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MISSOURI COOPERATIVE HIGHWAY RESEARCH PROGRAM

FINAL REPORT 97-4

LONGITUDINAL RESTRAINT RESPONSE OF EXISTING BRIDGE BEARINGS

MISSOURI DEPARTMENT OF TRANSPORTATION
UNIVERSITY OF MISSOURI - COLUMBIA
FEDERAL HIGHWAY ADMINISTRATION

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16. Abstract

Sixteen Type D bridge bearings were cyclically tested to determine the bearing response to vertical and simulated longitudinal loads. The purpose of the tests is to examine the load-deformation characteristics and energy dissipation capabilities of bearings that have been in service for many years. The results are to be used to determine if existing in-place bearings may be utilized in seismic retrofitting of earthquake susceptible bridges.

The bearings were cycled 1.75 in. each direction 40 times in the "as received" state. After this initial test, another 40 cycle test was conducted. The desired friction force-deformation hysteretic loops were determined from the net horizontal force-deformation test results. The cycles were applied in a sinusoidal manner in deflection control with a 4 second period to simulate dynamic demand on the bearing.

A coulomb (dry) friction coefficient was calculated for each bearing. Although the bearing responses were not rectangular (due to deterioration in the bearings), an approximate coefficient of friction was determined.

Four of the bearings were tested statically to failure to examine the limit state response. The ultimate limit tests produced horizontal load-deformation data. The horizontal force was applied slowly in deflection control (8 in. in 6 minutes) while acquiring data until failure. The modes of failure were slipping over the anchor rods and separation of the bearing pin from the seat. The ultimate bearing tests showed that all four bearings were able to move over 5 inches longitudinally prior instability.

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LONGITUDINAL RESTRAINT RESPONSE OF EXISTING BRIDGE BEARINGS

Prepared For
MISSOURI DEPARTMENT OF TRANSPORTATION

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May 1997

in cooperation with
U.S. Department of Transportation
Federal Highway Administration

The opinions, findings, and conclusions in this
publication are not necessarily those of the Department of Transportation,
Federal Highway Administration

ABSTRACT

Sixteen Type D bridge bearings were cyclically tested to determine the bearing response to vertical and simulated longitudinal loads. The purpose of the tests is to examine the load-deformation characteristics and energy dissipation capabilities of bearings that have been in service for many years. The results are to be used to determine if existing in-place bearings may be utilized in seismic retrofitting of earthquake susceptible bridges.

The bearings were cycled 1.75 in. each direction 40 times in the "as received" state. After this initial test, another 40 cycle test was conducted. The desired friction force-deformation hysteretic loops were determined from the net horizontal force-deformation test results. The cycles were applied in a sinusoidal manner in deflection control with a 4 second period to simulate dynamic demand on the bearing.

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TABLE OF CONTENTS

Page

INTRODUCTION AND OBJECTIVES 1

Hysteretic Behavior Characteristics 1

Force-Deformation Relations 2

Ultimate Horizontal Force-Deformation Limit 2

TESTING APPARATUS 2

CYCLIC BRIDGE BEARING TESTS 3

ULTIMATE BRIDGE BEARING TESTS 4

ADDITIONAL WORK PERFORMED 5

SUMMARY 6

LIST OF FIGURES

Page

FIGURE 1 BRIDGE BEARING TEST SETUP 7
FIGURE 2 HYSTERESIS LOOP AND RELATED MOVEMENTS AND FORCES 8
FIGURE 3 TEST SETUP FOR DETERMINING APPARATUS RESPONSE 9
FIGURE 4 HYSTERESIS LOOP FOR TEST APPARATUS 10
FIGURE 5 BEARING A1005_2 11
FIGURE 6 BEARING A1005_2 FIRST 3 CYCLES 11
FIGURE 7 BEARING A1005_2 FIRST 40 CYCLES 12
FIGURE 8 BEARING A1005_2 SECOND 40 CYCLES 12
FIGURE 9 BEARING A1005_3 13
FIGURE 10 BEARING A1005_3 FIRST 3 CYCLES 13
FIGURE 11 BEARING A1005_3 FIRST 40 CYCLES 14
FIGURE 12 BEARING A1005_3 SECOND 40 CYCLES 14
FIGURE 13 BEARING A1005_4 15
FIGURE 14 BEARING A1005_4 FIRST 3 CYCLES 15
FIGURE 15 BEARING A1005_4 FIRST 40 CYCLES 16
FIGURE 16 BEARING A1005_4 SECOND 40 CYCLES 16
FIGURE 17 BEARING A1005_5 17
FIGURE 18 BEARING A1005_5 FIRST 3 CYCLES 17
FIGURE 19 BEARING A1005_5 FIRST 40 CYCLES 18
FIGURE 20 BEARING A1005_5 SECOND 40 CYCLES 18
FIGURE 21 BEARING A860_1 19
FIGURE 22 BEARING A860_1 FIRST 3 CYCLES 19
FIGURE 23 BEARING A860_1 FIRST 40 CYCLES 20
FIGURE 24 BEARING A860_1 SECOND 40 CYCLES 20
FIGURE 25 BEARING A860_2 21
FIGURE 26 BEARING A860_2 FIRST 3 CYCLES 21
FIGURE 27 BEARING A860_2 FIRST 40 CYCLES 22
FIGURE 28 BEARING A860_2 SECOND 40 CYCLES 22
FIGURE 29 BEARING A860_3 23
FIGURE 30 BEARING A860_3 FIRST 3 CYCLES 23
FIGURE 31 BEARING A860_3 FIRST 40 CYCLES 24
FIGURE 32 BEARING A860_3 SECOND 40 CYCLES 24
FIGURE 33 BEARING A860_4 25
FIGURE 34 BEARING A860_4 FIRST 3 CYCLES 25
FIGURE 35 BEARING A860_4 FIRST 40 CYCLES 26
FIGURE 36 BEARING A860_4 SECOND 40 CYCLES 26
FIGURE 37 BEARING A860_5 27
FIGURE 38 BEARING A860_5 FIRST 3 CYCLES 27
FIGURE 39 BEARING A860_5 FIRST 40 CYCLES 28
FIGURE 40 BEARING A860_5 SECOND 40 CYCLES 28
FIGURE 41 BEARING A860_6 FIRST 3 CYCLES 29
FIGURE 42 BEARING A860_6 FIRST 40 CYCLES 29
FIGURE 43 BEARING A860_6 SECOND 40 CYCLES 30
FIGURE 44 BEARING A860_7 FIRST 3 CYCLES 31
FIGURE 45 BEARING A860_7 FIRST 40 CYCLES 31
FIGURE 46 BEARING A860_7 SECOND 40 CYCLES 32
FIGURE 47 BEARING A860_8 FIRST 3 CYCLES 33
FIGURE 48 BEARING A860_8 FIRST 40 CYCLES 33
FIGURE 49 BEARING A860_8 SECOND 40 CYCLES 34
FIGURE 50 BEARING L_1 35
FIGURE 51 BEARING L_1 SECOND 40 CYCLES 35
FIGURE 52 BEARING L_2 36

FIGURE 53 BEARING L_2 FIRST 3 CYCLES 36
FIGURE 54 BEARING L_2 FIRST 40 CYCLES 37
FIGURE 55 BEARING L_2 SECOND 40 CYCLES 37
FIGURE 56 BEARING L_3 FIRST 3 CYCLES 38
FIGURE 57 BEARING L_3 FIRST 40 CYCLES 38
FIGURE 58 BEARING L_3 SECOND 40 CYCLES 39
FIGURE 59 BEARING A1005_2 ULTIMATE TEST 40
FIGURE 60 BEARING A860_4 ULTIMATE TEST 40
FIGURE 61 BEARING L_1 ULTIMATE TEST 41
FIGURE 62 BEARING L_2 ULTIMATE TEST 41
FIGURE 63 BEARING A1005_2 42
FIGURE 64 BEARING L_1 42
FIGURE 65 BEARING A1005_4 40 CYCLES AT 50 KIPS 43
FIGURE 66 BEARING A1005_4 40 CYCLES AT 25 KIPS 43
FIGURE 67 BEARING A860_3 40 CYCLES AT 25 KIPS (180 DEGREES ROTATED) 44
FIGURE 68 BEARING A860_3 40 CYCLES AT 25 KIPS (ORIGINAL POSITION) 44
FIGURE 69 BEARING A1005_4 40 CYCLES (BRUSHED AND GREASED) 45

LONGITUDINAL RESTRAINT RESPONSE OF EXISTING BRIDGE BEARINGS

INTRODUCTION AND OBJECTIVES

The University of Missouri – Columbia Department of Civil Engineering has contracted with the Missouri Department of Transportation to test Type D bridge roller bearings for longitudinal restraint behavior. The purpose of the tests is to examine the load-deformation characteristics and energy dissipation capabilities of bearings that have been in service for many years. The results are to be used to determine if existing in-place bearings may be utilized in seismic retrofitting of earthquake susceptible bridges.

Sixteen Type D bridge bearings were tested to determine the bearing response to vertical and simulated longitudinal loads. MoDOT desires experimental data addressing three main bearing response topics:

1. Energy dissipation characteristics,
2. Friction forces in the bearings, and
3. Bearing deflection limit response.

These topics were examined during an experimental program where the 16 bearings were tested dynamically in the expected working range and 4 bearings were tested statically to failure. Although the bearings were all Type D, there were two different footprint geometries tested, 14.5 in. and 16.5 in. anchor hole bases.

The bearings were tested as shown in Figure 1. The design vertical bearing load on the south actuator of Figure 1 was 75 kips. The north actuator was used to stabilize the beam with very little load and the horizontal actuator applied the simulated longitudinal movement.

Hysteretic Behavior Characteristics

The bearings were cycled 1.75 in. each direction (except one bearing which was 1.50 in. and one at 2.0 in.) 40 times in the "as received" state. After this initial test, another 40 cycle test was conducted. The desired friction force-deformation hysteretic loops can be determined from the net horizontal force-deformation test results. The cycles were applied in a sinusoidal manner in deflection control with a 4 second period to simulate dynamic demand on the bearing.

The hysteretic loops illustrate the energy dissipation characteristics and whether there is degradation of the dissipation with number of cycles. The test results presented herein are explained in Figure 2. The net horizontal force is the resistance force from the bearing. It is determined from the horizontal actuator and the horizontal component of the vertical

actuators with respect to longitudinal displacement. A positive net horizontal force is defined as an external force to the north (pulling on the beam/bearing). Likewise, a positive horizontal deflection is defined as a beam position north of vertical. The longitudinal restraint of the bearing opposes movement (direction of velocity). Figure 2 illustrates the position, horizontal force, and velocity for the four quadrants of a typical cyclic test.

The cyclic test experimental plots presented in this report include hysteretic behavior from the bearing friction and the friction in the testing apparatus. Energy dissipation conclusions drawn from the results must subtract the effects of the testing apparatus. The test apparatus had a well defined hysteretic behavior (rectangular) with an equivalent coefficient of friction of 1.55% (see TESTING APPARATUS).

Force-Deformation Relations

The friction in the bearings can be thought of as coulomb (dry) friction. Although the bearing responses were not rectangular (due to deterioration in the bearings), an approximate coefficient of friction (equal to a percentage of the normal force) can be determined. The coefficient of friction in the test apparatus (loading ram) was 1.55%, determined prior to testing bearings by a similar test setup as shown in Figure 3. The bearings were subjected to slow moving horizontal movements to produce a horizontal force-deformation plot as illustrated in Figure 2. The figure contains the total (bearing plus apparatus) friction force-deformation relation.

The total coefficient of friction was determined by dividing the average friction force magnitude (upper and lower arms of Figure 2) by the normal force of 75 kips. The average friction force magnitude represents the restraint forces occurring above a frictionless state. The averages were based on a deflection range of ±1.25 in. (except for one bearing 1.0 in. was used) to avoid transition zones.

The coefficient of friction for the bearing alone is found by subtracting 1.55% (apparatus) from the total coefficient.

Ultimate Horizontal Force-Deformation Limit

The ultimate limit tests produced horizontal load-deformation data. The test setup is shown in Figure 1. The horizontal force was applied slowly in deflection control (8 in. in 6 minutes in the negative direction) while acquiring data until failure. The modes of failure were slipping over the anchor rods and separation of the bearing pin from the seat.

TESTING APPARATUS

When testing the friction or longitudinal restraint in the bridge bearings, the measured response also contains a component from the testing apparatus itself. The friction and

hysteretic behavior of the testing apparatus must be removed from the measured response to estimate that from the bearing.

A test was conducted to determine the response of the testing apparatus (Figure 3). Two actuators acted against each other in place of the bearing. The remaining setup was identical to the bearing test setup. It was assumed that the great majority of the friction was from the clevis pins in the heavily loaded actuators.

The actuators were cycled 1.75 in. each direction 40 times. The desired friction force-deformation hysteretic loops can be determined from the net horizontal force-deformation test results. The cycles were applied in a sinusoidal manner in deflection control with a 4 second period to simulate dynamic demand on the test apparatus.

The hysteretic loops illustrate the energy dissipation characteristics and whether there is degradation of the dissipation with number of cycles. Figure 4 shows the cyclic response of one apparatus test. The net horizontal force is the resistance force from the actuators. It is determined from the horizontal actuator and the horizontal component of the vertical actuators with respect to movement.

The test apparatus cyclic test experimental plot in Figure 4 includes hysteretic behavior from two actuators (assumed the primary energy dissipater). Bearing energy dissipation conclusions drawn from the results of the bearing tests must subtract one-half the effects of the testing apparatus.

The test apparatus had a well defined hysteretic behavior (rectangular) with an average coefficient of friction of 1.55% per actuator. Several tests were conducted with the friction coefficients ranging from 1.51% to 1.60%. The coefficient of friction was determined by dividing the average friction force magnitude (upper and lower arms of Figure 4) by the normal force of 75 kips. The average friction force magnitude represents the restraint forces occurring above a frictionless state. The coefficients were based on a deflection range of ±1.25 in. to avoid transition zones.

The coefficients of friction for the bearings were determined by subtracting 1.55% from the measured coefficient which contains resistance from the bearing and one actuator.

CYCLIC BRIDGE BEARING TESTS

Sixteen bearings were cyclically tested as described above. The results are shown in Figures 6 through 58. Each bearing (with one exception due to lost test data) has at least three figures associated with the results. Many have an initial picture of the bearing. The first experimental result figure is the hysteretic loops for the first 3 cycles. These are important since the initial response includes effects from pack rust crushing, rust dust pumping, and obstructions in the anchor rod holes. Some results are more prevalent than others.

The next figure for each bearing is the results for the initial 40 cycles. It shows how the bearings settle down to a uniform behavior. On this figure is also the estimated coefficient of friction from the 40 cycles as described earlier. The last figure is the second set of 40 cycles, conducted immediately after the first 40 cycles. It illustrates the steady-state force deformation response of the bearing.

The different bearings show different results. Many plots have significant dips and risers in the upper and lower arms of the behavior. This was observed to be due to the deterioration in the roller surface. Many of the bearings had flat surfaces that would force the beam to move vertically, whereas the bearings are designed to move strictly longitudinally (concentric circles). The dips and risers in the results correlate to the vertical movement (as they should).

The hysteretic loops illustrate the energy dissipation characteristics and whether there is degradation of the dissipation with number of cycles. The test results presented herein are explained in Figure 2. The cyclic test experimental plots presented in this report include hysteretic behavior from the bearing friction and the friction in the testing apparatus. Energy dissipation conclusions drawn from the results must subtract the effects of the testing apparatus. The test apparatus had a well defined hysteretic behavior (rectangular) with an equivalent coefficient of friction of 1.55% (see TESTING APPARATUS).

The coefficients of friction for the bearings were determined by subtracting 1.55% (testing apparatus) from the measured coefficient which contains the bearing and one actuator.

Sixteen bearings were tested cyclically. These included 5 bearings with a 14.5 in. footprint and 3 bearings with a 16.5 in. footprint from MoDOT Bridge A1005 and 8 bearings from MoDOT Bridge A860 with a 14.5 in. footprint. These are labeled as A1005_1 through A1005_5, L_1 though L_3, and A860_1 though A860_8, respectively. A1005_1 is not presented since it was used to setup and calibrate the test procedures and the results may be inappropriate. The bearing coefficients of friction are summarized in Table 1.

ULTIMATE BRIDGE BEARING TESTS

Four bearings were tested to determine the ultimate load-deformation characteristics. The results are shown in Figures 59 through 62. The bearings were tested using a stroke controlled ramp movement from the horizontal actuator as shown in Figure 1. The hydraulic ram was to ramp from zero to 8 in. in 6 minutes. Each bearing failed before obtaining an 8 in. horizontal deflection.

Two 14.5 in. footprint (A1005_2 and A860_4) and two 16.5 in. footprint (L_1 and L_2) bearings were tested. Figures 63 and 64 illustrate bearings at large horizontal displacements. The failure mode was the roller bearing surface slipping over the anchor rods for A1005_2 and L_2. A860_4 failed by losing the pin (shot out) and slipping of the pin sleeves with respect to each other. However, the pin sleeves were bearing on each other prior

to losing the pin. L_1 failed by slipping of the pin sleeves with respect to each other. In all the ultimate tests, a gap had developed between the pins and the sleeves prior to failure.

The ultimate test figures show a positive load in the beginning of each test. This represents the net horizontal load required to push the pin from the vertical position. After significant horizontal deflection, however, the horizontal load becomes negative. To remain in this position, a load must hold back the bearing because of the overturning (unstable) moment created by 75 kips at a relatively large deflection. The only reason the bearing does not fall over is that the test is run in deflection control. Hence, zero horizontal load indicates instability. The Type D bearings were all able to move over 5 inches longitudinally prior to zero load instability. The load in the load-deflection plots also contain longitudinal resistance from the testing apparatus.

TABLE 1 Bearing Coefficients of Friction

Bearing	Deterioration	Coeff. of Friction 1st 40 Cycles	Coeff. of Friction 2nd 40 Cycles	Relating Figures
A1005_1	Heavy	N/A	N/A	N/A
A1005_2	Heavy	6.87%	7.00%	6-8,59[1]
A1005_3	Heavy	9.79%	8.80%	9-12
A1005_4	Heavy	8.90%	8.98%	13-16
A1005_5	Heavy	9.64%	8.66%	17-20
A860_1	Mild	3.22%	3.26%	21-24
A860_2	Mild	3.57%	3.31%	25-28
A860_3	Mild	2.68%	2.39%	29-32
A860_4	Mild	2.54%	3.01%	33-36,60[1]
A860_5	Mild	3.11%	2.63%	37-40
A860_6	Mild	3.41%	3.47%	41-43
A860_7	Mild	3.33%	3.15%	44-46
A860_8	Mild	2.95%	3.28%	47-49
L_1	Mild	Lost Data	4.38%	50-51,61[1]
L_2	Mild	3.58%	3.38%	52-55,62[1]
L_3	Mild	3.27%	3.59%	56-58

[1] Ultimate Test Bearing

ADDITIONAL WORK PERFORMED

To examine the variability of the coefficients of friction, the bearings were tested at 50 and 25 kip vertical loads to compare with the 75 kip results. Figures 65 and 66 illustrate the cyclic response for bearing A1005_4 at 50 and 25 kips. The coefficients of friction are 9.23% and 9.52%, respectively. These compare well with 9.64% and 8.66% shown in Figures 19 and 20 for 75 kips. Similar comparisons were found for the other bearings.

Two additional items not specified in the contract were performed due to the perceived importance of the results. The first examined the consistency of the dips and risers in the cyclic test results. Bearing A860_3, which had a significant dip, was turned 180° and retested at a 25 kip vertical load. Figure 67 illustrates that the behavior was nearly identical, although reversed, to an original position test shown in Figure 68 for a 25 kip vertical load.

The second item dealt with the effect of the corrosion on the coefficient of friction. Bearing A1005_4 had a 2nd 40 cycle coefficient of friction of 8.66% as shown in Figure 20. After this test, the bearing was cleaned with a wire brush and the pin was greased. Another 40 cycles were applied to compare to the "as received condition." Figure 69 shows the 75 kip vertical load cyclic test for the cleaned and greased bearing. The coefficient of friction dropped from 8.66% to 2.99%.

SUMMARY

The purpose of testing 16 roller bearings is to examine the load-deformation characteristics and energy dissipation capabilities of bearings that have been in service for many years. The results are to be used to determine if existing in-place bearings may be utilized in seismic retrofitting of earthquake susceptible bridges. Sixteen Type D bridge bearings were tested to determine the bearing response to vertical and simulated longitudinal loads. Four bearings were tested to determine the ultimate load-deformation characteristics.

The cyclic test results presented in this report include hysteretic behavior from the bearing friction and the friction in the testing apparatus. Energy dissipation conclusions drawn from the results must subtract the effects of the testing apparatus. The test apparatus had a well defined hysteretic behavior (rectangular) with an equivalent coefficient of friction of 1.55%.

The coefficients of friction for the bearings (Table 1) were determined by subtracting 1.55% (testing apparatus) from the measured coefficient which contains the bearing and one actuator.

The ultimate bearing tests showed that all four bearings were able to move over 5 inches longitudinally prior to zero load instability.

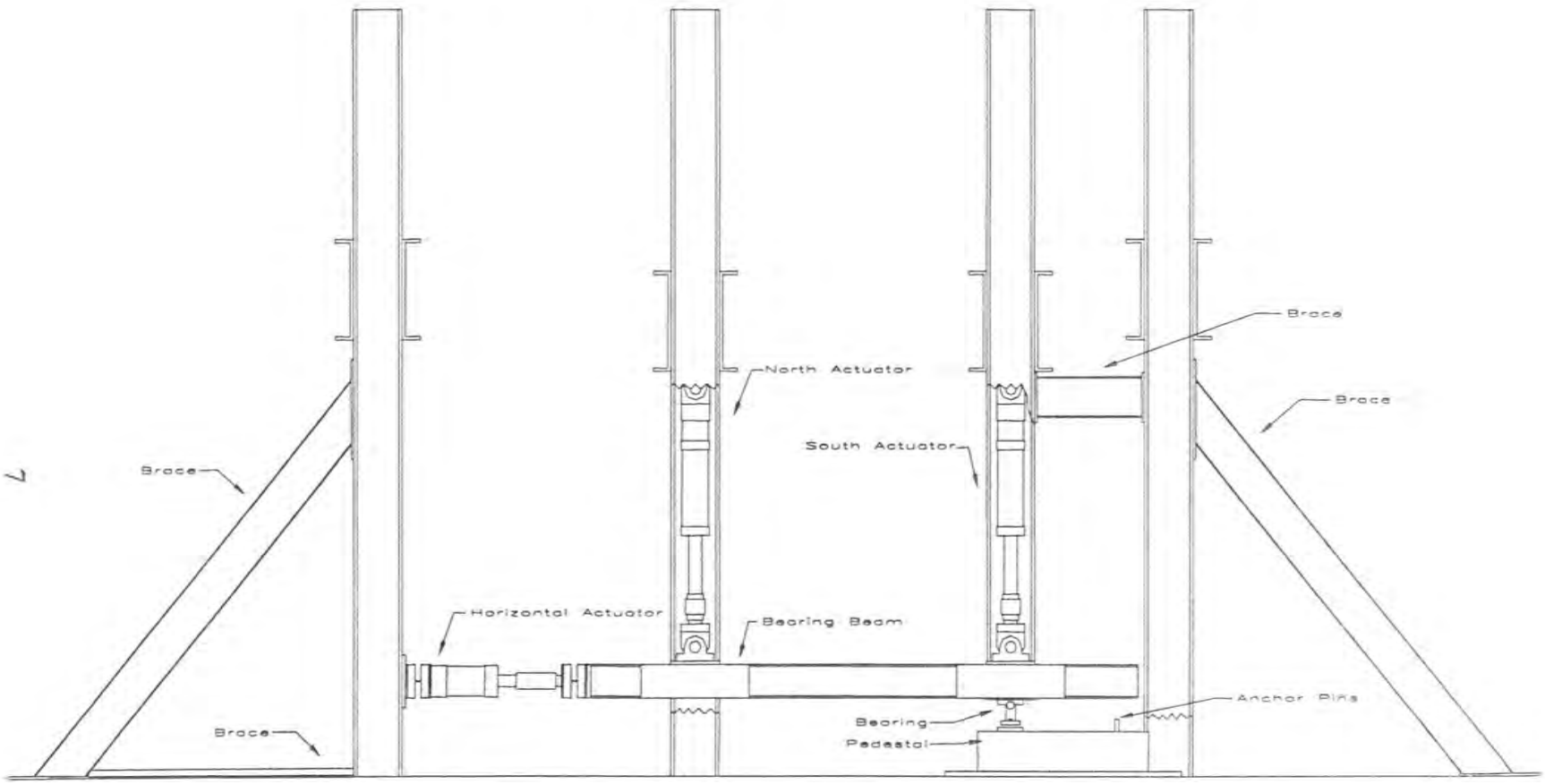

Figure 1 Bridge Bearing Test Setup

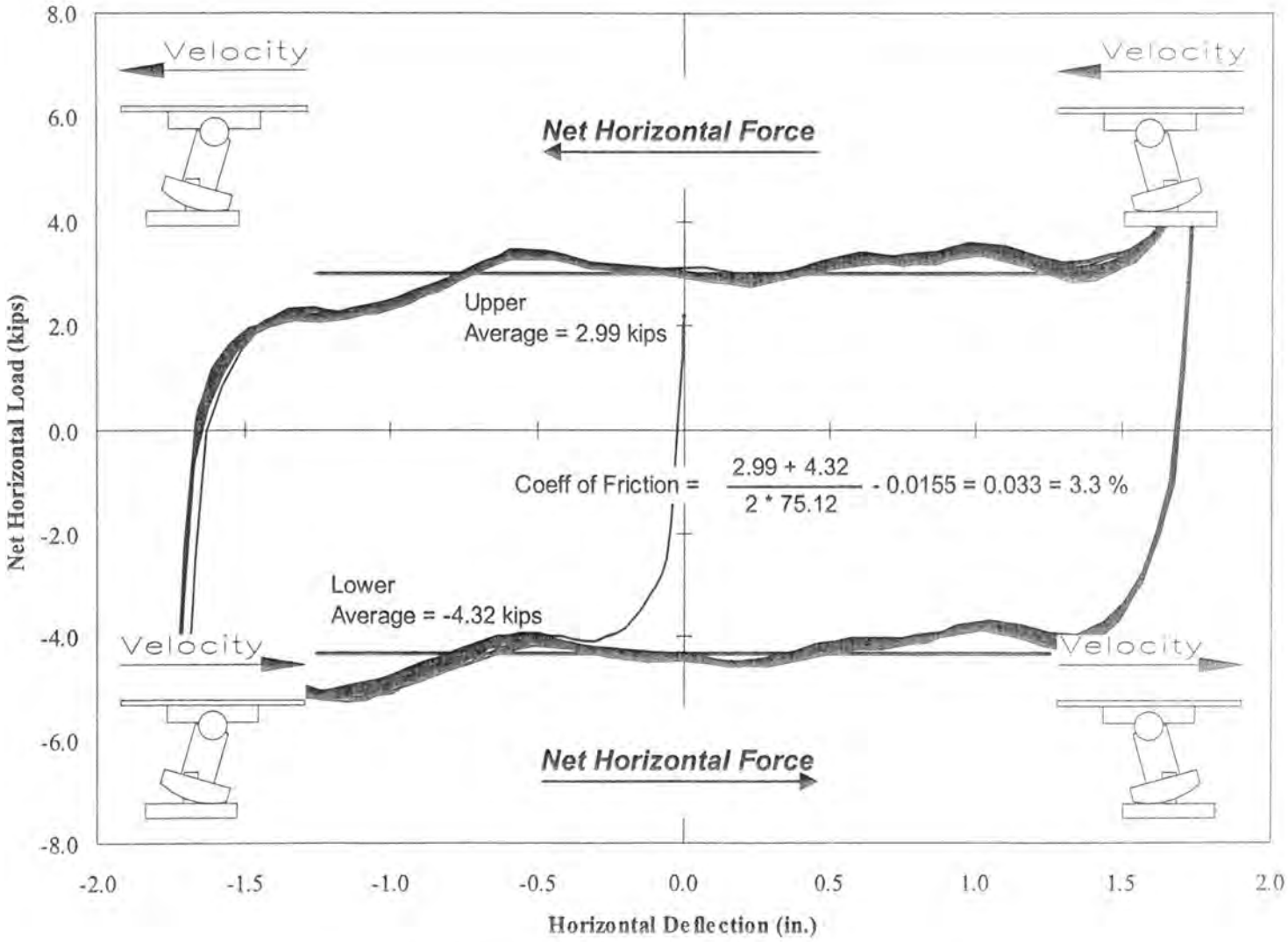

Figure 2 Hysteresis Loop and Related Movements and Forces

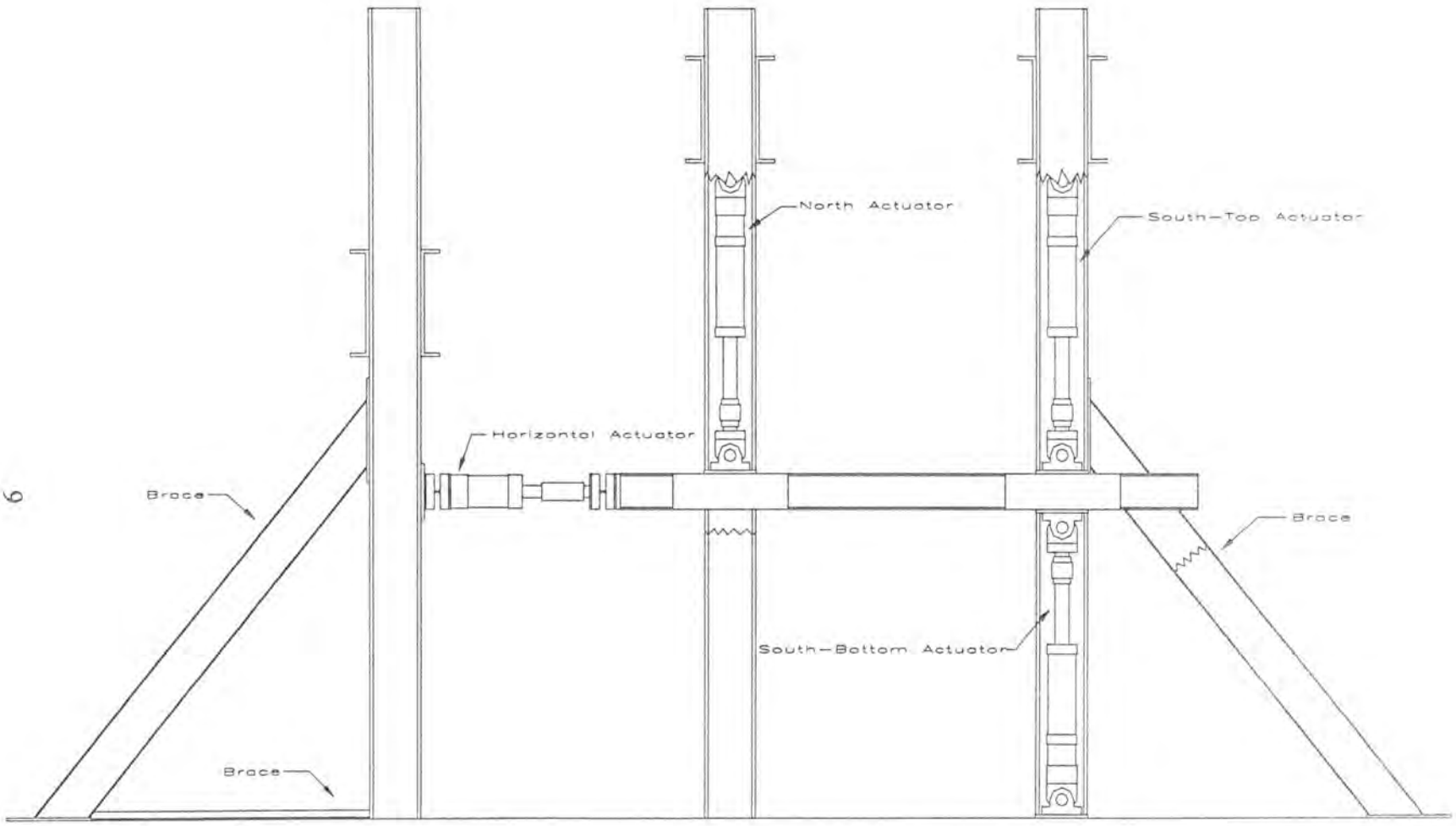

Figure 3 Test Setup for Determining Apparatus Response

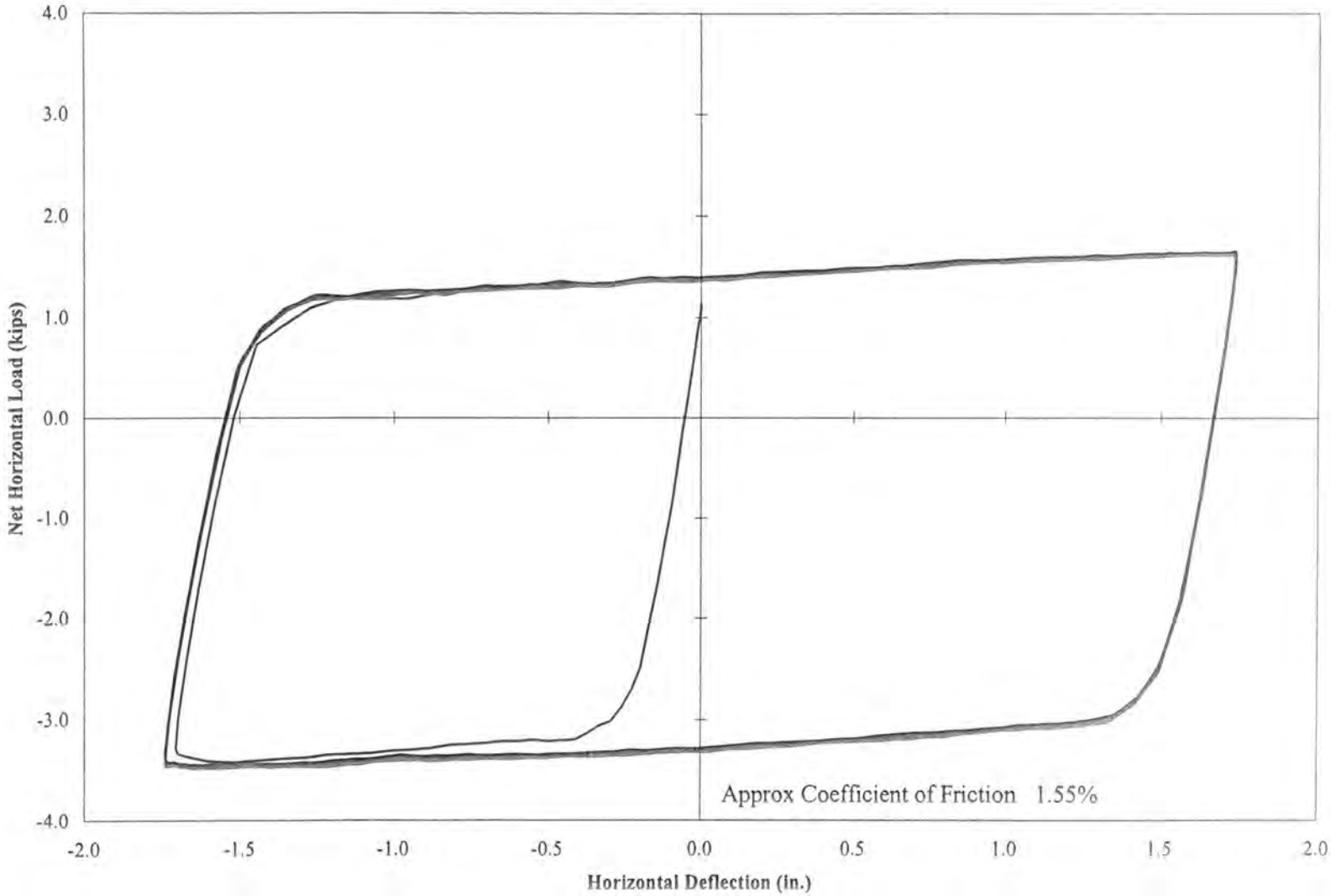

Figure 4 Hysteresis Loop for Test Apparatus

Figure 5 Bearing A1005_2

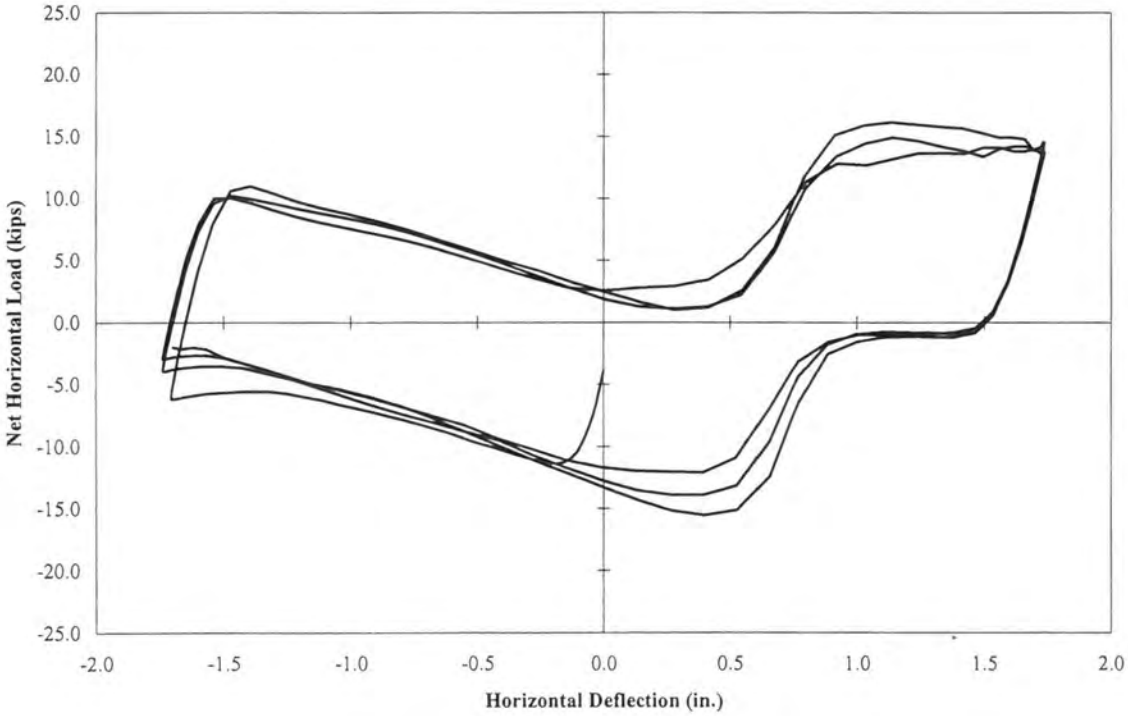

Figure 6 Bearing A1005_2 First 3 Cycles

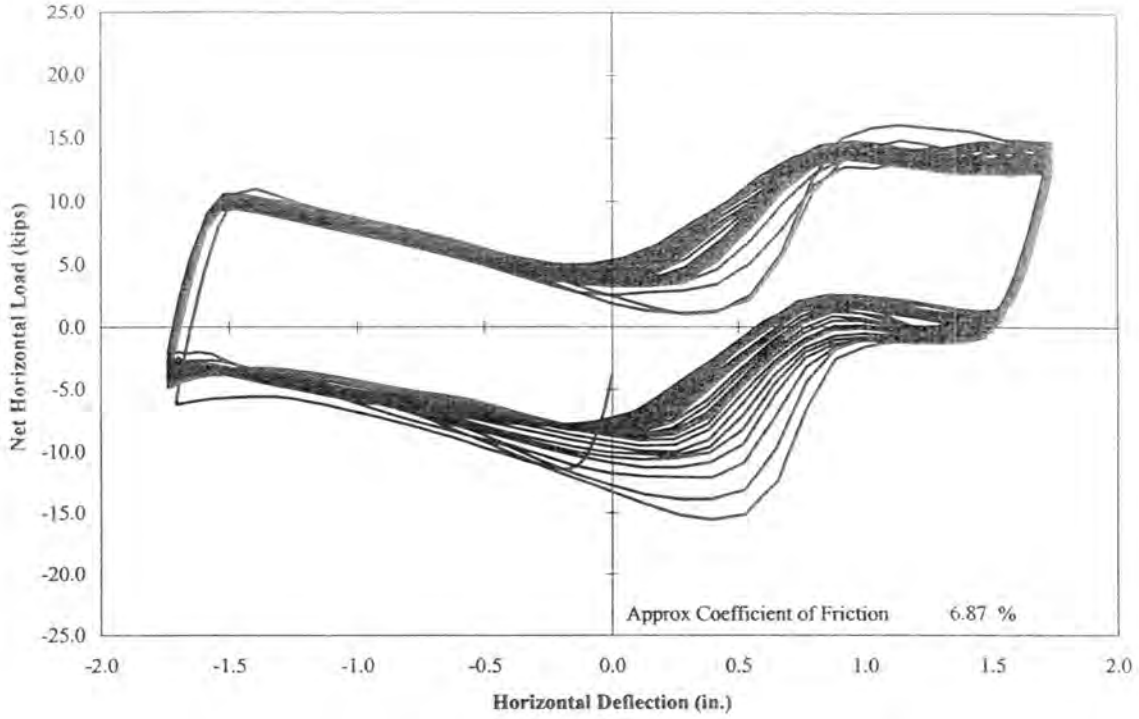

Figure 7 Bearing A1005_2 First 40 Cycles

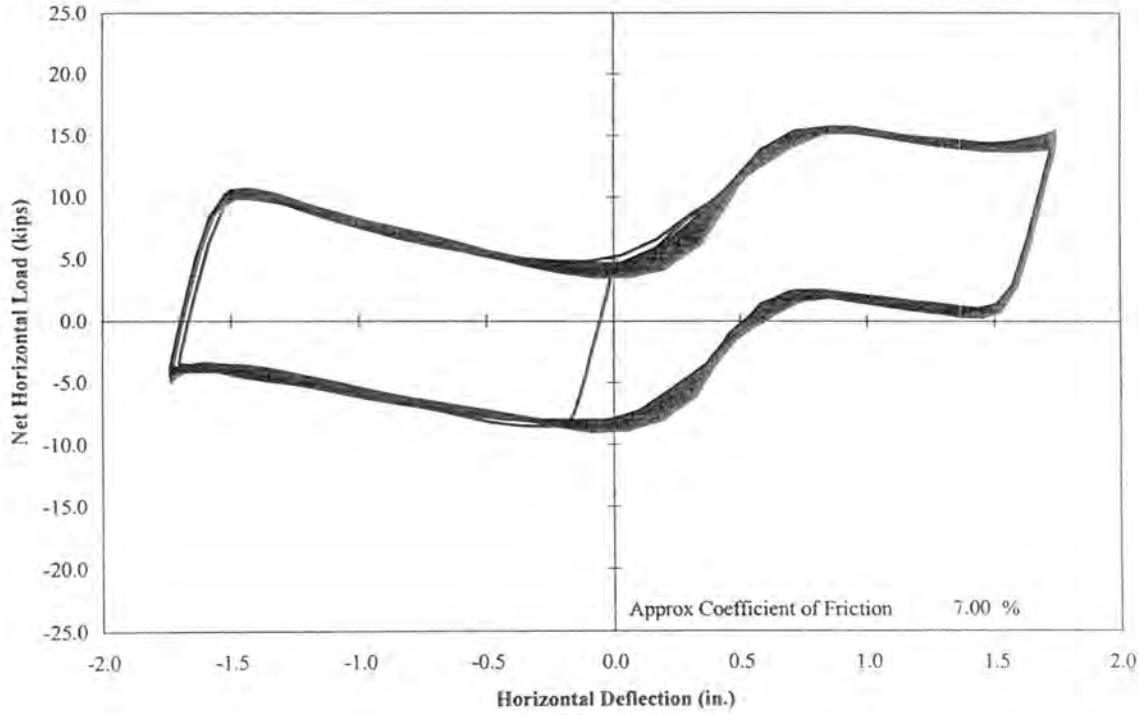

Figure 8 Bearing A1005_2 Second 40 Cycles

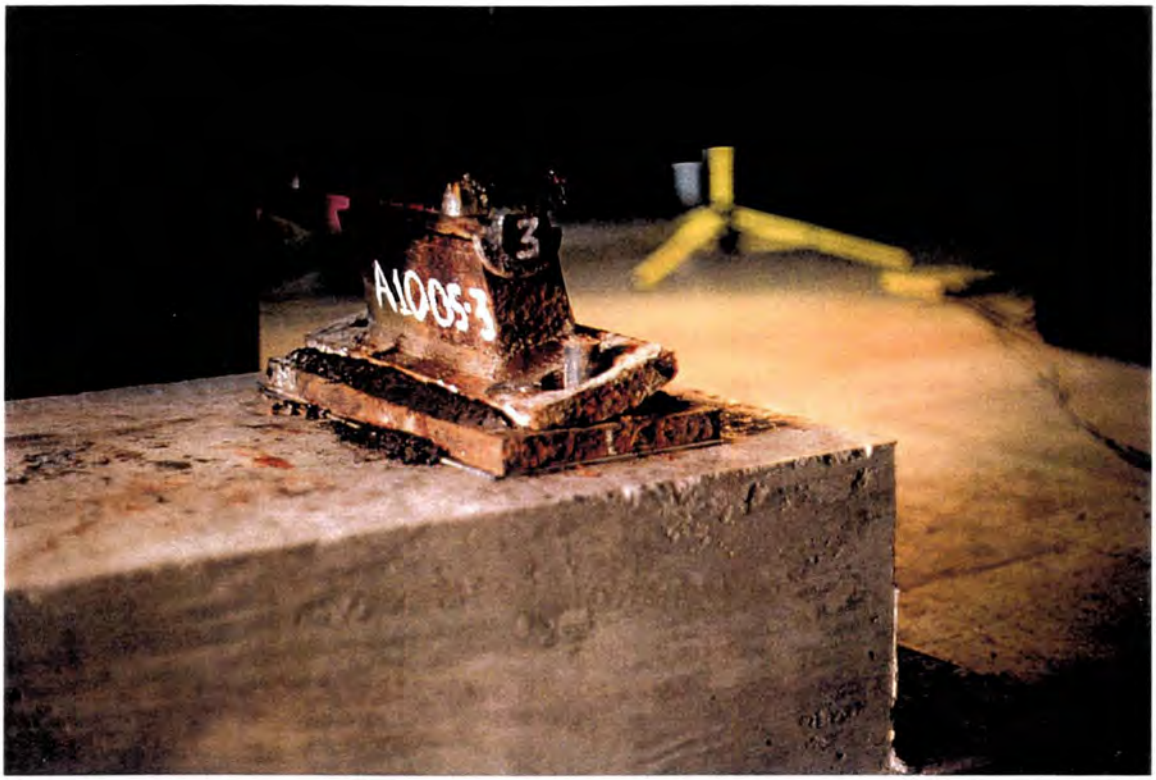

Figure 9 Bearing A1005_3

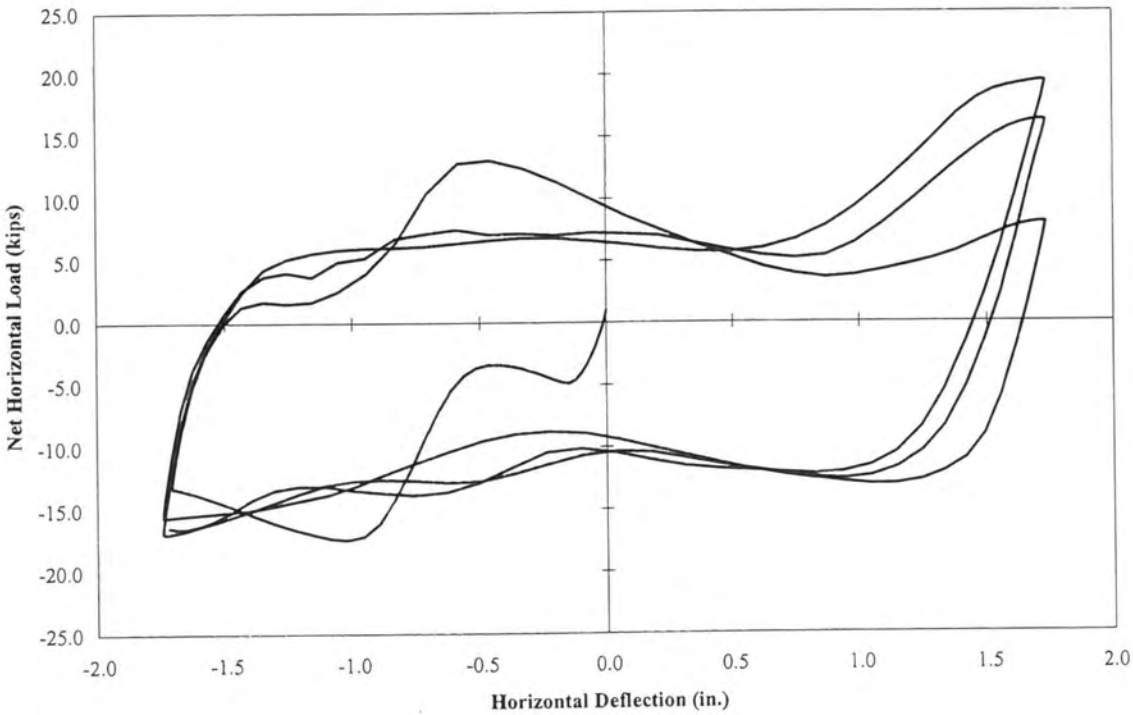

Figure 10 Bearing A1005_3 First 3 Cycles

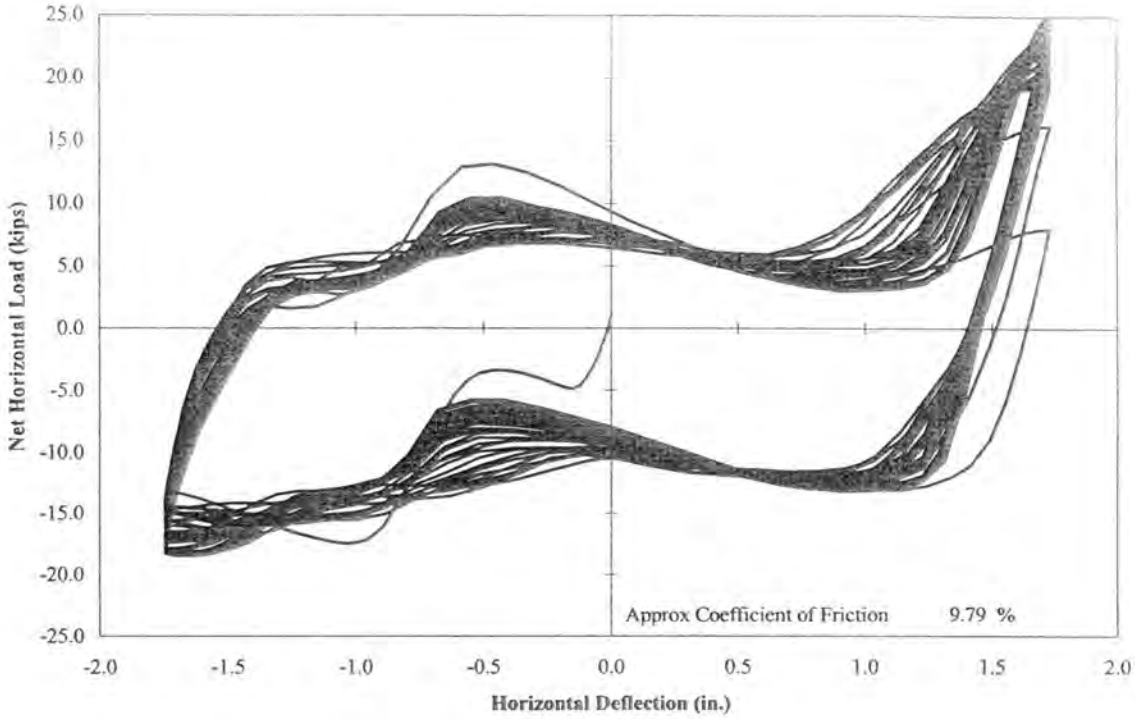

Figure 11 Bearing A1005_3 First 40 Cycles

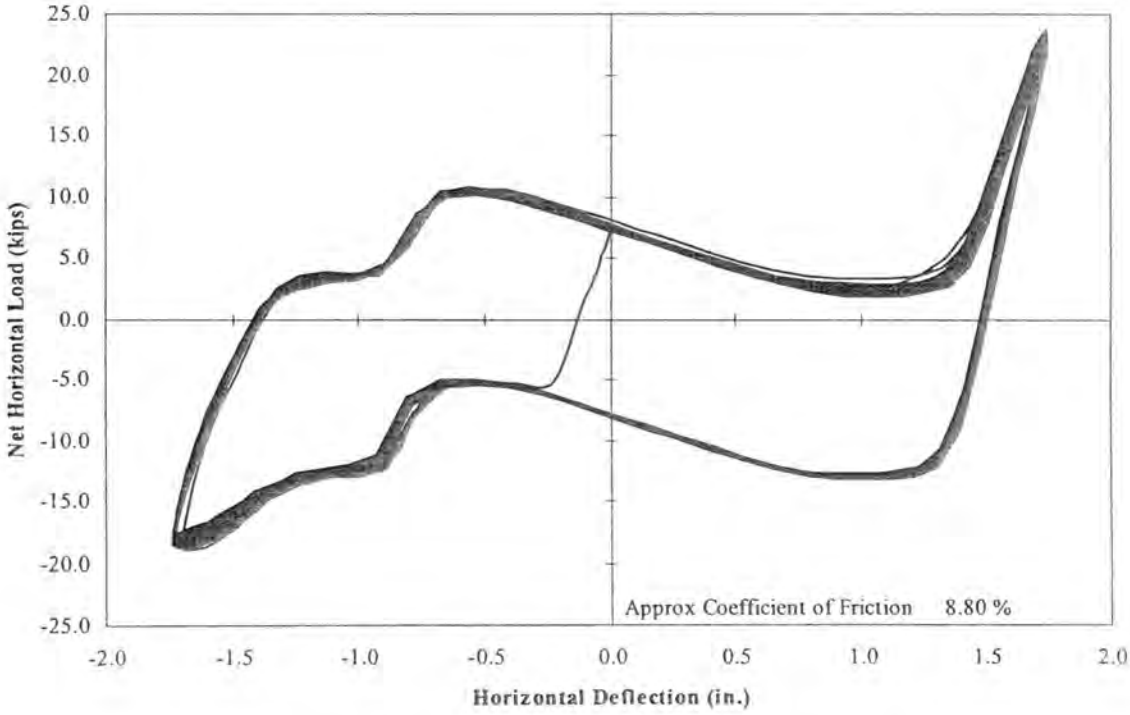

Figure 12 Bearing A1005_3 Second 40 Cycles

Figure 13 Bearing A1005_4

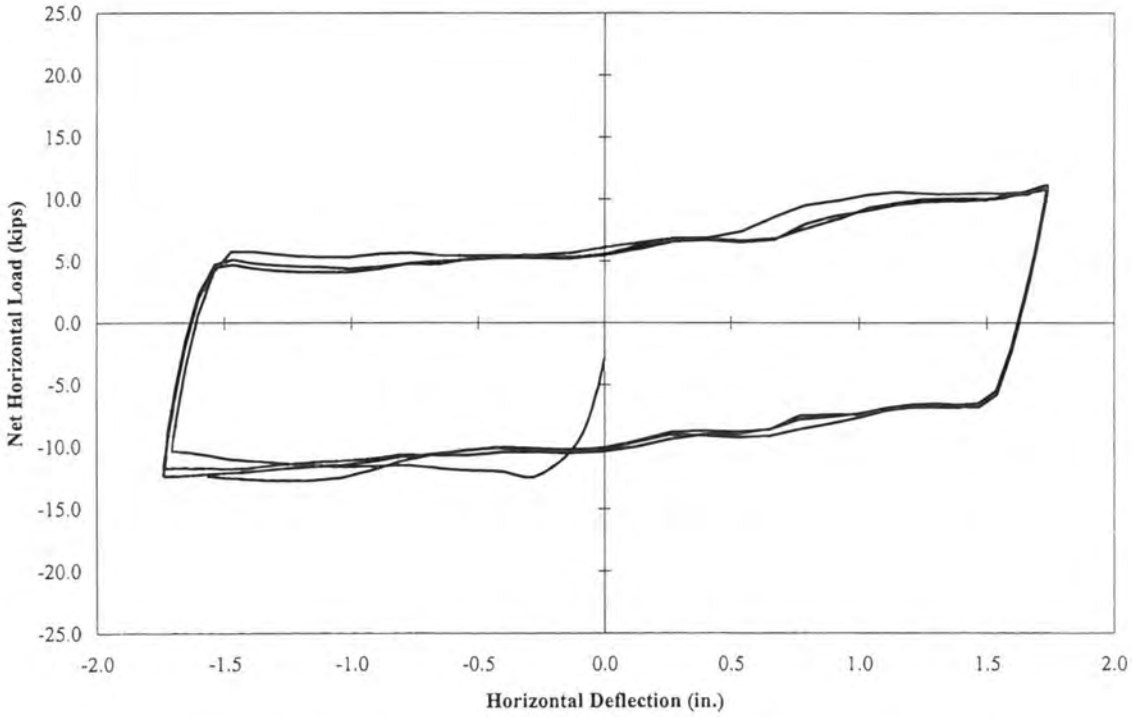

Figure 14 Bearing A1005_4 First 3 Cycles

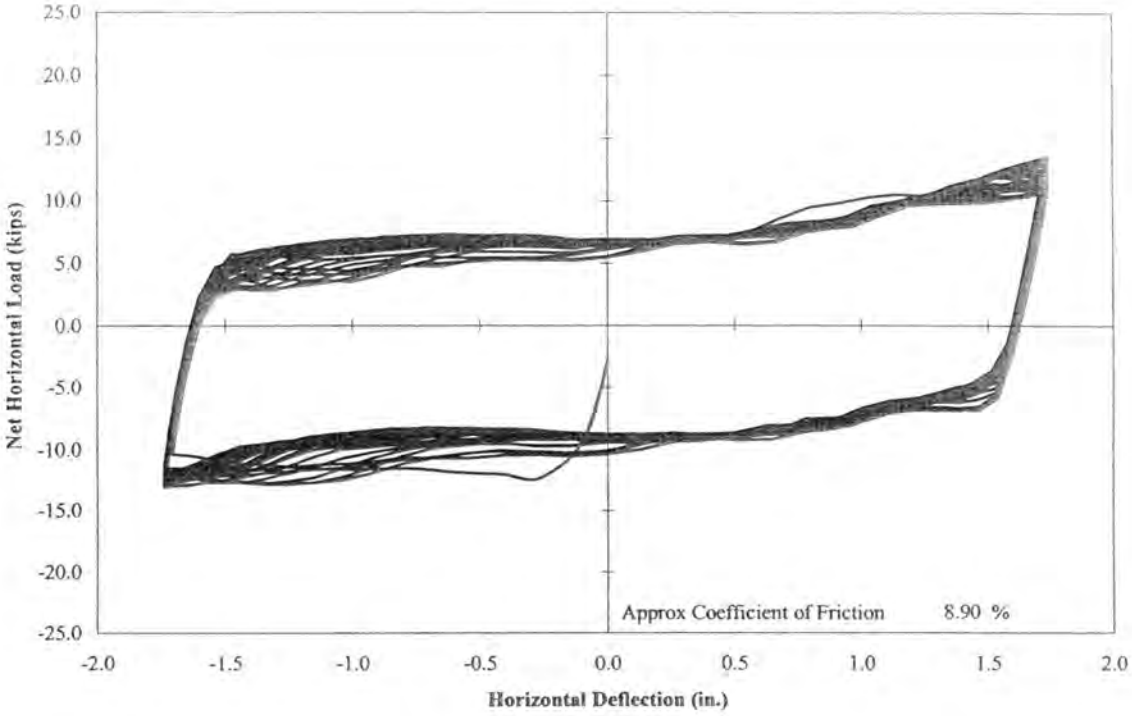

Figure 15 Bearing A1005_4 First 40 Cycles

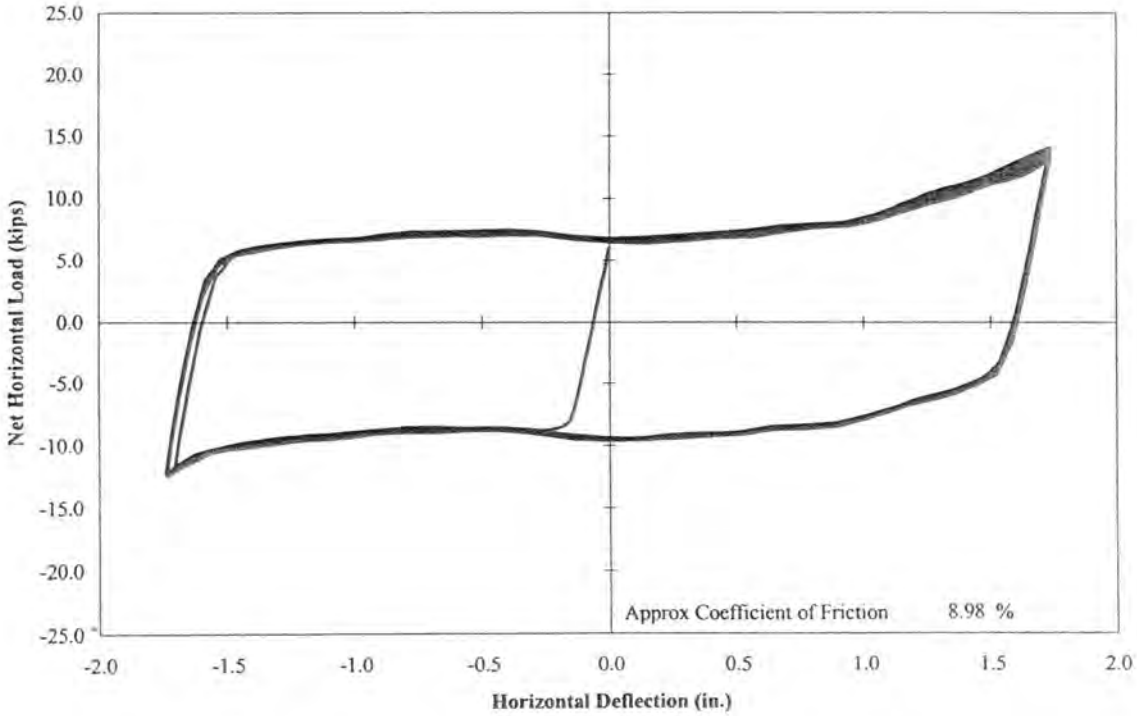

Figure 16 Bearing A1005_4 Second 40 Cycles

Figure 17 Bearing A1005_5

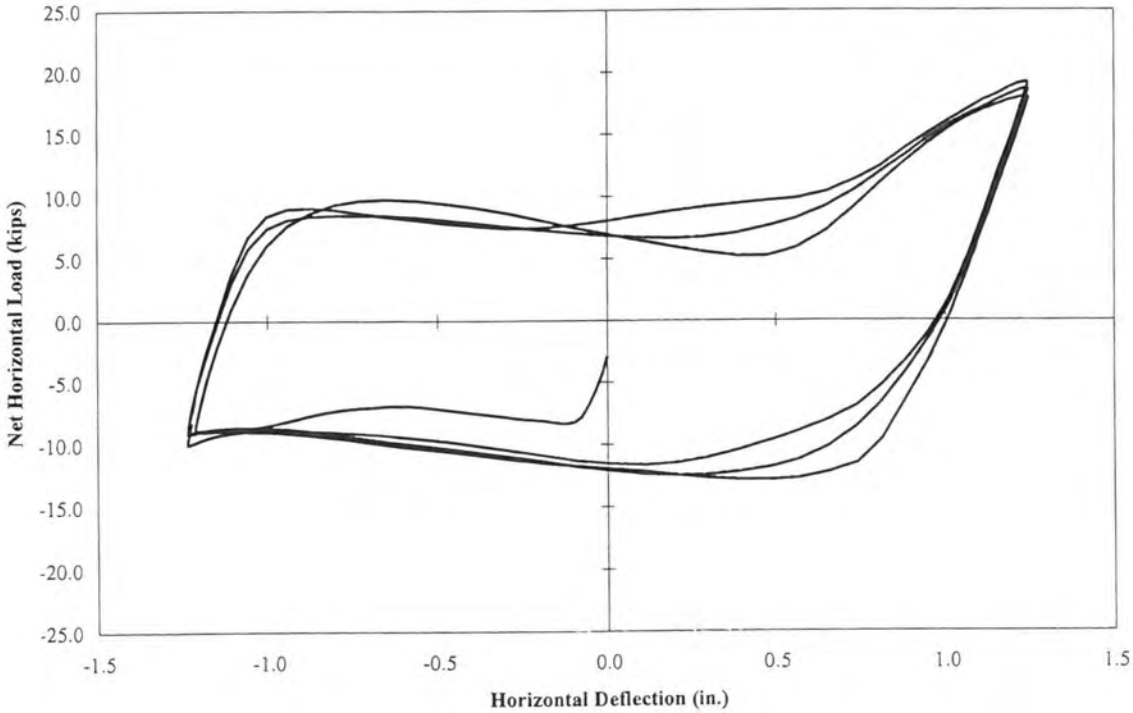

Figure 18 Bearing A1005_5 First 3 Cycles

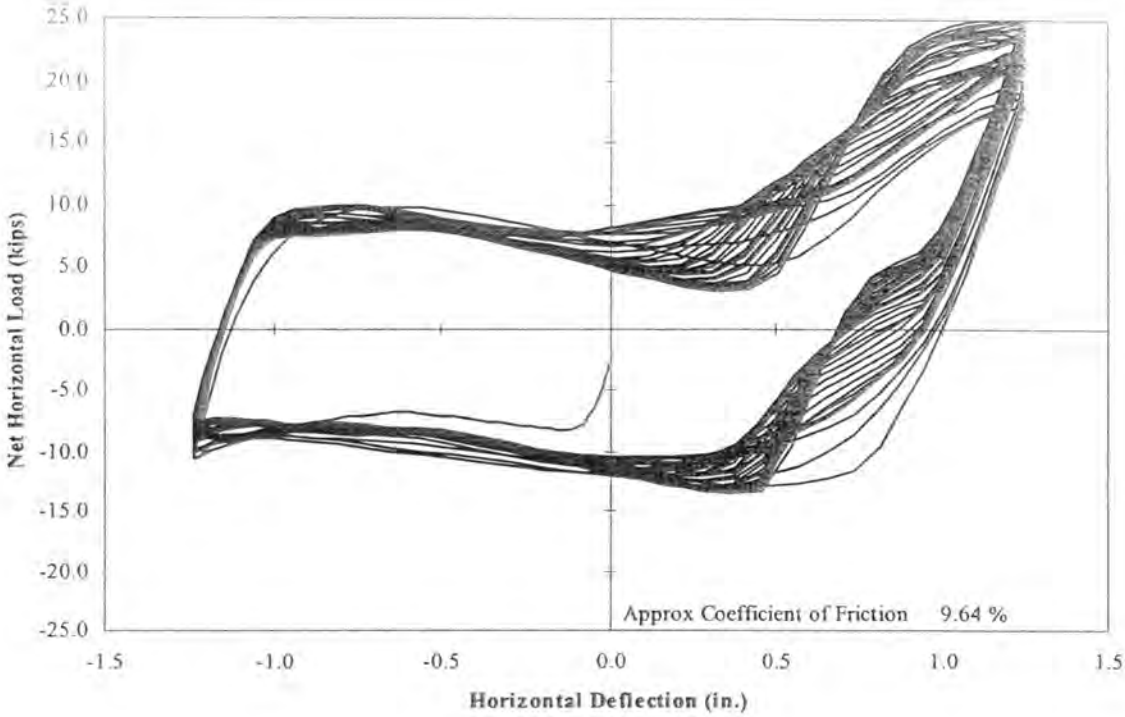

Figure 19 Bearing A1005_5 First 40 Cycles

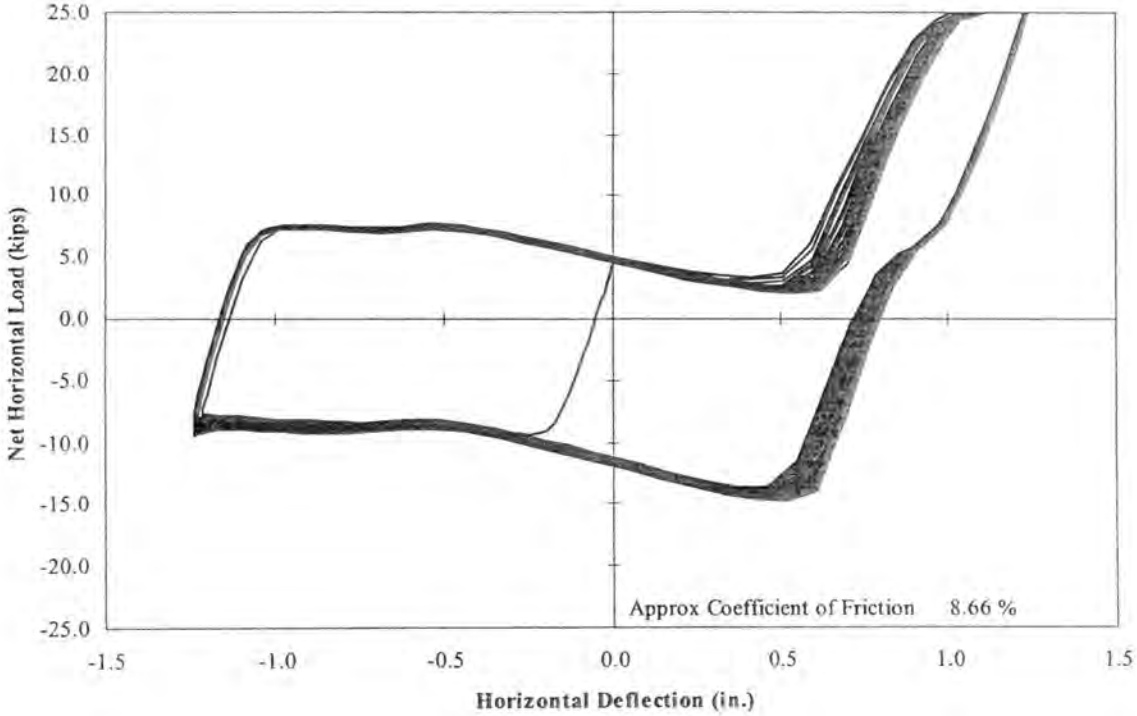

Figure 20 Bearing A1005_5 Second 40 Cycles

Figure 21 Bearing A860_1

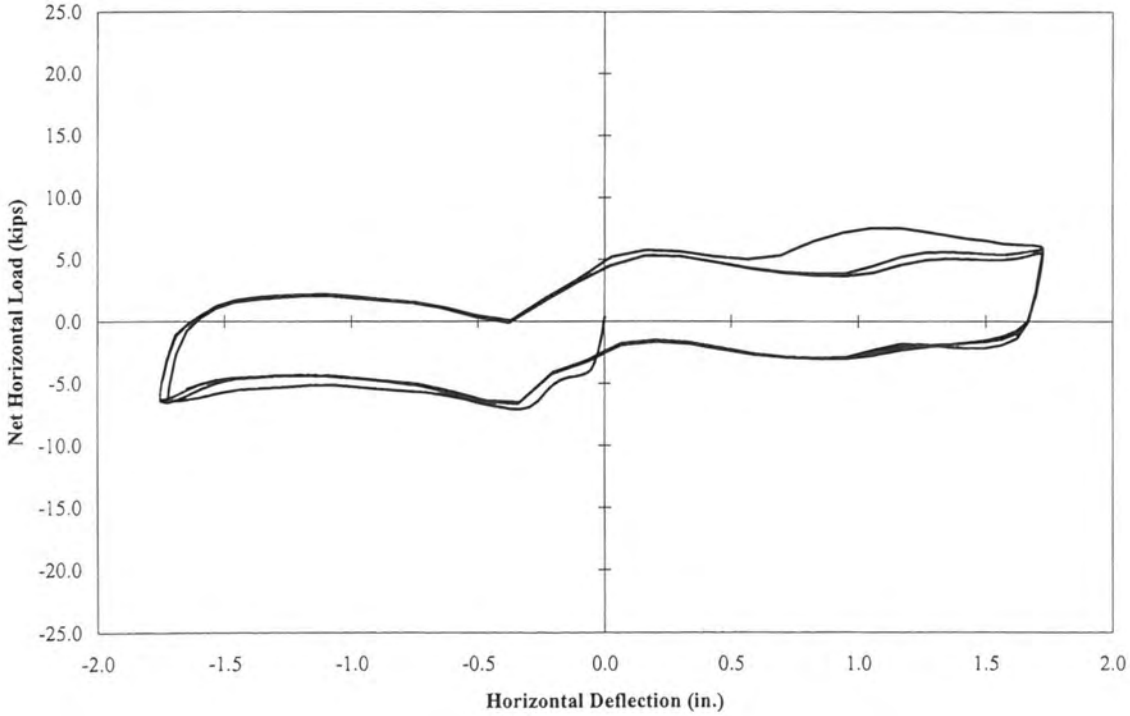

Figure 22 Bearing A860_1 First 3 Cycles

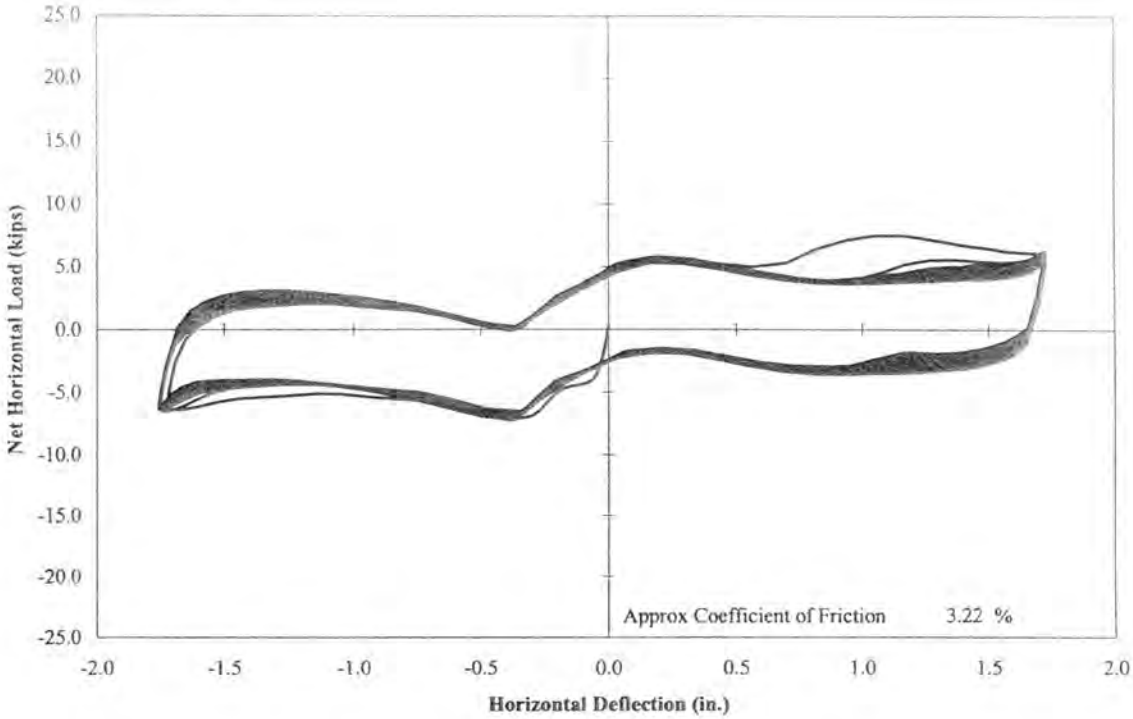

Figure 23 Bearing A860_1 First 40 Cycles

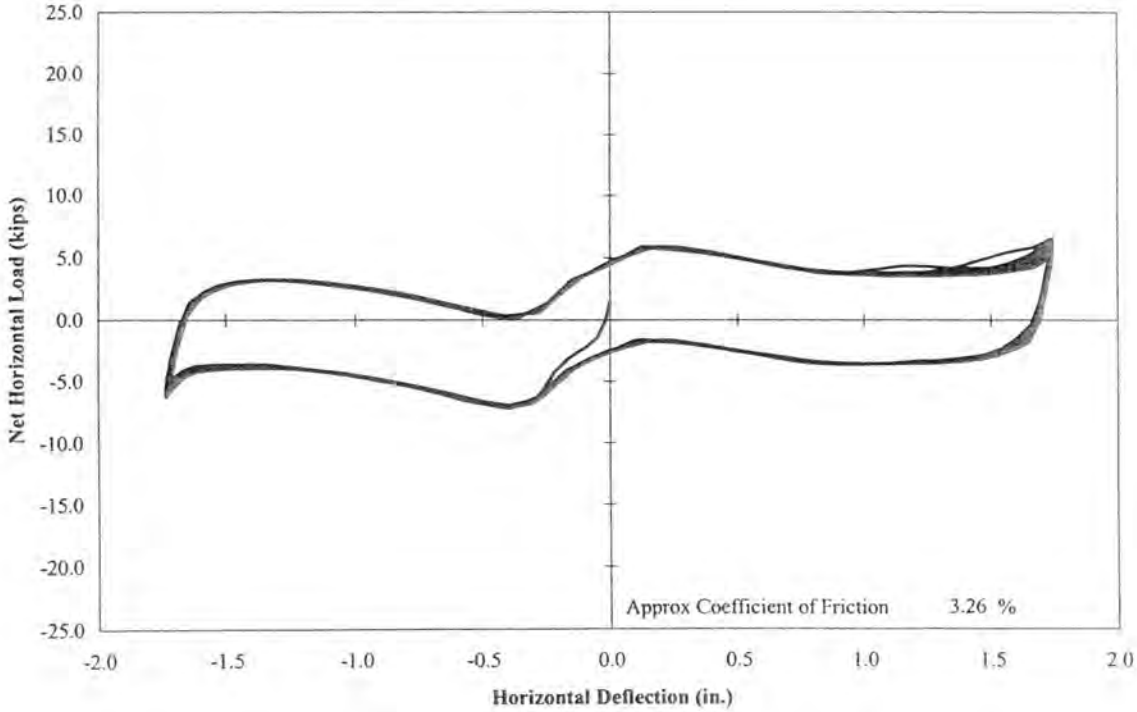

Figure 24 Bearing A860_1 Second 40 Cycles

Figure 25 Bearing A860_2

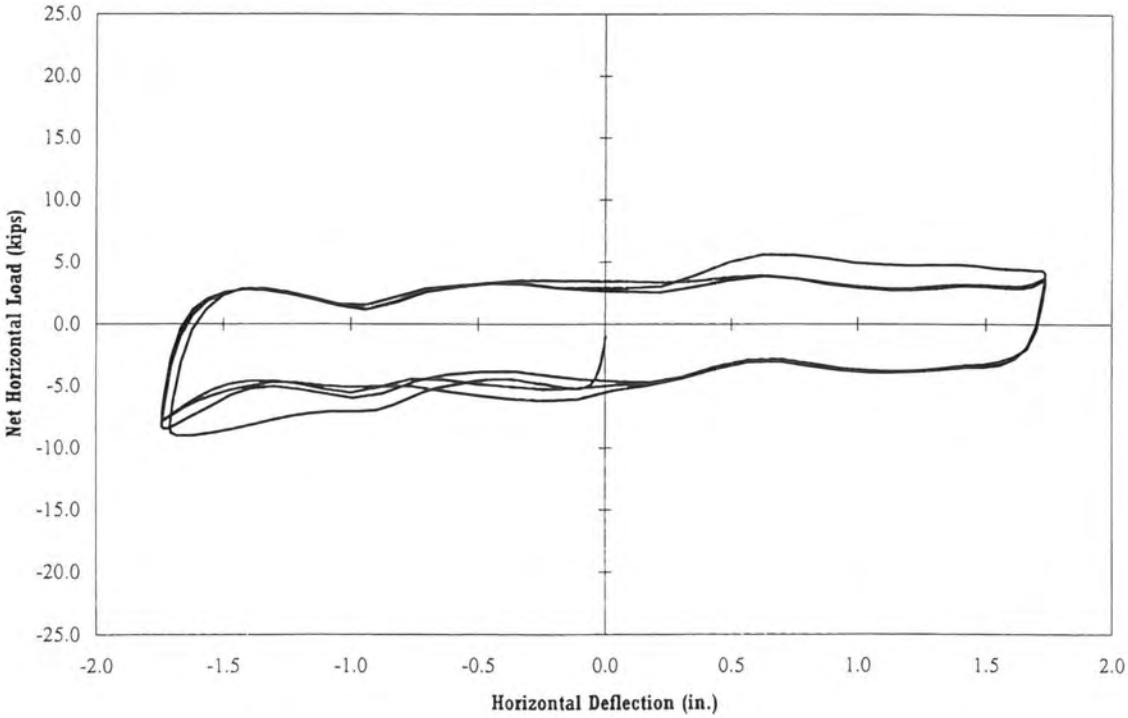

Figure 26 Bearing A860_2 First 3 Cycles

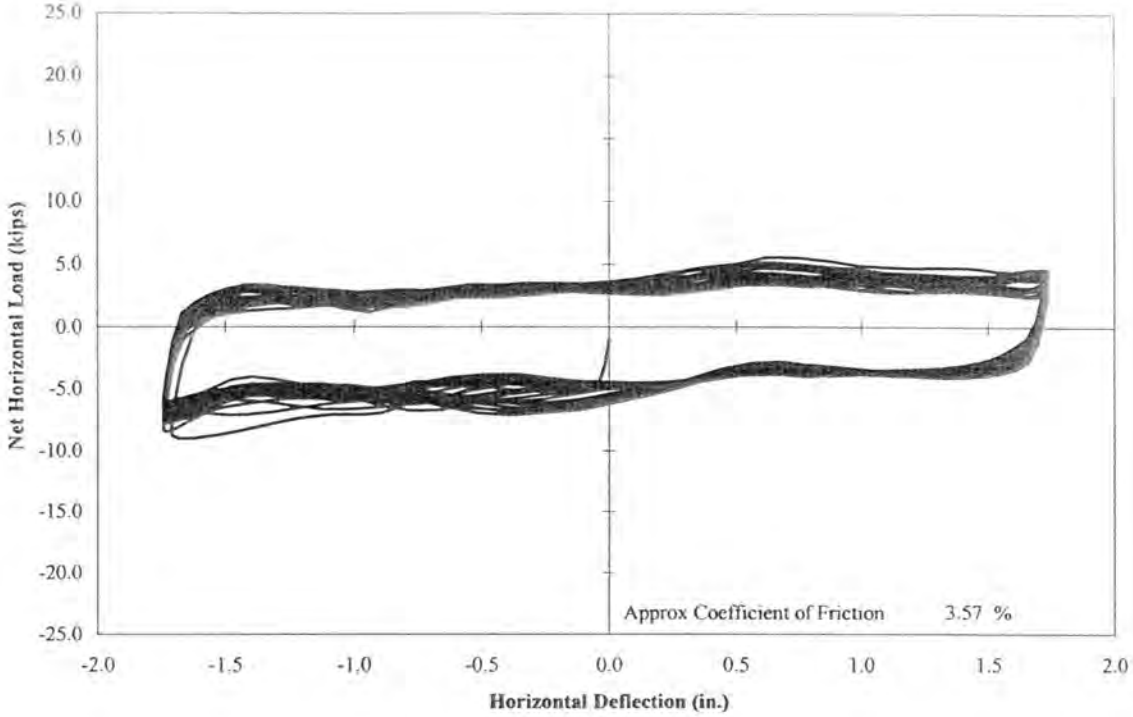

Figure 27 Bearing A860_2 First 40 Cycles

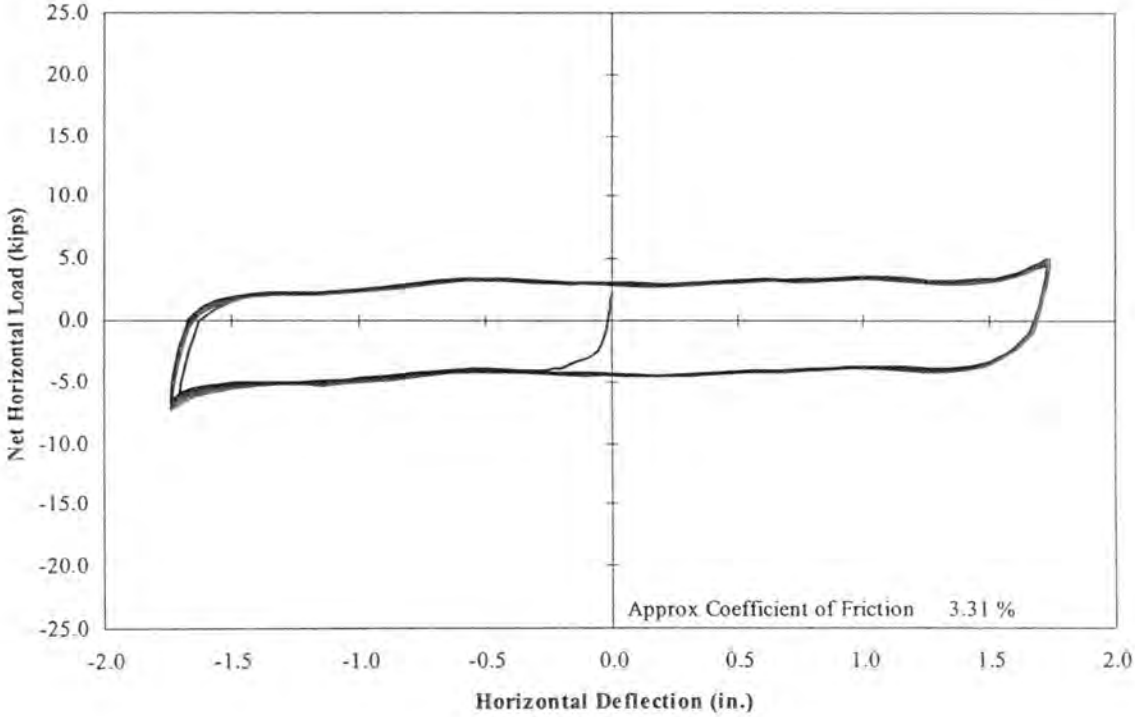

Figure 28 Bearing A860_2 Second 40 Cycles

Figure 29 Bearing A860_3

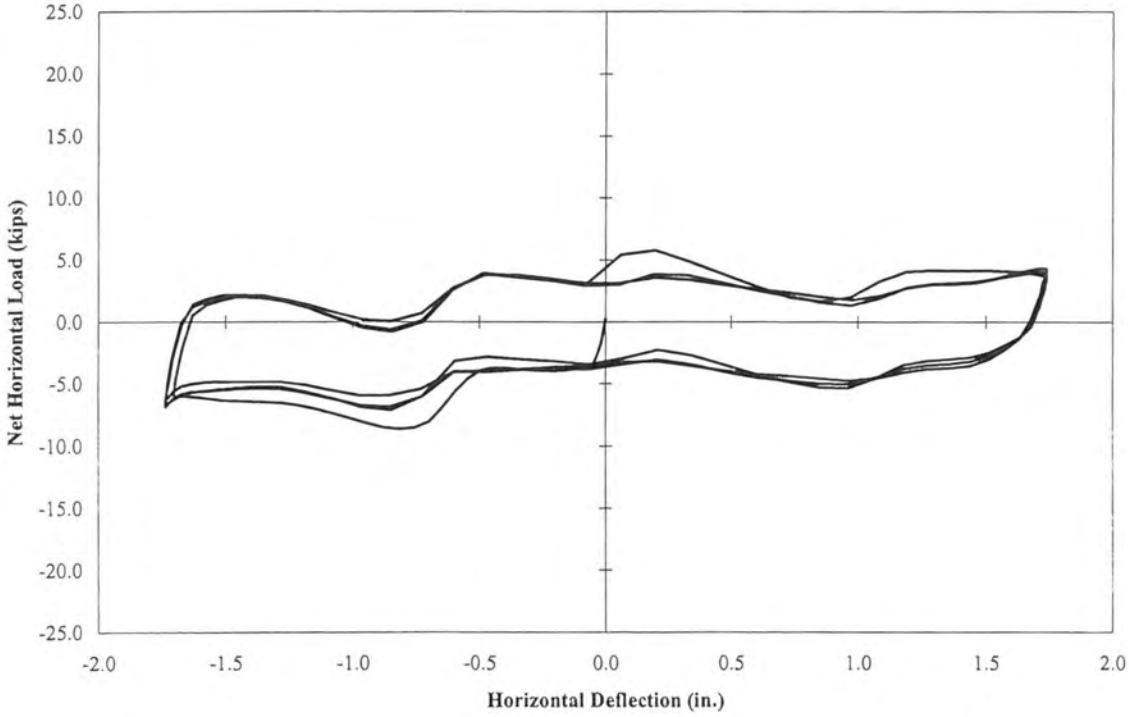

Figure 30 Bearing A860_3 First 3 Cycles

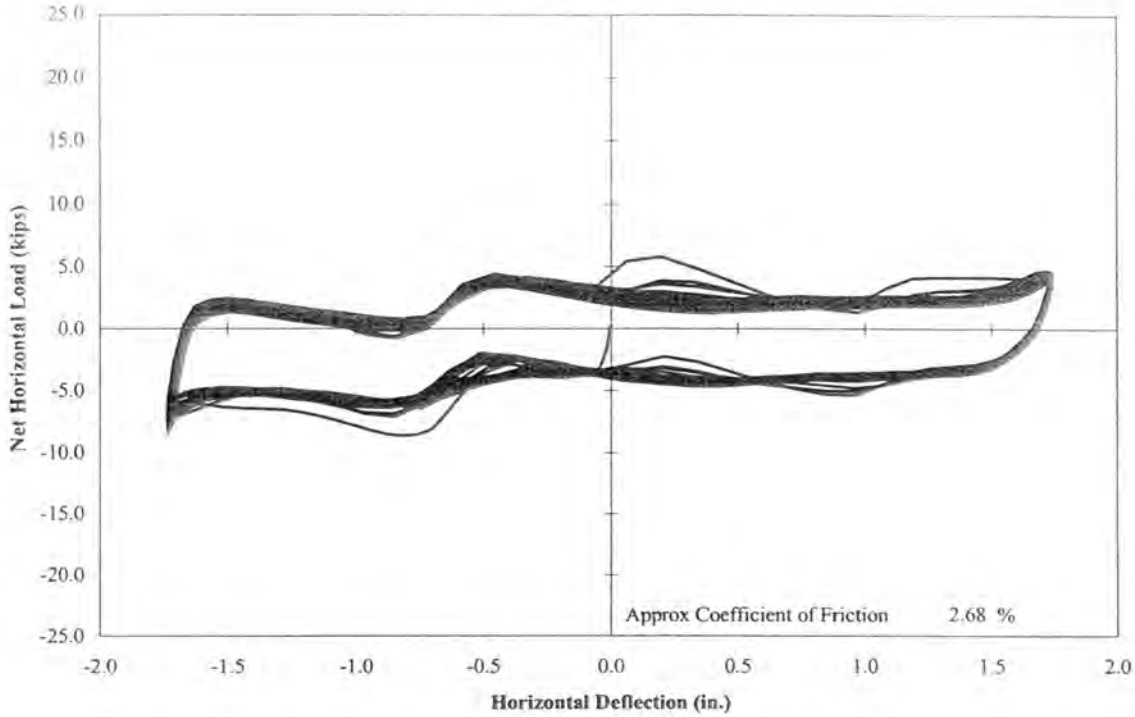

Figure 31 Bearing A860_3 First 40 Cycles

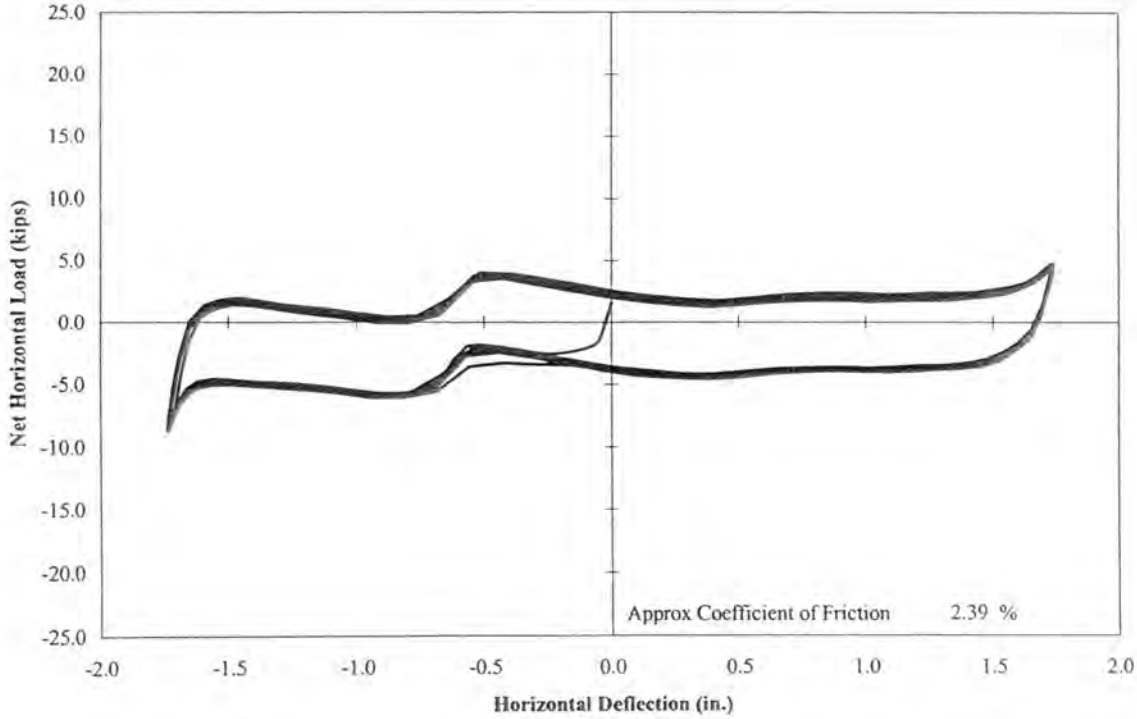

Figure 32 Bearing A860_3 Second 40 Cycles

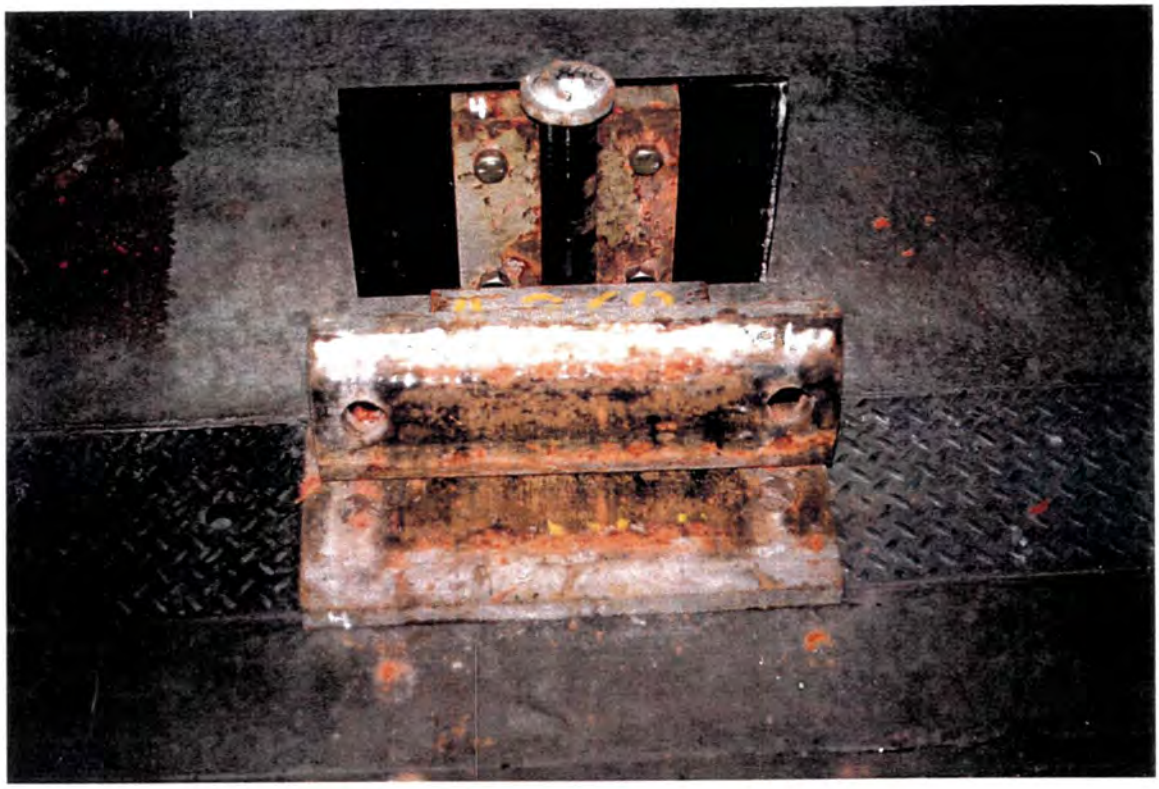

Figure 33 Bearing A860_4

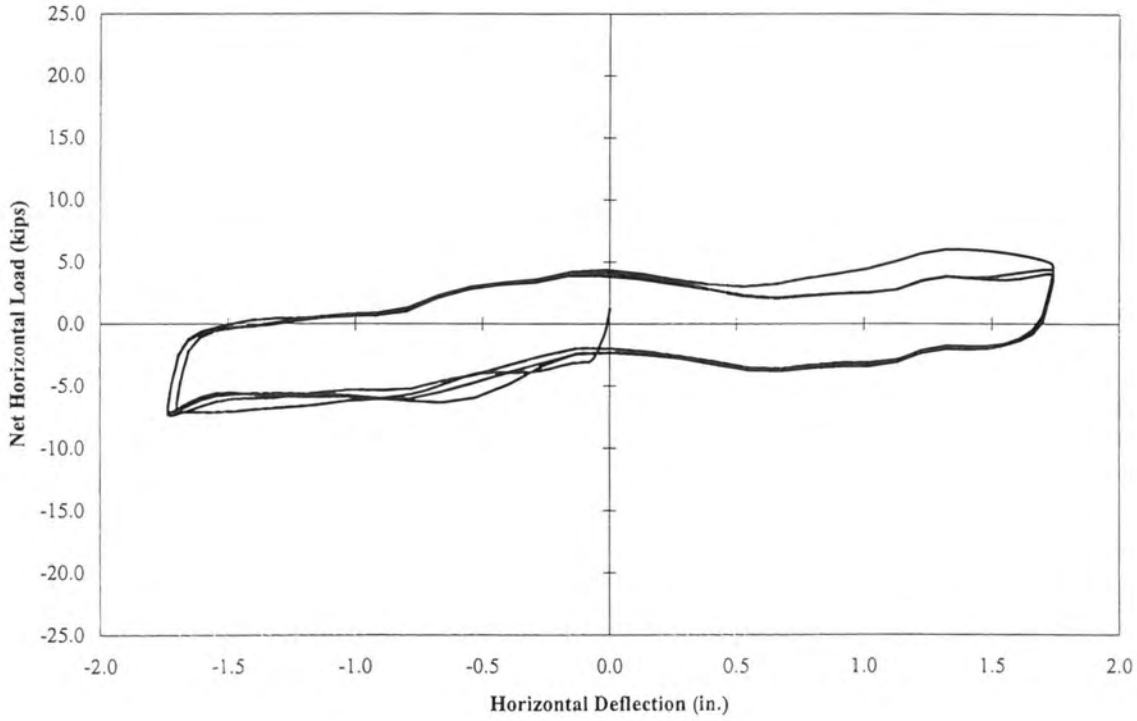

Figure 34 Bearing A860_4 First 3 Cycles

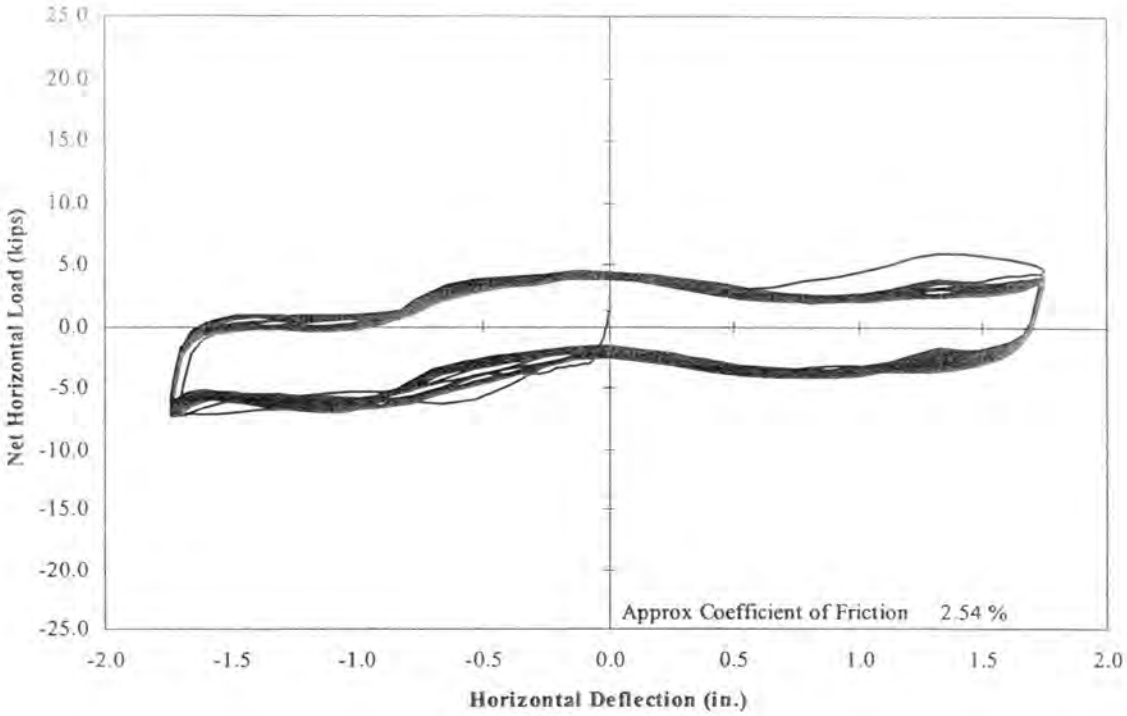

Figure 35 Bearing A860_4 First 40 Cycles

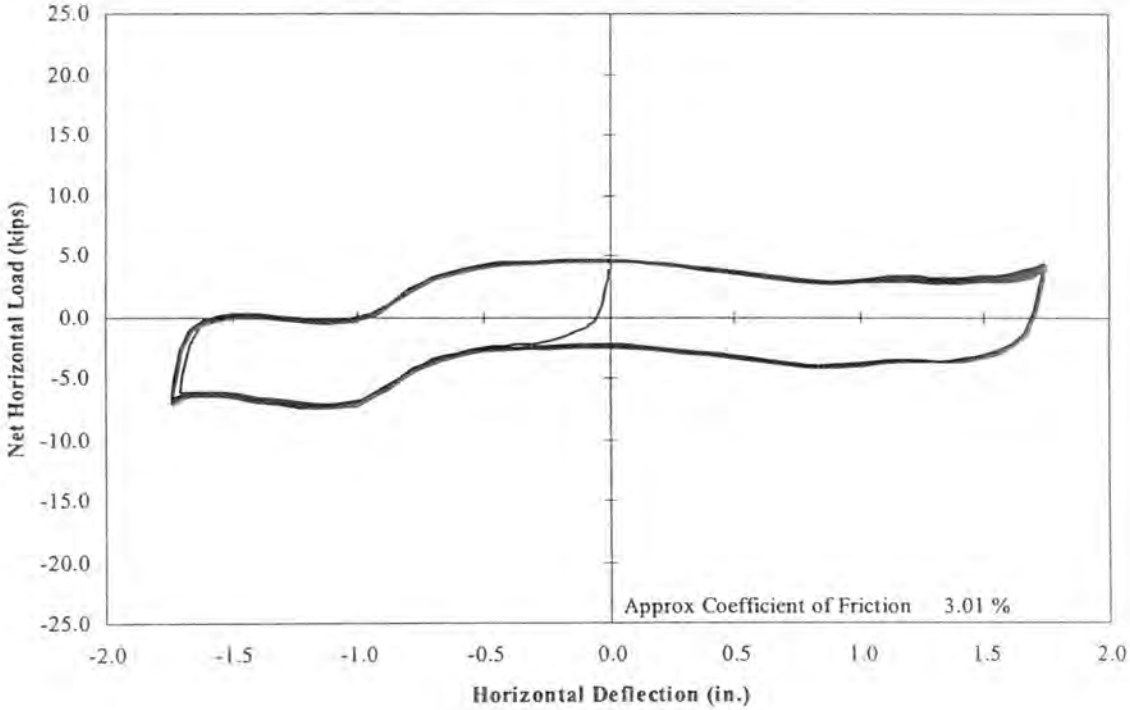

Figure 36 Bearing A860_4 Second 40 Cycles

Figure 37 Bearing A860_5

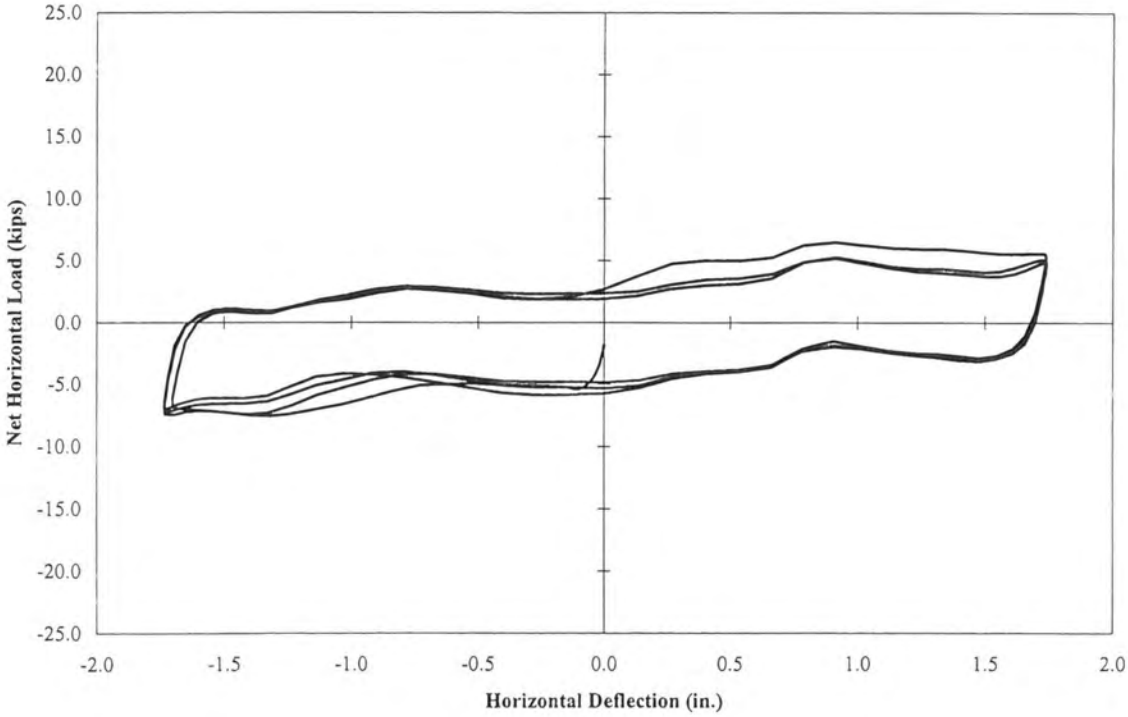

Figure 38 Bearing A860_5 First 3 Cycles

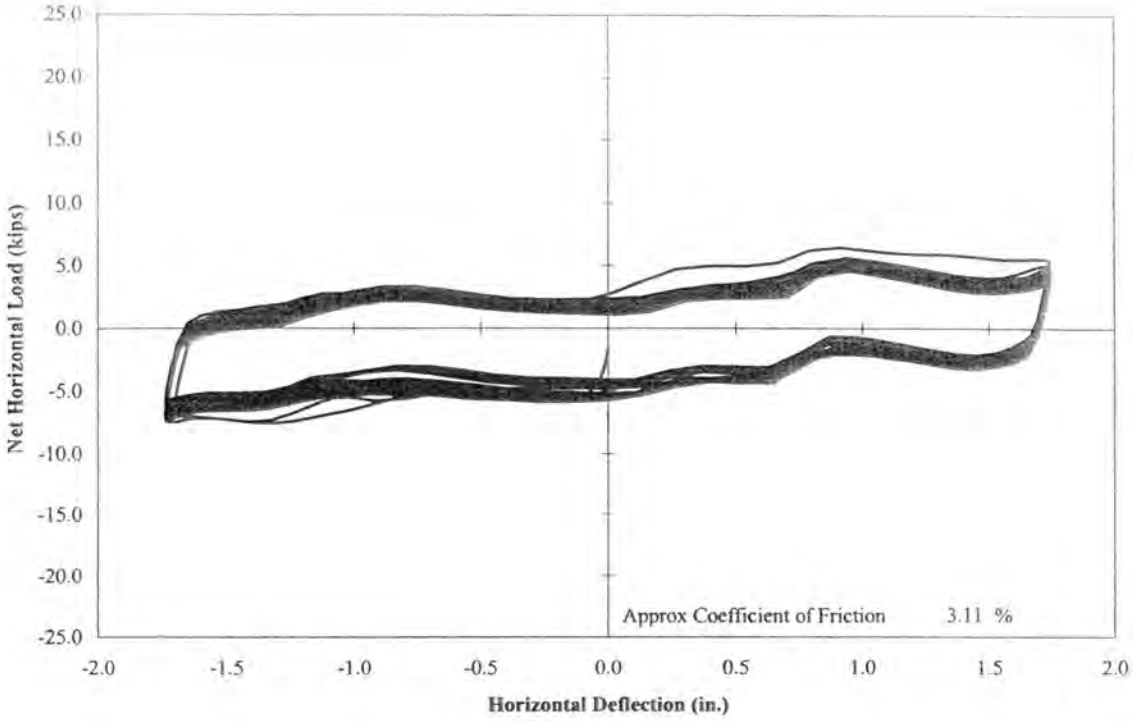

Figure 39 Bearing A860_5 First 40 Cycles

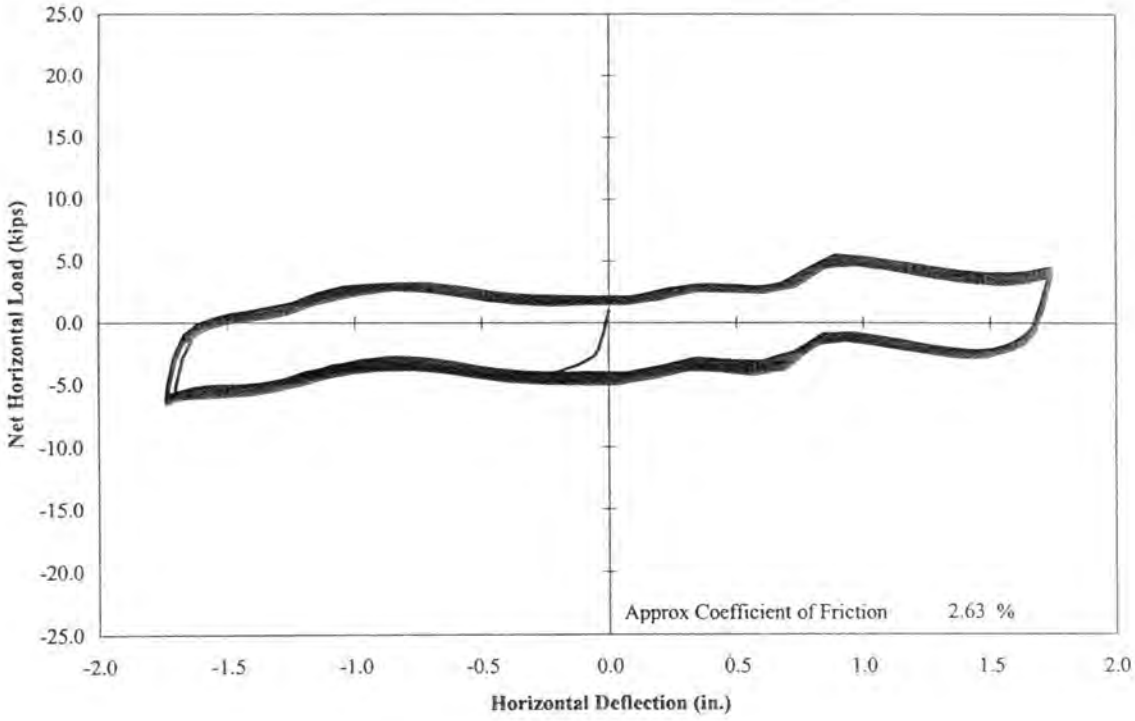

Figure 40 Bearing A860_5 Second 40 Cycles

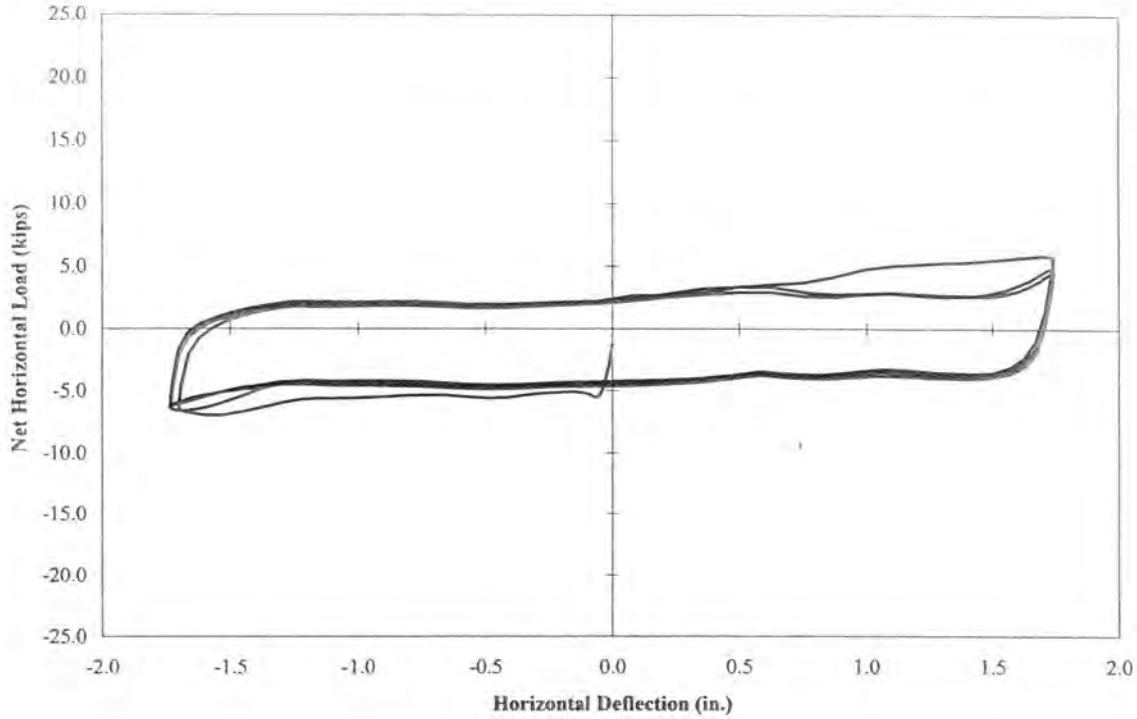

Figure 41 Bearing A860_6 First 3 Cycles

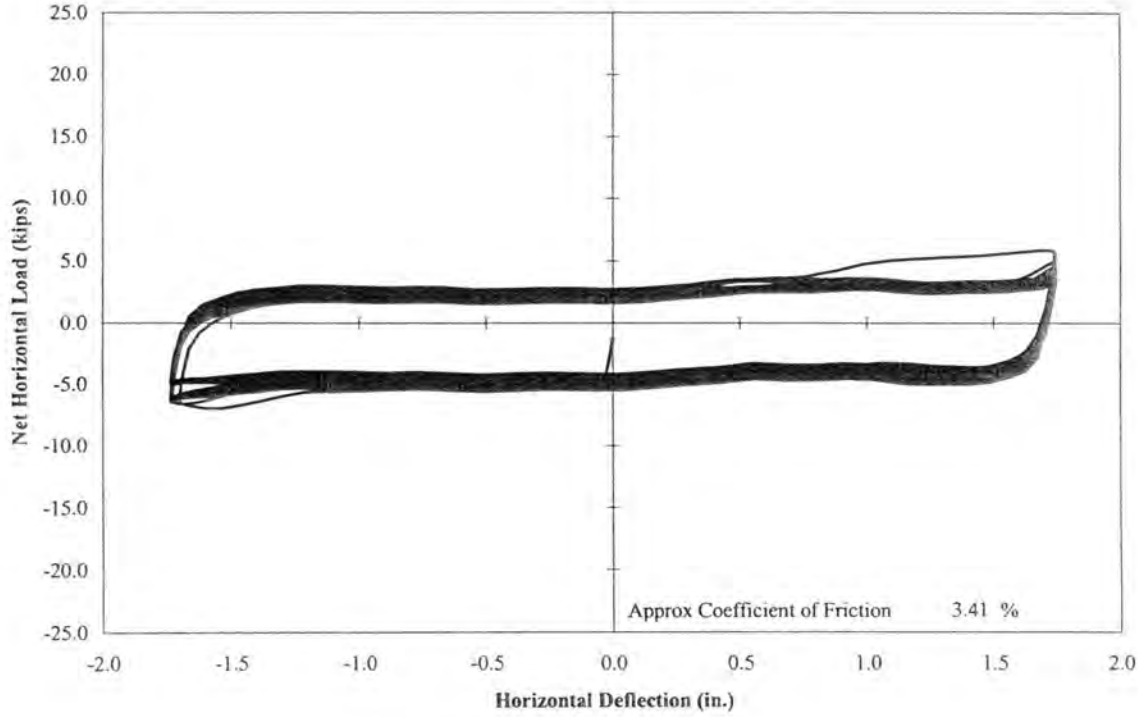

Figure 42 Bearing A860_6 First 40 Cycles

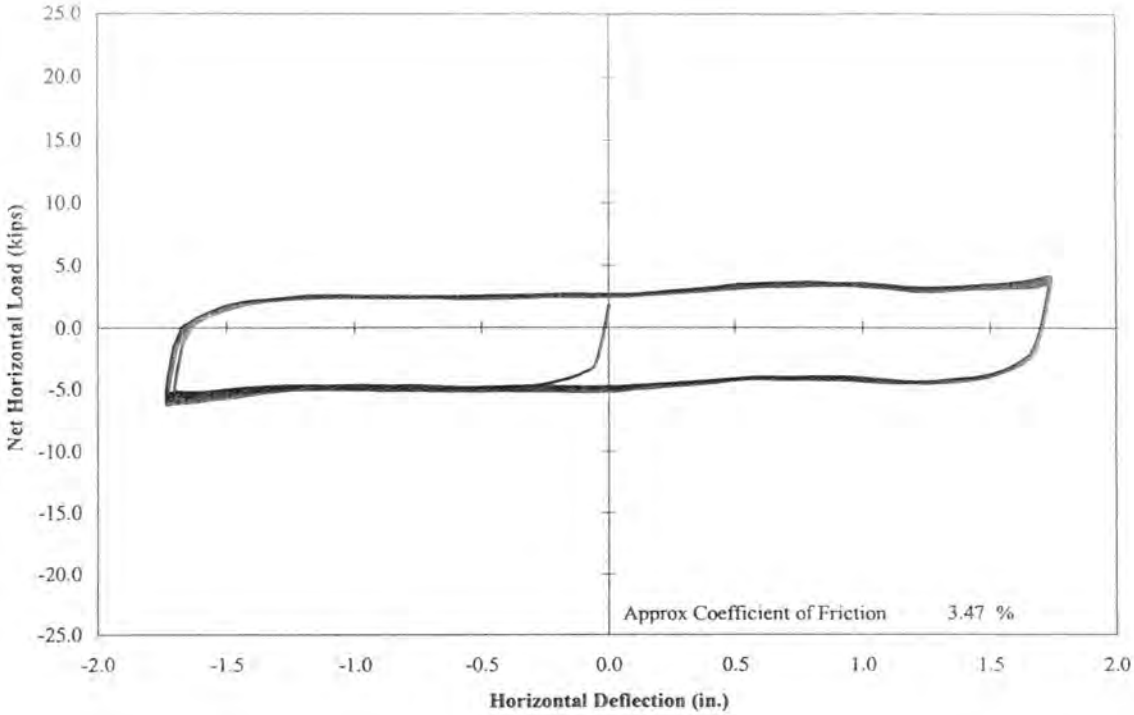

Figure 43 Bearing A860_6 Second 40 Cycles

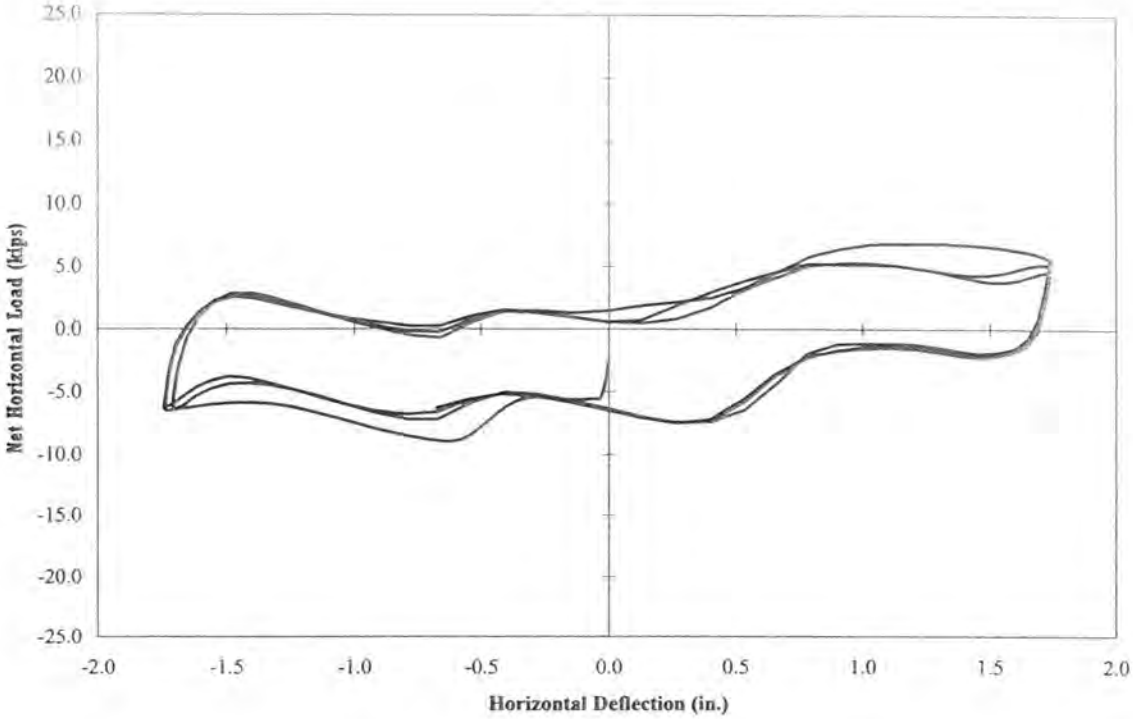

Figure 44 Bearing A860_7 First 3 Cycles

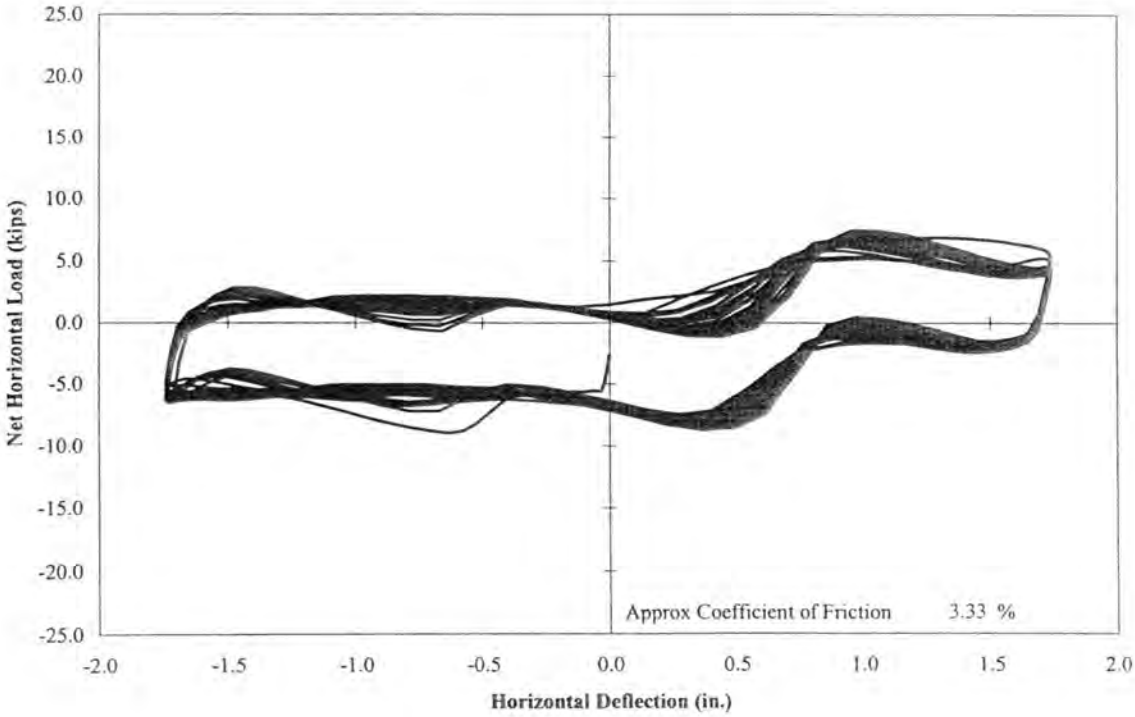

Figure 45 Bearing A860_7 First 40 Cycles

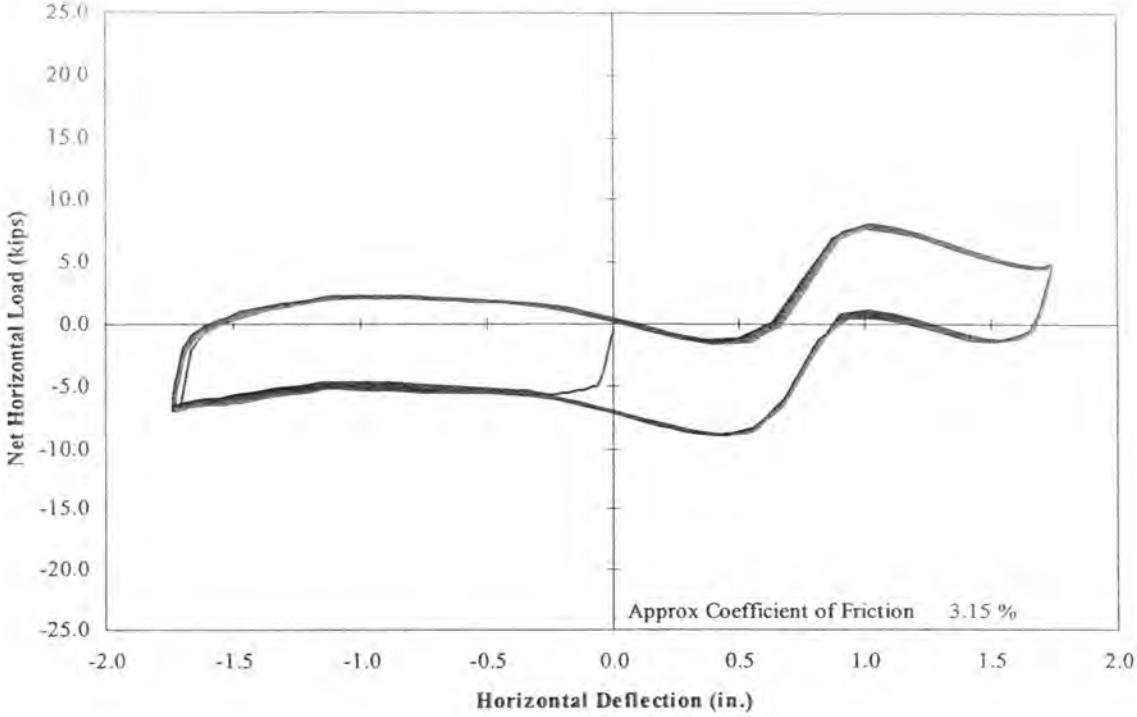

Figure 46 Bearing A860_7 Second 40 Cycles

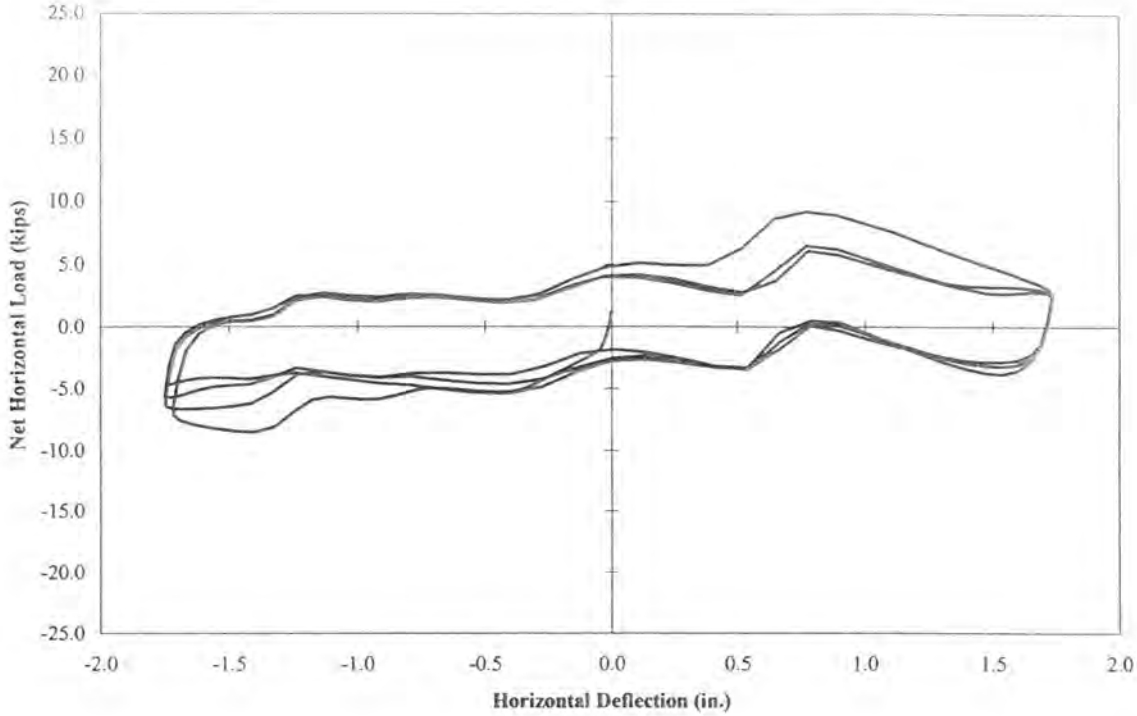

Figure 47 Bearing A860_8 First 3 Cycles

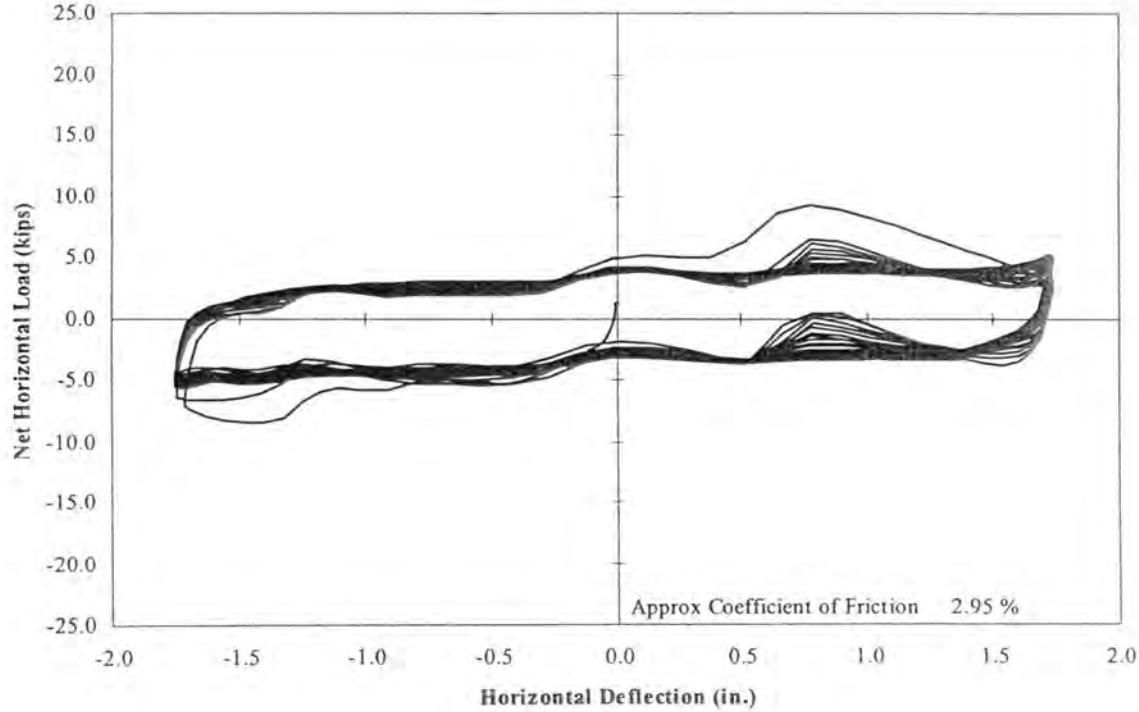

Figure 48 Bearing A860_8 First 40 Cycles

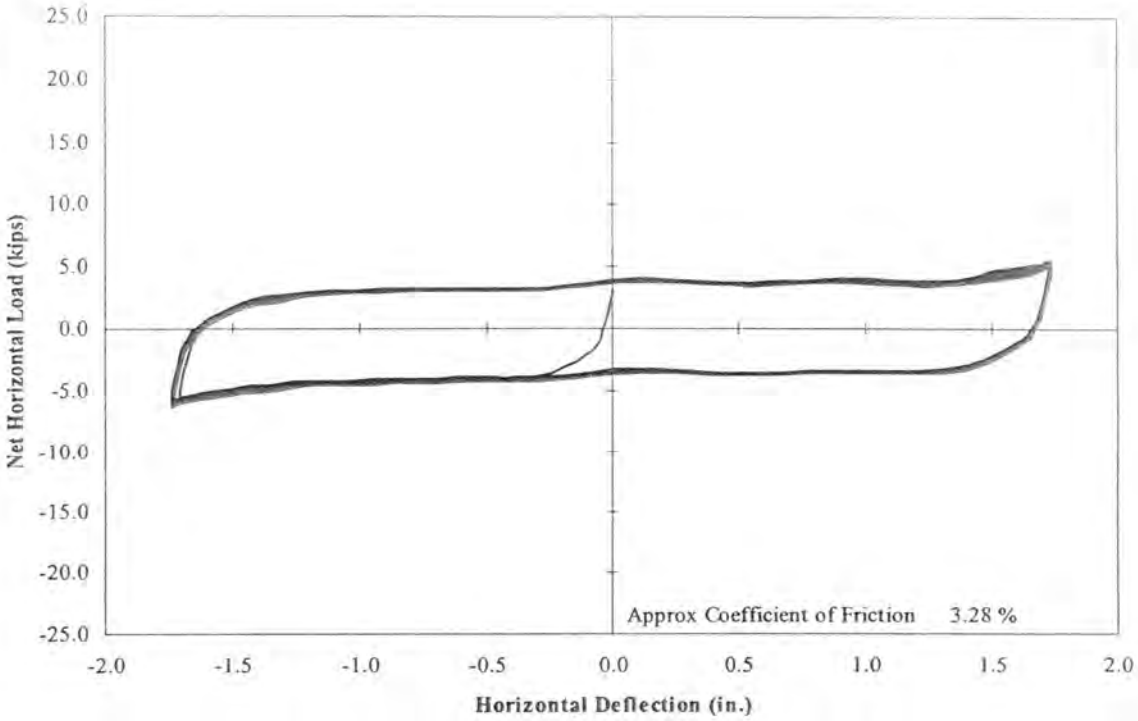

Figure 49 Bearing A860_8 Second 40 Cycles

Figure 50 Bearing L_1

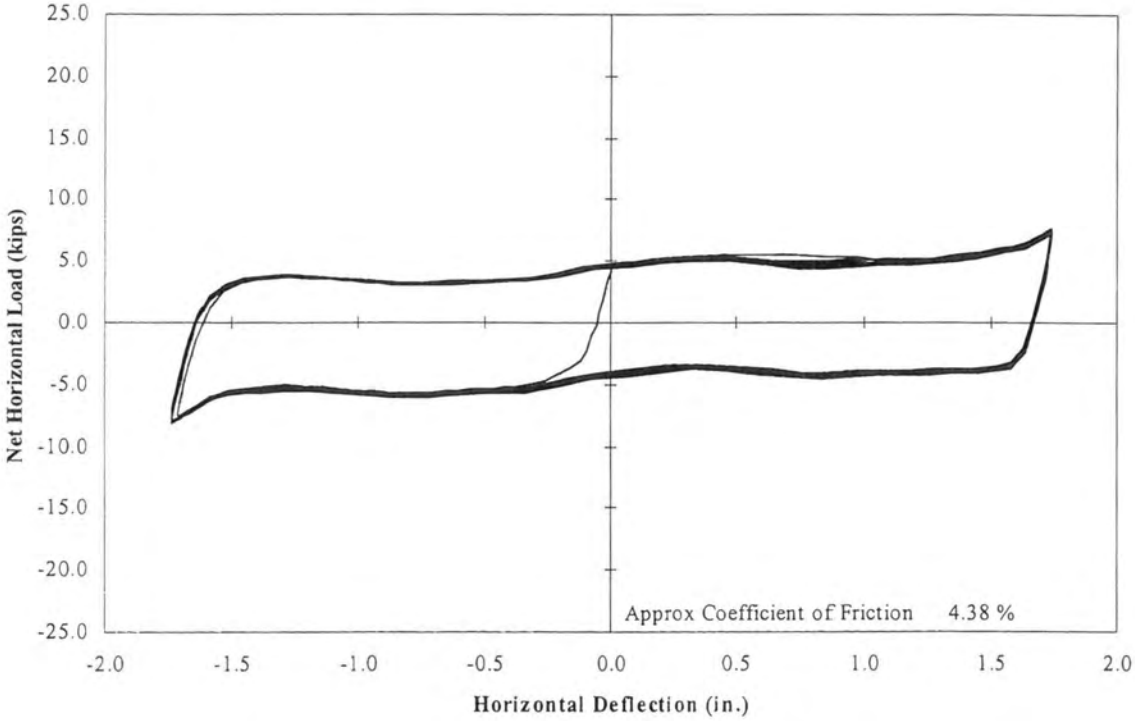

Figure 51 Bearing L_1 Second 40 Cycles

Figure 52 Bearing L_2

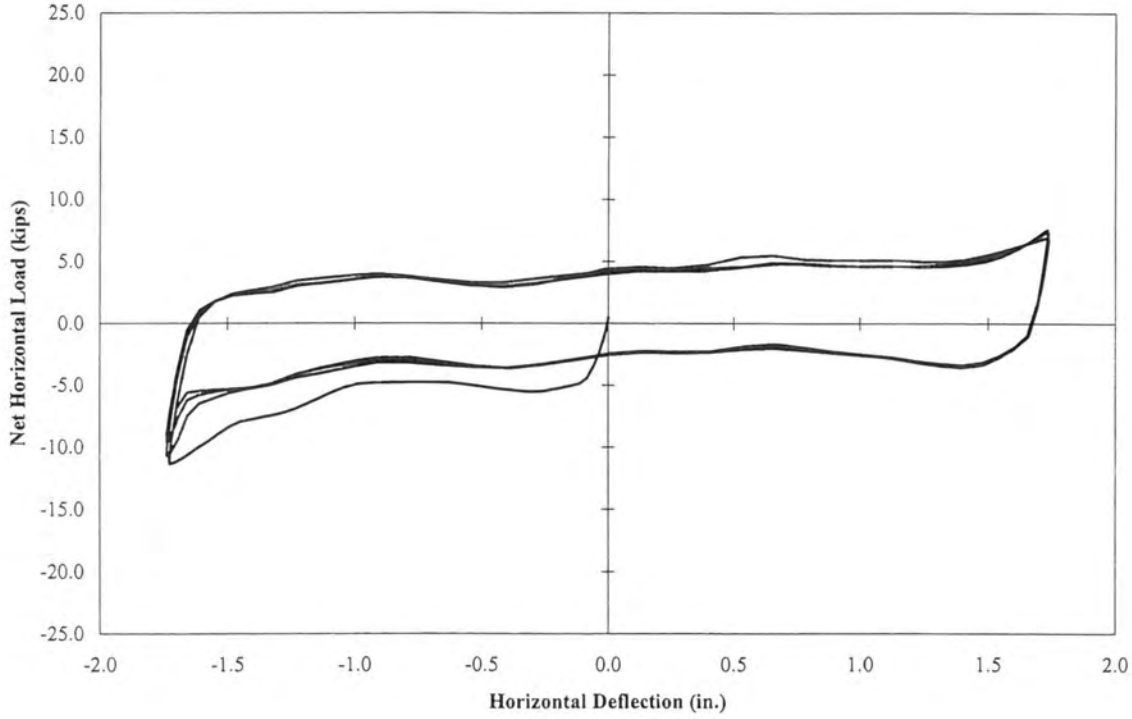

Figure 53 Bearing L_2 First 3 Cycles

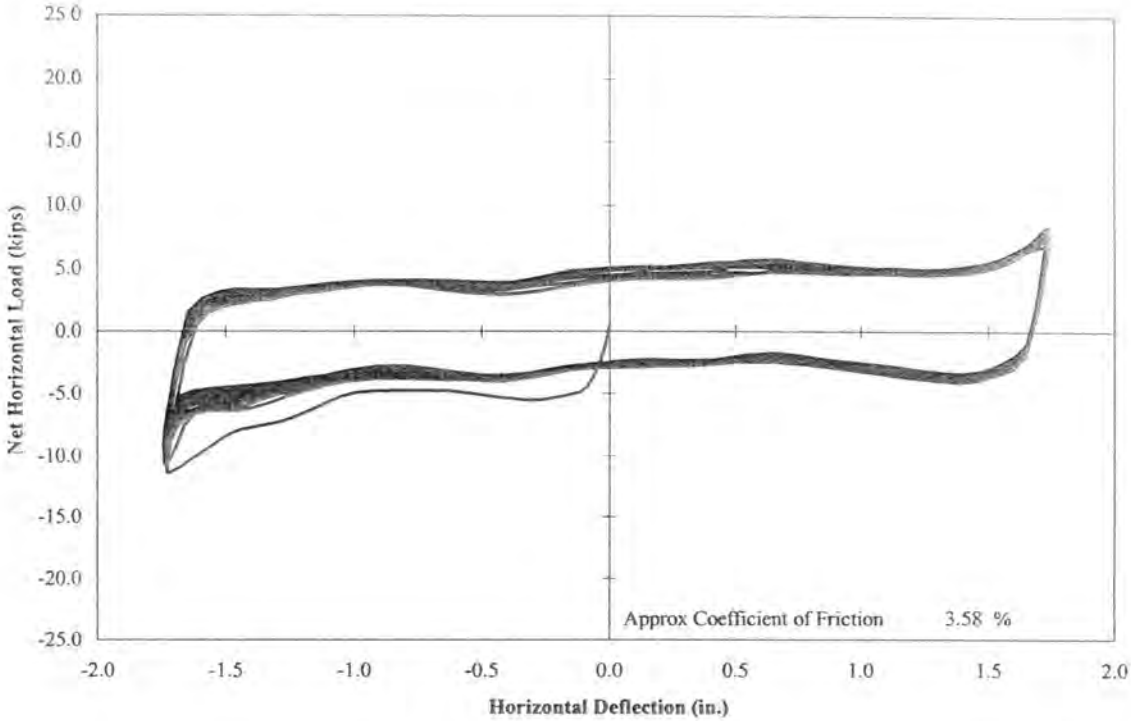

Figure 54 Bearing L_2 First 40 Cycles

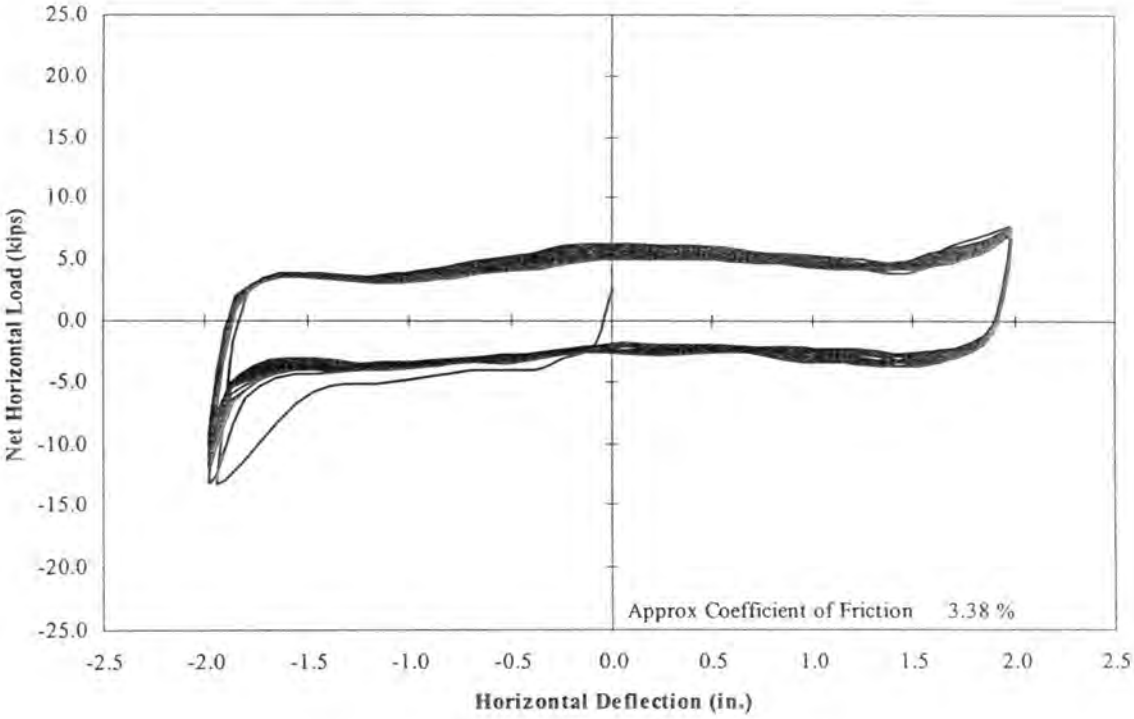

Figure 55 Bearing L_2 Second 40 Cycles

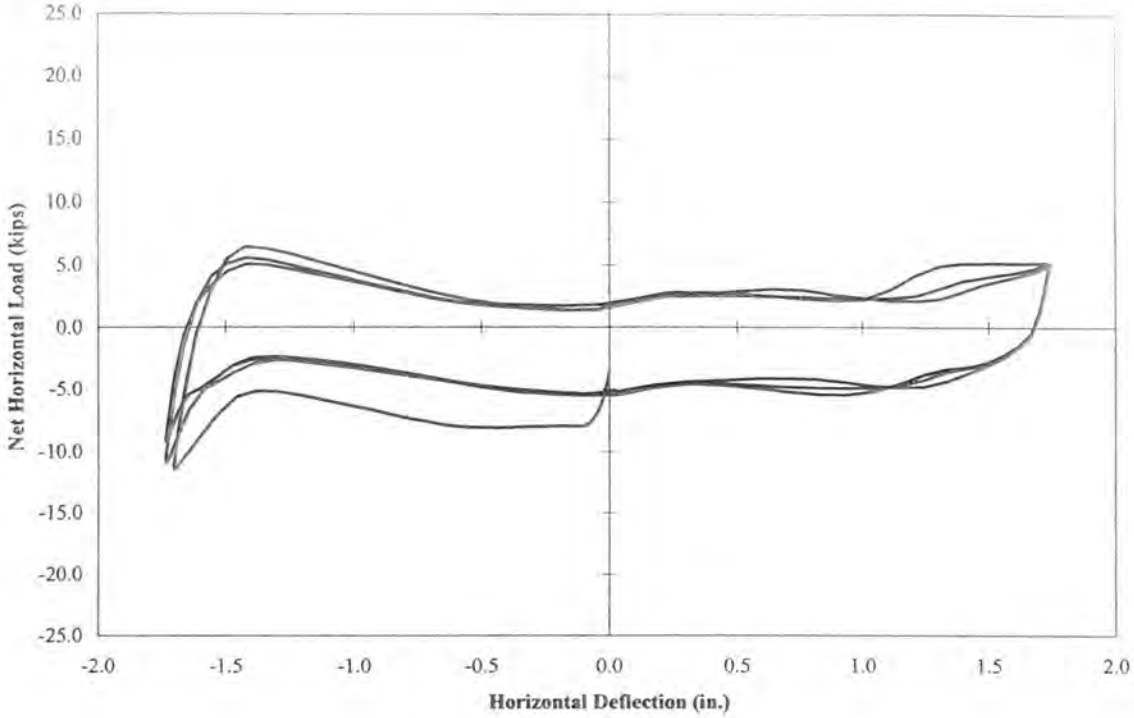

Figure 56 Bearing L_3 First 3 Cycles

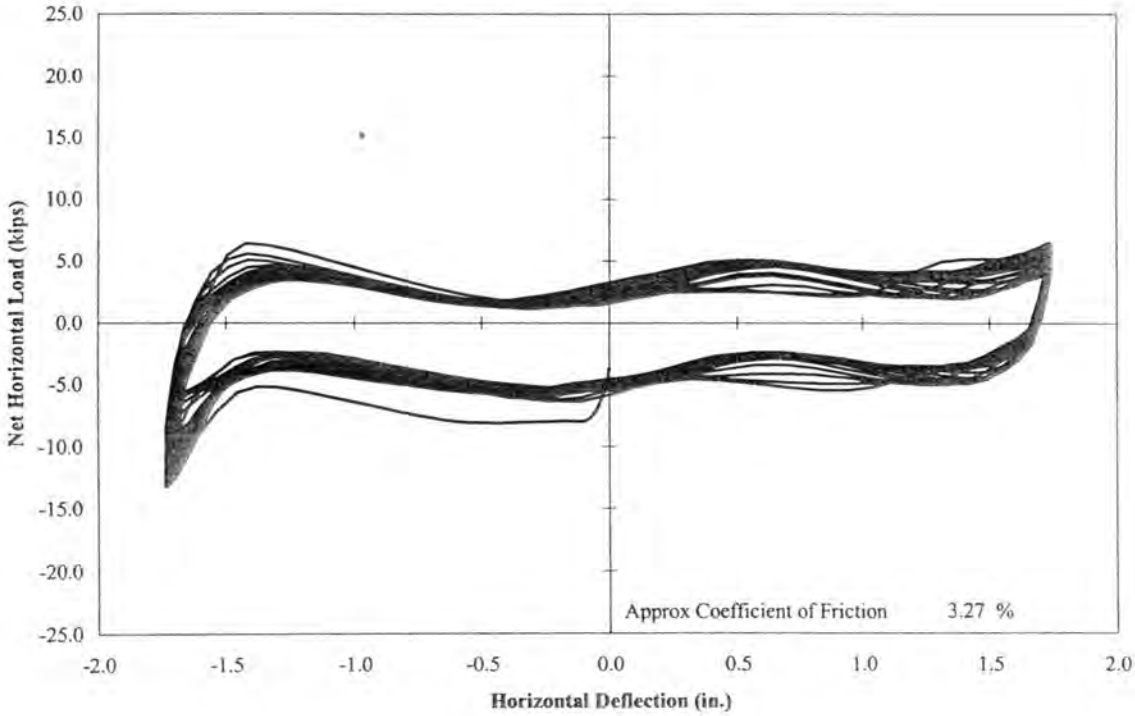

Figure 57 Bearing L_3 First 40 Cycles

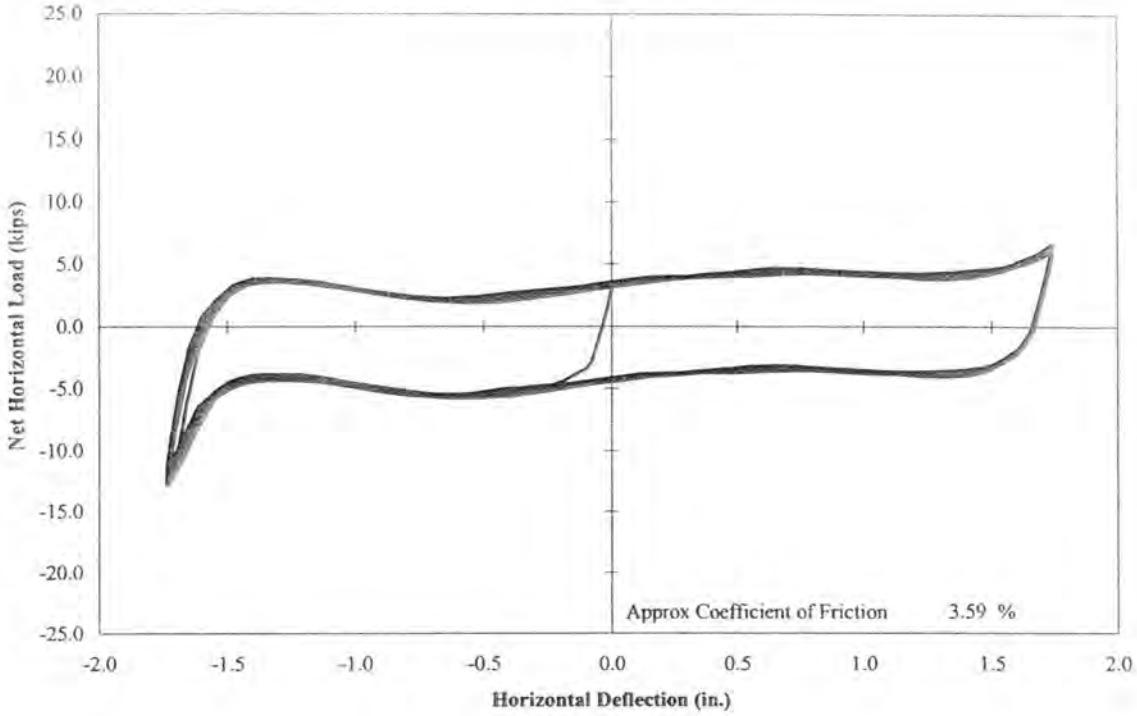

Figure 58 Bearing L_3 Second 40 Cycles

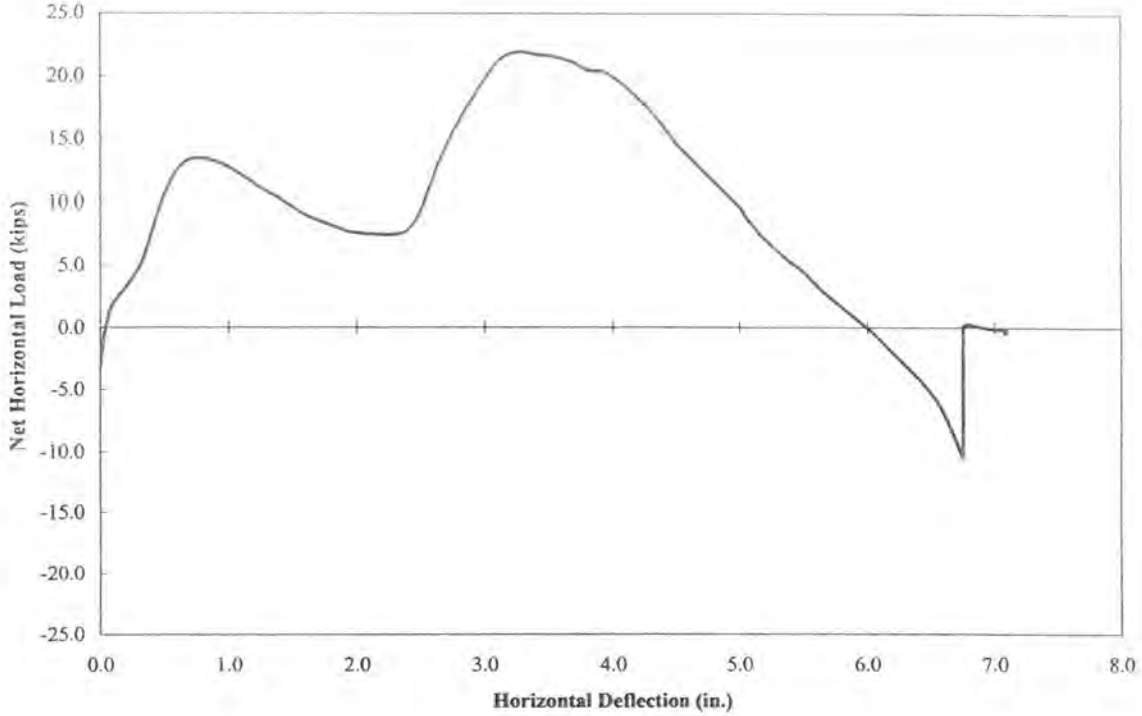

Figure 59 Bearing A1005_2 Ultimate Test

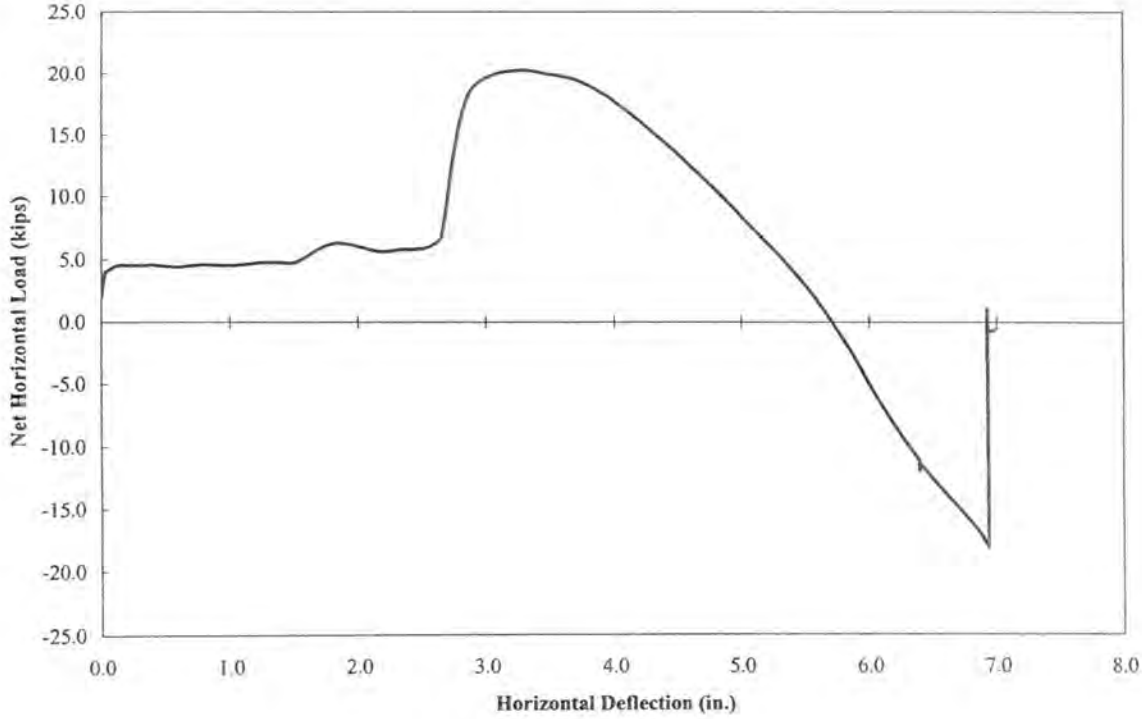

Figure 60 Bearing A860_4 Ultimate Test

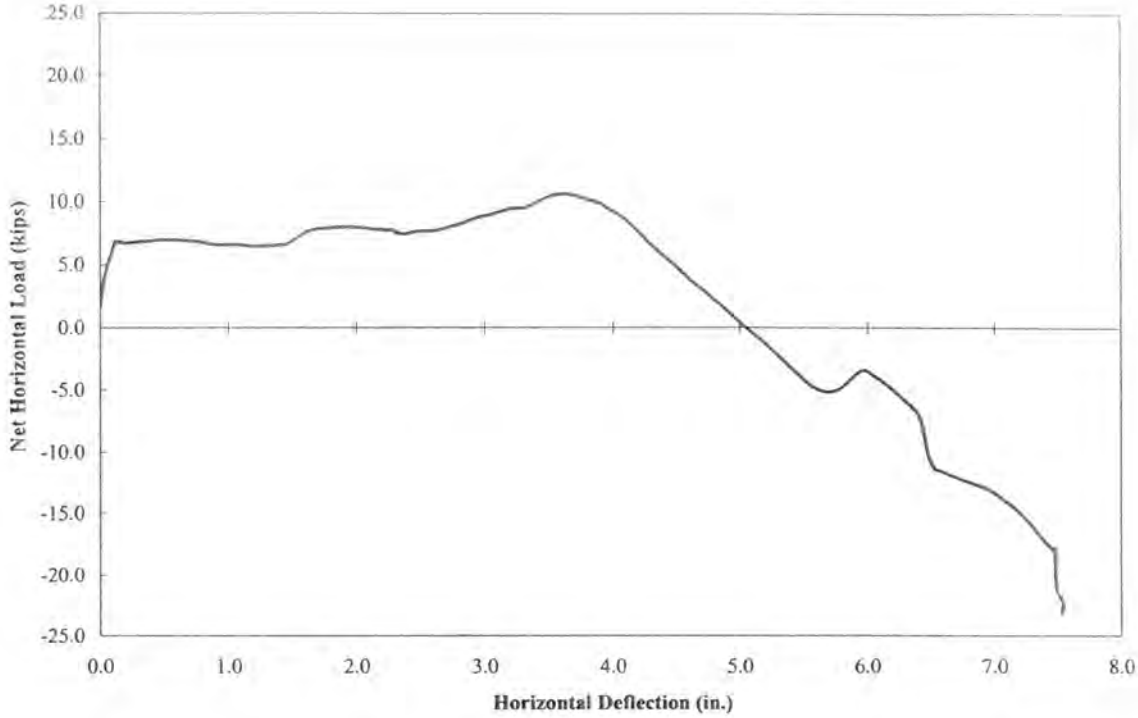

Figure 61 Bearing L_1 Ultimate Test

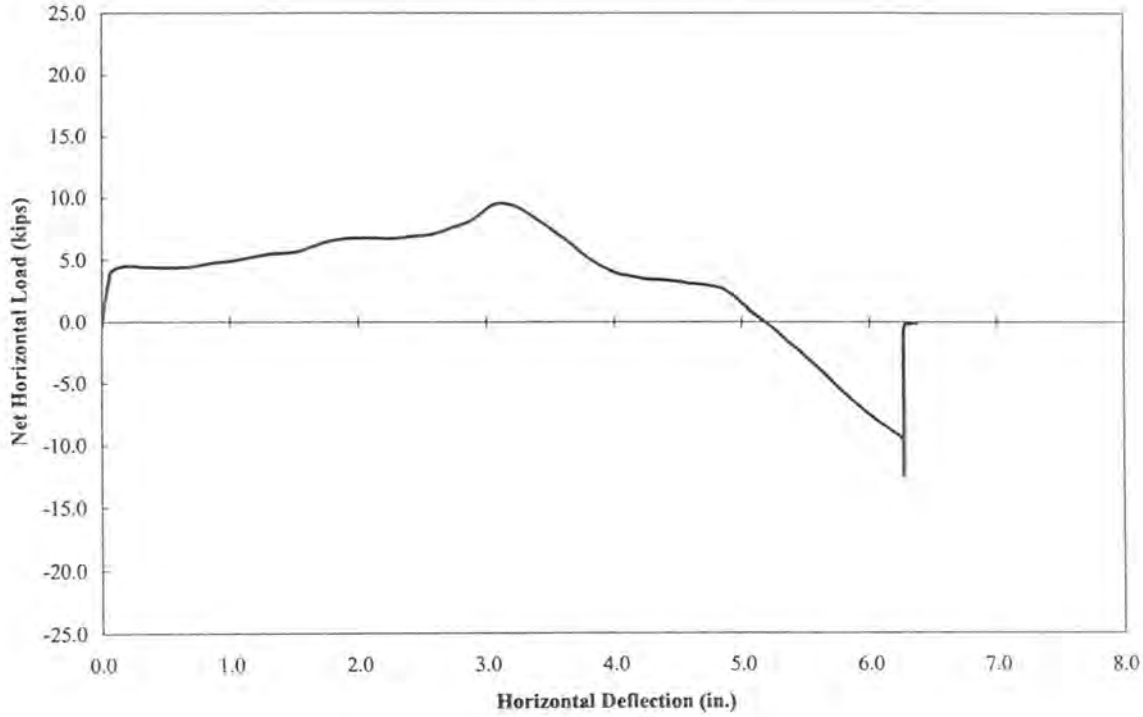

Figure 62 Bearing L_2 Ultimate Test

Figure 63 Bearing A1005_2

Figure 64 Bearing L_1

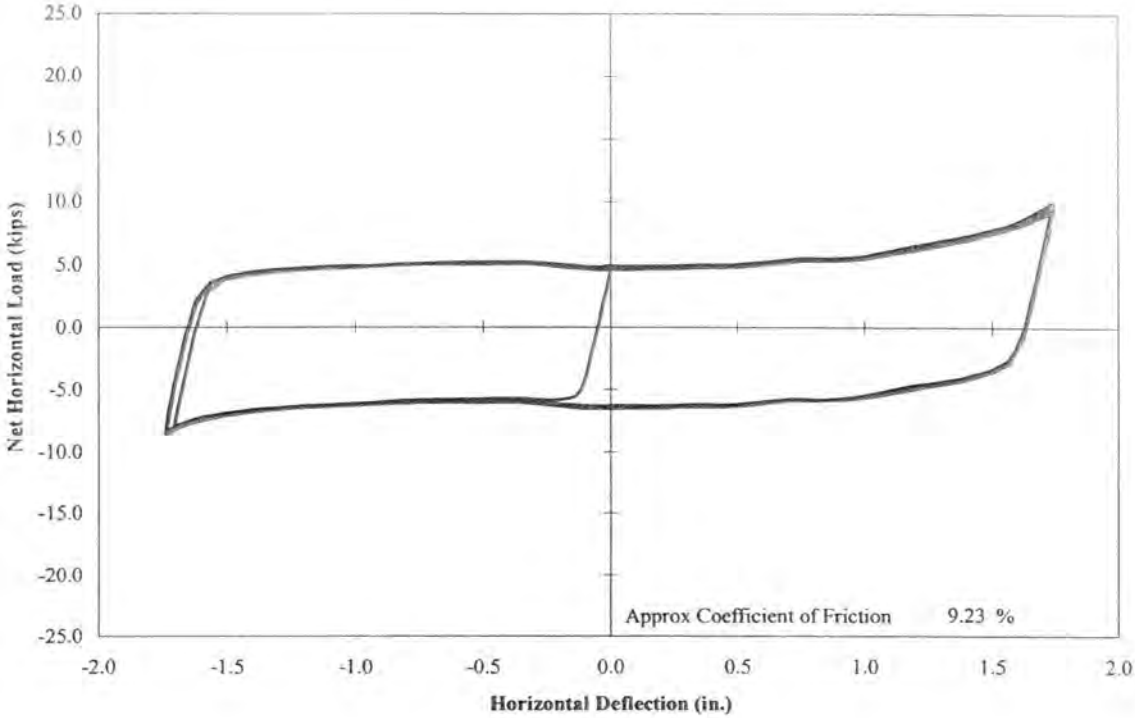

Figure 65 Bearing A1005_4 40 Cycles At 50 kips

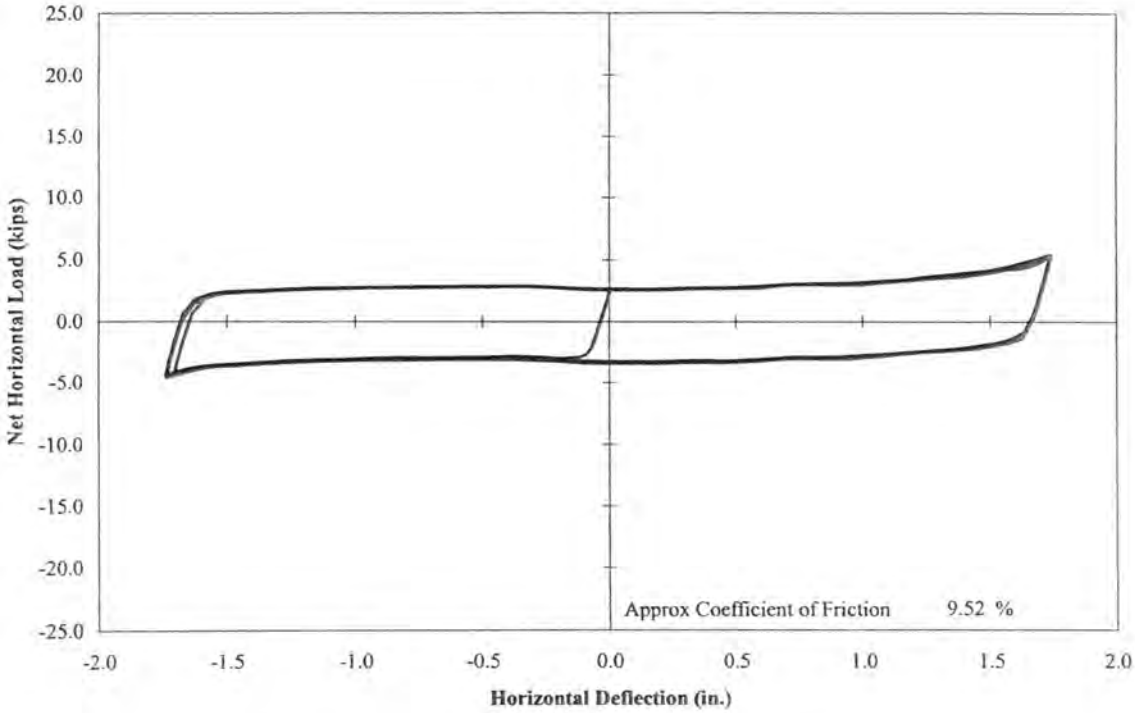

Figure 66 Bearing A1005_4 40 Cycles At 25 kips

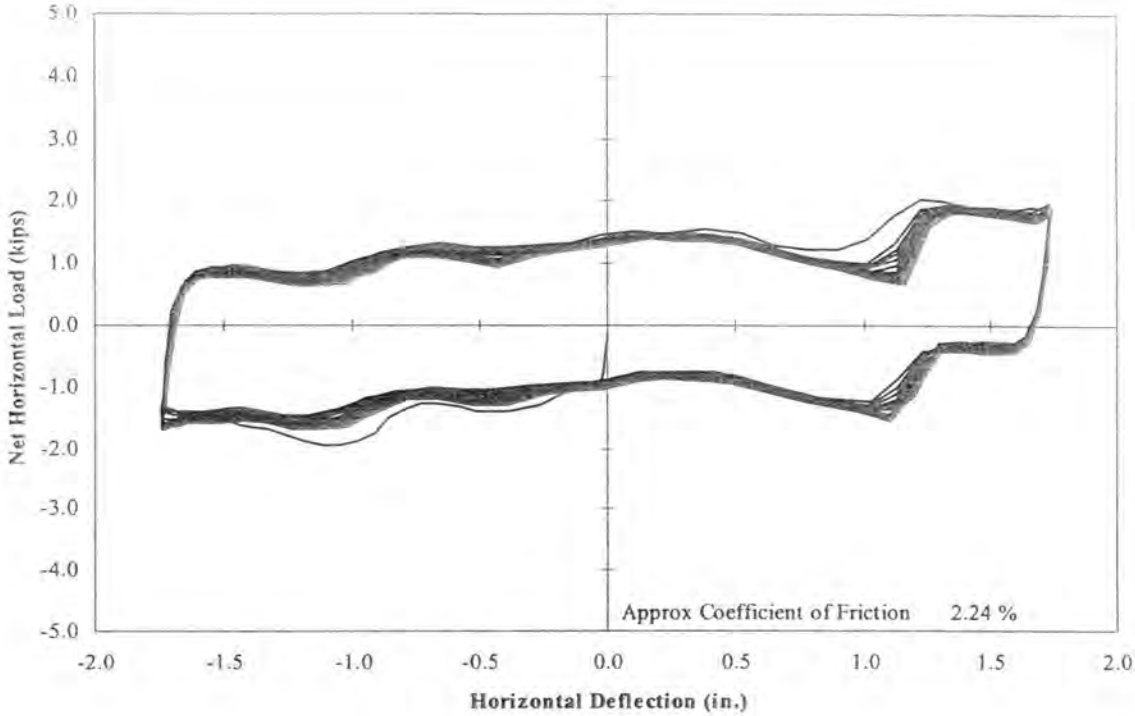

Figure 67 Bearing A860_3 40 Cycles At 25 kips (180 Degrees Rotated)

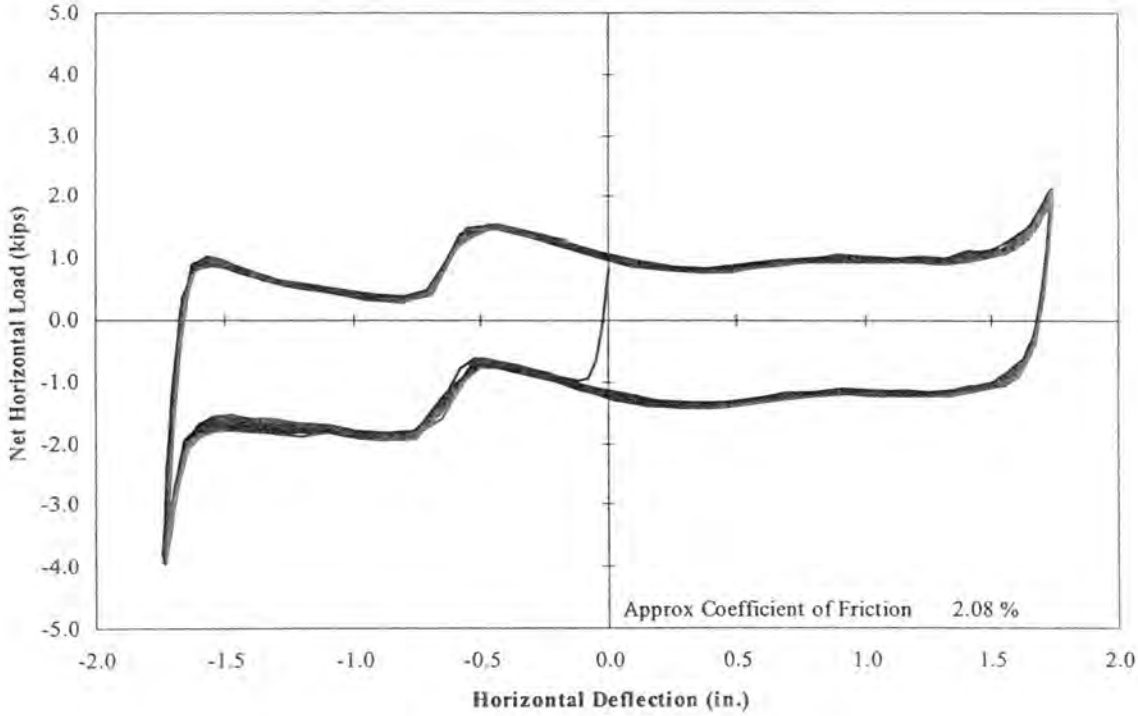

Figure 68 Bearing A860_3 40 Cycles At 25 kips (Original Position)

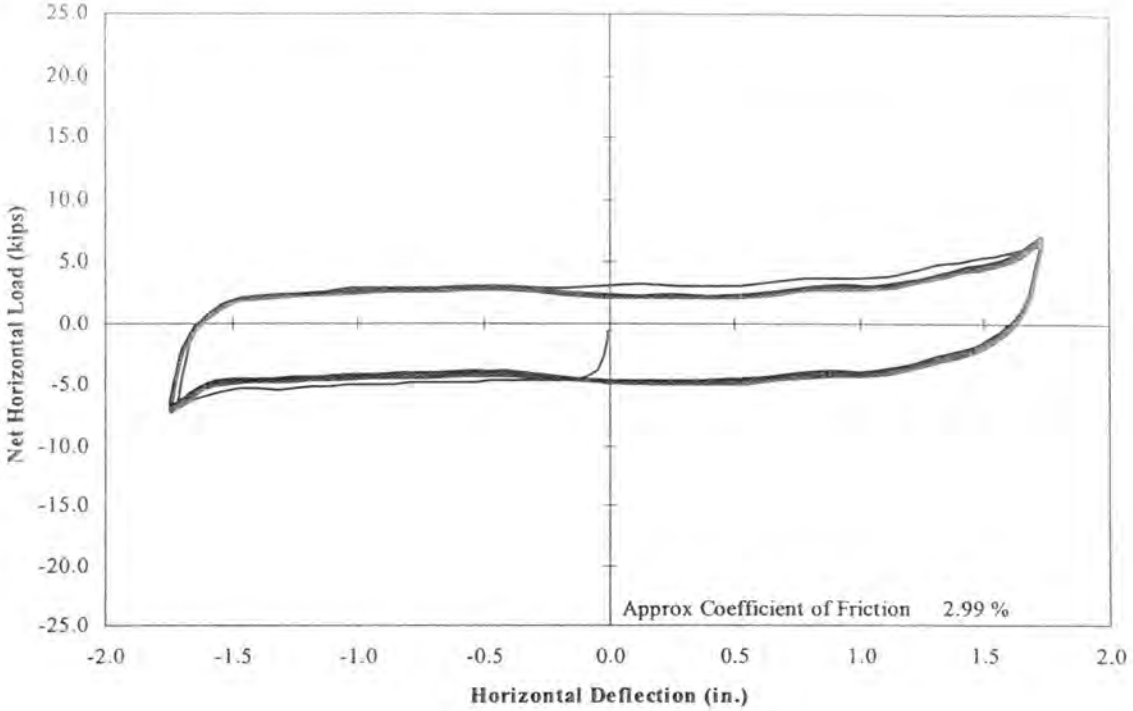

Figure 69 Bearing A1005_4 40 Cycles (Brushed and Greased)