination of these tension stresses, the bonding requirements for this new type of bearing are reduced.

In the thermal expansion bearings that are the subject of this study, the steel reinforcing plates are relatively thin compared to the reinforcing in current designs of building isolators. This flexibility allows the unbonded surfaces to roll off the loading surfaces and thus relieves the tensile stresses that would be produced if the top and bottom surfaces of the bearing were bonded. This in turn puts much lower demands on the internal bonding between elastomer and reinforcing.

The experimental results show that the roll-off response is limited by the fact that the free edge of the bearing rotates from the vertical towards the horizontal with increasing shear displacement, and the limit of this process is reached when the originally vertical surfaces at each side come in contact with the horizontal surfaces at both top and bottom. Further horizontal displacement beyond this point can only be achieved by slip. The friction factor between rubber and other surfaces often can take very large values, possibly as high as 1, and slip can produce damage to the bearing through tearing of the surface, distortion of the reinforcing steel, and heat generated by the sliding motion (see Figure 2).

Thus the maximum displacement for a bearing of this type can be specified as that which transforms the vertical free edge to a horizontal plane. In the normal situation, where the bearing thickness is small in comparison to the plan dimension in the direction of loading, this can be estimated by studying only the deformation of one side and neglecting the interaction between the deformations at each end.

TEST PROGRAM

The test program on the elastomeric pads included a number of sinusoidal input signals varying in frequency and amplitude. The tests were conducted under a high vertical load of 401kips (corresponding to 1200psi average vertical pressure) and a low vertical load of 67kips (200psi average vertical pressure). The pads were tested with 0° rotation as well as with a 1.5^o rotation about the axis transverse to the loading axis. This imposed rotation was intended to replicate the in-situ boundary conditions where the bridge girder supported by the bearing may be rotated.

Figure 2. Damage caused due to slipping that is induced after the originally vertical free edges of the bearing come in contact with the horizontal surfaces at both top and bottom.

10- and 50-cycle serviceability tests at shear strains up to 50% and frequencies up to 0.33Hz were conducted. The recorded load-displacement loops indicated that the response of the bearings did not get affected by repeated cycles.

To test the response of the bearings to loading conditions that would result from earthquake shaking, 3-cycle signals with various amplitudes ranging from 100% up to 300% shear strain and frequencies up to 0.9Hz were used. Figure 3 shows a photograph of the S-120 pad at about 150% shear strain. For each pad, the tests were carried no further than the shear strain that would result

Figure 3. The corners of the S-120 Scougal elastomeric pad rolling off the top and bottom supports as the bearing is sheared in the direction pointed by the arrow. The gleaming ribs on the side of the bearing indicate the flexing of the reinforcing steel shims.

in the originally vertical face becoming horizontal since further shearing resulted in damage. Figure 2 shows such damage that resulted when the S-48 bearing was sheared to 300% strain.

Figure 4 shows typical load-displacement loops recorded during the test; these are for the unrotated S-120 bearing subjected to a signal with shear strain amplitude 150% (7.1in. peak displacement) and frequency 0.4Hz (17.6in./s peak velocity). The top graph is for a vertical load of 401kips while the bottom graph is for 67kips. Table 3 shows a complete list of the tests that were conducted on the unrotated S-120 bearing together with selected results extracted from the recorded data. On the top half of the table, the tests are ordered in terms of peak velocity while the vertical load is fixed. The dashed lines separate tests of different shear strains. This ordering allows us to point out that the value of Q is not conclusively dependent on the loading rate although it does increase with increasing peak shear strain; the horizontal stiffness, K, is independent of loading rate but decreases with peak shear strain; the energy dissipated per cycle, *EDC*, is also fairly rate-independent except for larger strains (150%) for which the *EDC* increases slightly with loading rate. The bottom half of Table 3 orders the tests in terms of vertical load for fixed loading frequency. Again the dashed lines separate tests of different shear strain. This ordering shows that Q increases with vertical load, yet this increase becomes less pronounced for the larger strain tests; under lower vertical load, the bearing is slightly stiffer; there is a very small increase in the *EDC* with increasing vertical load.

ACKNOWLEDGEMENTS
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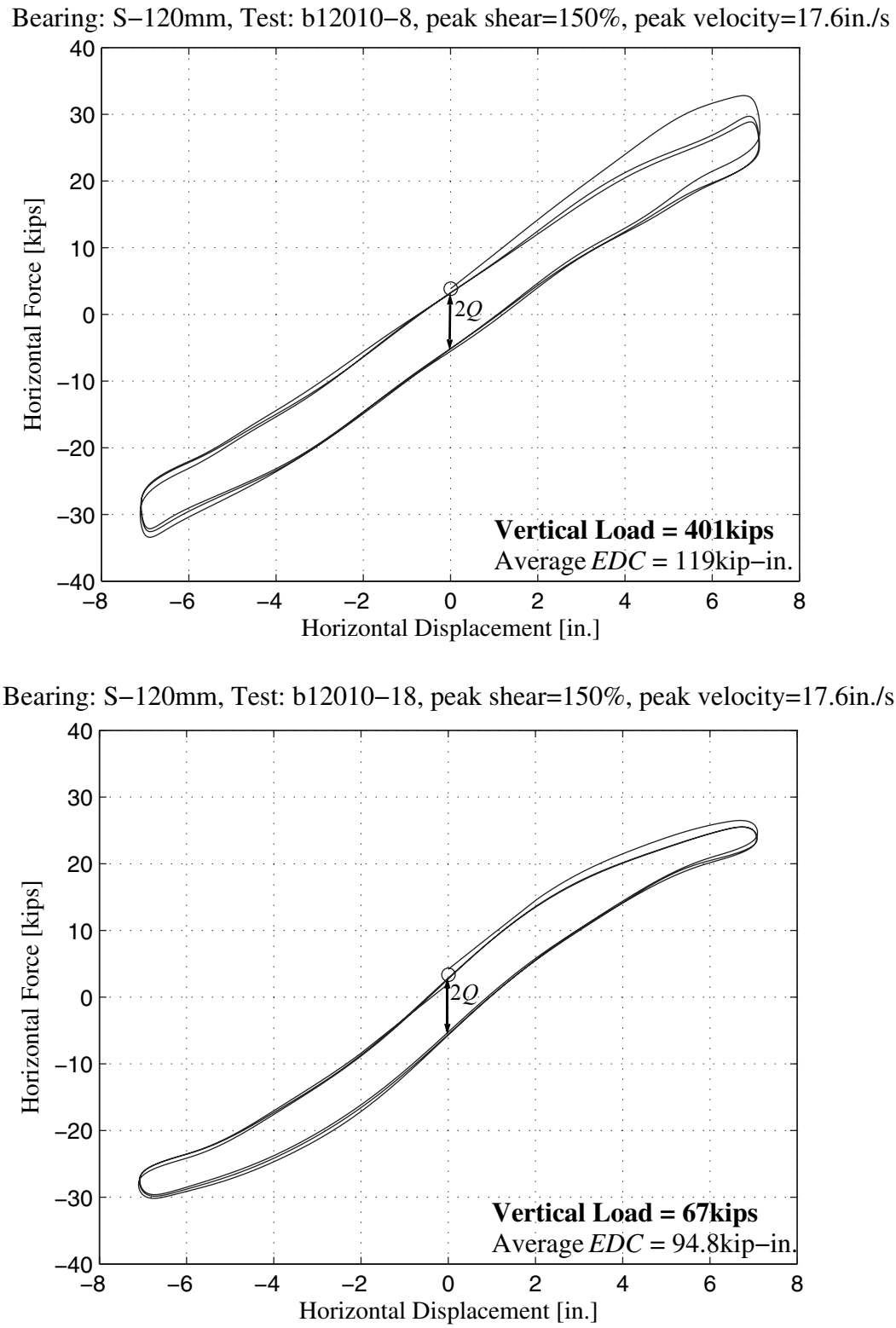

Figure 4. Recorded load-displacement histories for two cyclic test performed on the 120-mm-tall elastomeric pad.

Table 3. Selected results extracted from the cyclic tests on the S-120 elastomeric pad.

Specimen: S-120 bearing at 0 degrees (transverse loading)

As a function of peak velocity (same vertical load, same strain)

Test number	vert. load [kips]	# of cycles	shear strain [%]	v_{peak} [in./s]	Q_{ave} [kips]	K_{ave} [kips/in.]	EDC [kip-in.]
b12010-01	401	50	25	**0.15**	1.6	7.5	7
b12010-02	401	10	25	**1.14**	1.9	7.4	8
b12010-03	401	10	50	**0.30**	2.7	6.0	24
b12010-04	401	10	50	**1.01**	2.6	6.0	22
b12010-05	401	3	100	**11.76**	4.0	5.7	55
b12010-07	401	3	101	**16.68**	3.4	5.6	56
b12010-08	401	3	150	**17.64**	4.3	4.5	119
b12010-10	401	3	151	**25.03**	4.8	4.6	129
b12010-11	67	10	25	**0.16**	1.3	8.5	6
b12010-12	67	10	24	**1.12**	1.1	7.5	5
b12010-13	67	10	50	**0.31**	2.2	7.1	20
b12010-14	67	10	50	**1.01**	1.7	6.9	14
b12010-15	67	3	100	**11.74**	3.5	5.8	51
b12010-17	67	3	100	**16.66**	3.4	5.9	50
b12010-18	67	3	150	**17.60**	4.6	4.8	95
b12010-20	67	3	151	**25.01**	5.1	5.0	112

As a function of vertical load (same peak velocity, same strain)

Test number	vert. load [kips]	# of cycles	shear strain [%]	v_{peak} [in./s]	Q_{ave} [kips]	K_{ave} [kips/in.]	EDC [kip-in.]
b12010-11	**67**	10	25	0.16	1.3	8.5	6
b12010-01	**401**	50	25	0.15	1.6	7.5	7
b12010-12	**67**	10	24	1.12	1.1	7.5	5
b12010-02	**401**	10	25	1.14	1.9	7.4	8
b12010-13	**67**	10	50	0.31	2.2	7.1	20
b12010-03	**401**	10	50	0.30	2.7	6.0	24
b12010-14	**67**	10	50	1.01	1.7	6.9	14
b12010-04	**401**	10	50	1.01	2.6	6.0	22
b12010-15	**67**	3	100	11.74	3.5	5.8	51
b12010-05	**401**	3	100	11.76	4.0	5.7	55
b12010-17	**67**	3	100	16.66	3.4	5.9	50
b12010-07	**401**	3	101	16.68	3.4	5.6	56
b12010-18	**67**	3	150	17.60	4.6	4.8	95
b12010-08	**401**	3	150	17.64	4.3	4.5	119
b12010-20	**67**	3	151	25.01	5.1	5.0	112
b12010-10	**401**	3	151	25.03	4.8	4.6	129