VOLUME II

TESTING AND EVALUATION OF GROUT STRENGTHENED AND REPAIRED TUBULAR MEMBERS

FINAL REPORT
(Appendices)

TEES Projects 32525-30900, 30920, 30930, 30980, 41720

by

T. L. Kohutek, J. M. Nunn, and S. L. Faseler

Texas Engineering Experiment Station
Texas A&M University
College Station, Texas

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APPENDIX A

FIGURES OF REDUCED DATA FOR ALL SPECIMENS

Figure A-1. EFFECTIVE LENGTH VS. LOAD STEP
SPECIMEN 01

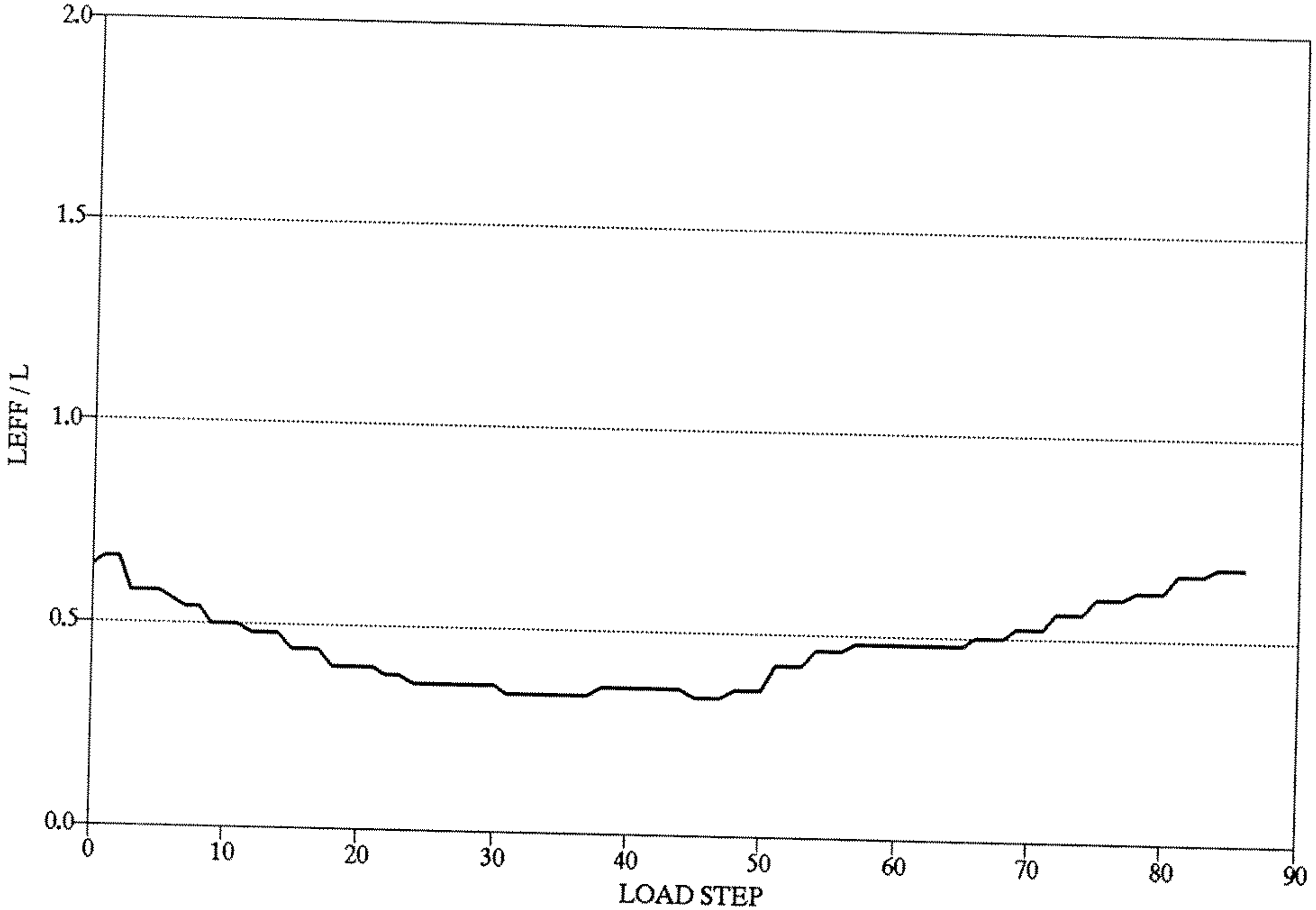


Figure A-2. LOAD AND DEFLECTION VS. LOAD STEP
SPECIMEN 01

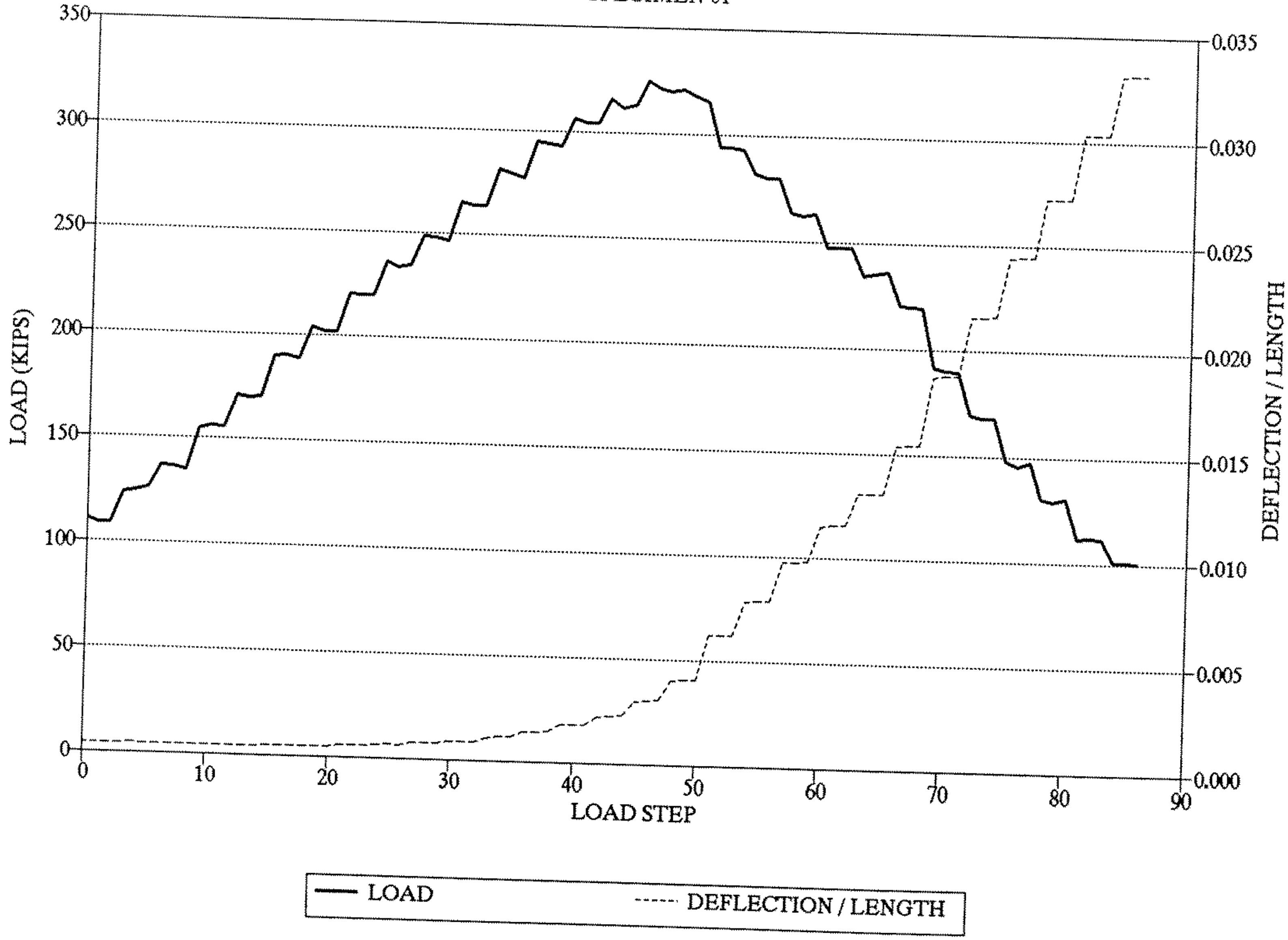


Figure A-3. LOAD VS. CHORD SHORTENING
SPECIMEN 01

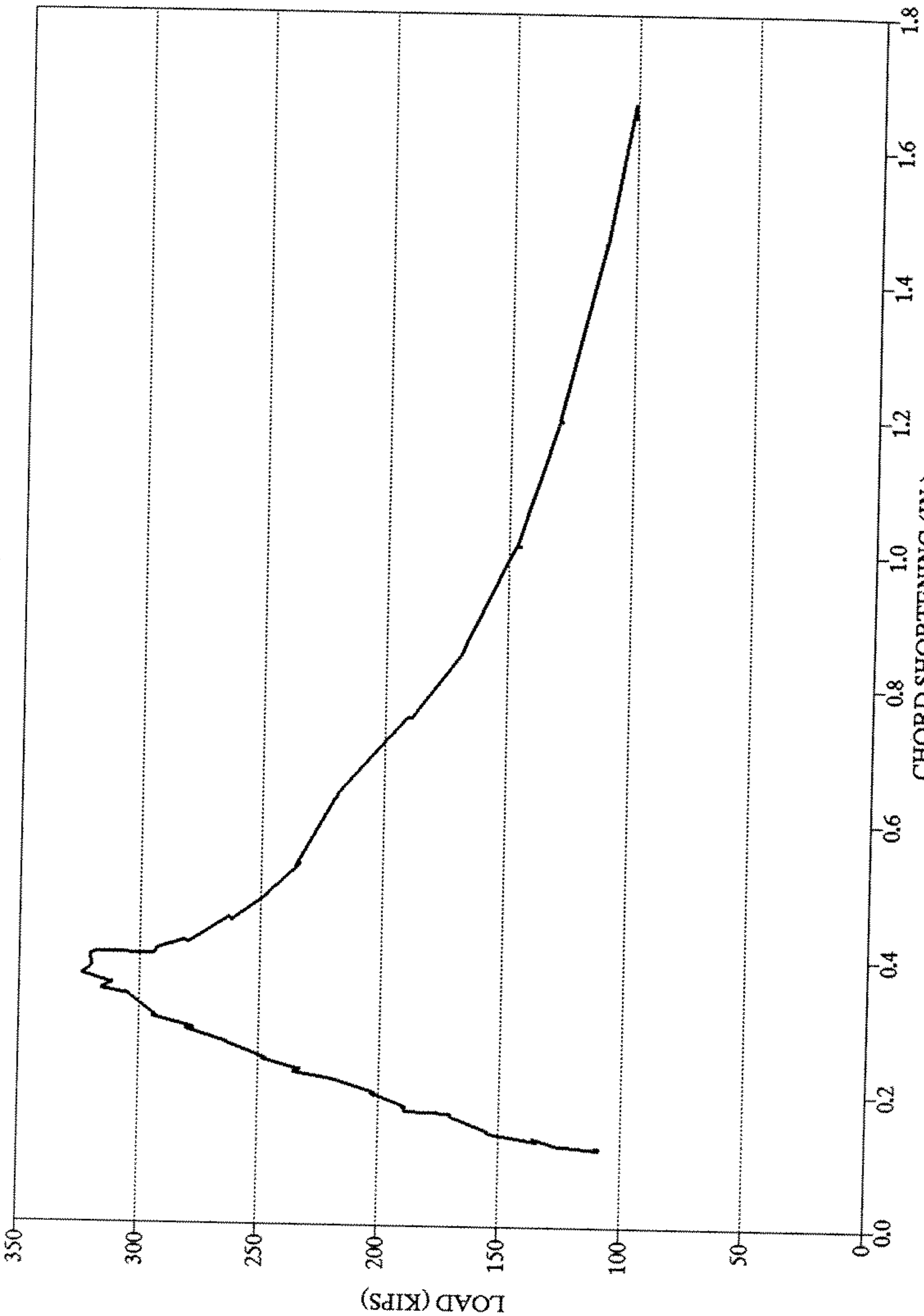


Figure A-4. HORIZONTAL DISPLACEMENTS
SPECIMEN 01

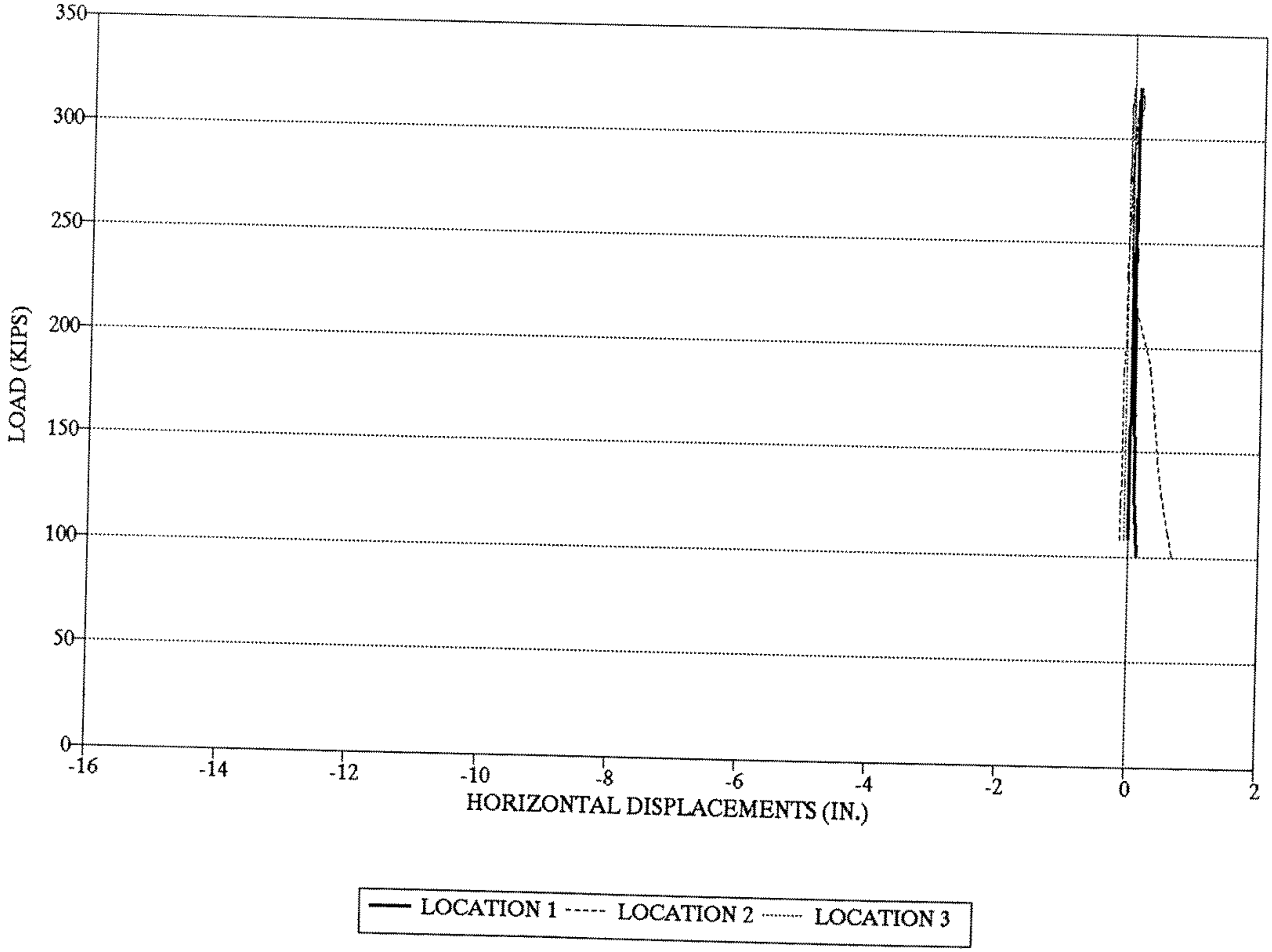


Figure A-5. VERTICAL DISPLACEMENTS
SPECIMEN 01

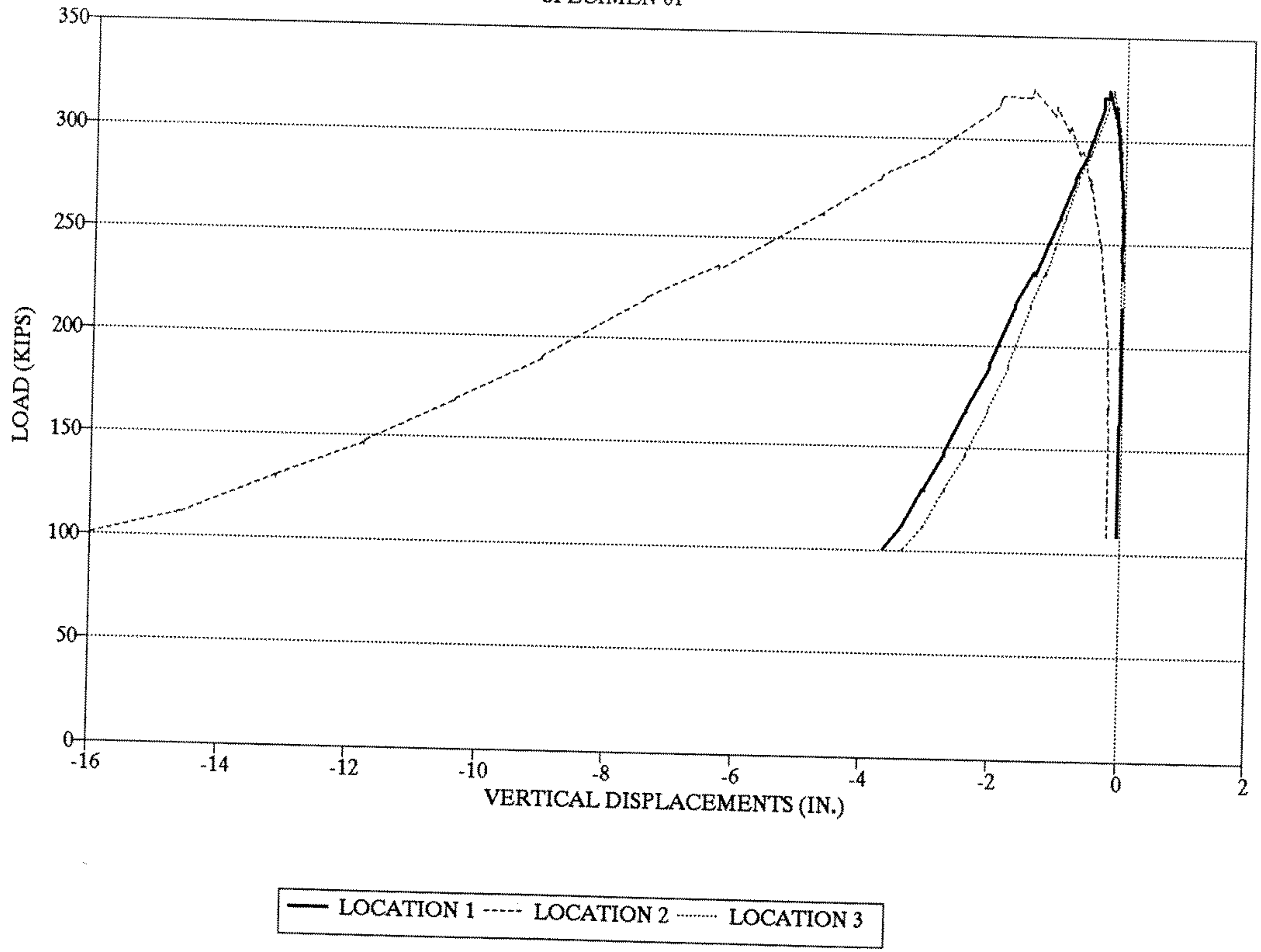


Figure A-6. LOAD AND ECCENTRICITY VS. LOAD STEP

SPECIMEN 01: X ECCENTRICITIES FROM INFLECTION POINTS

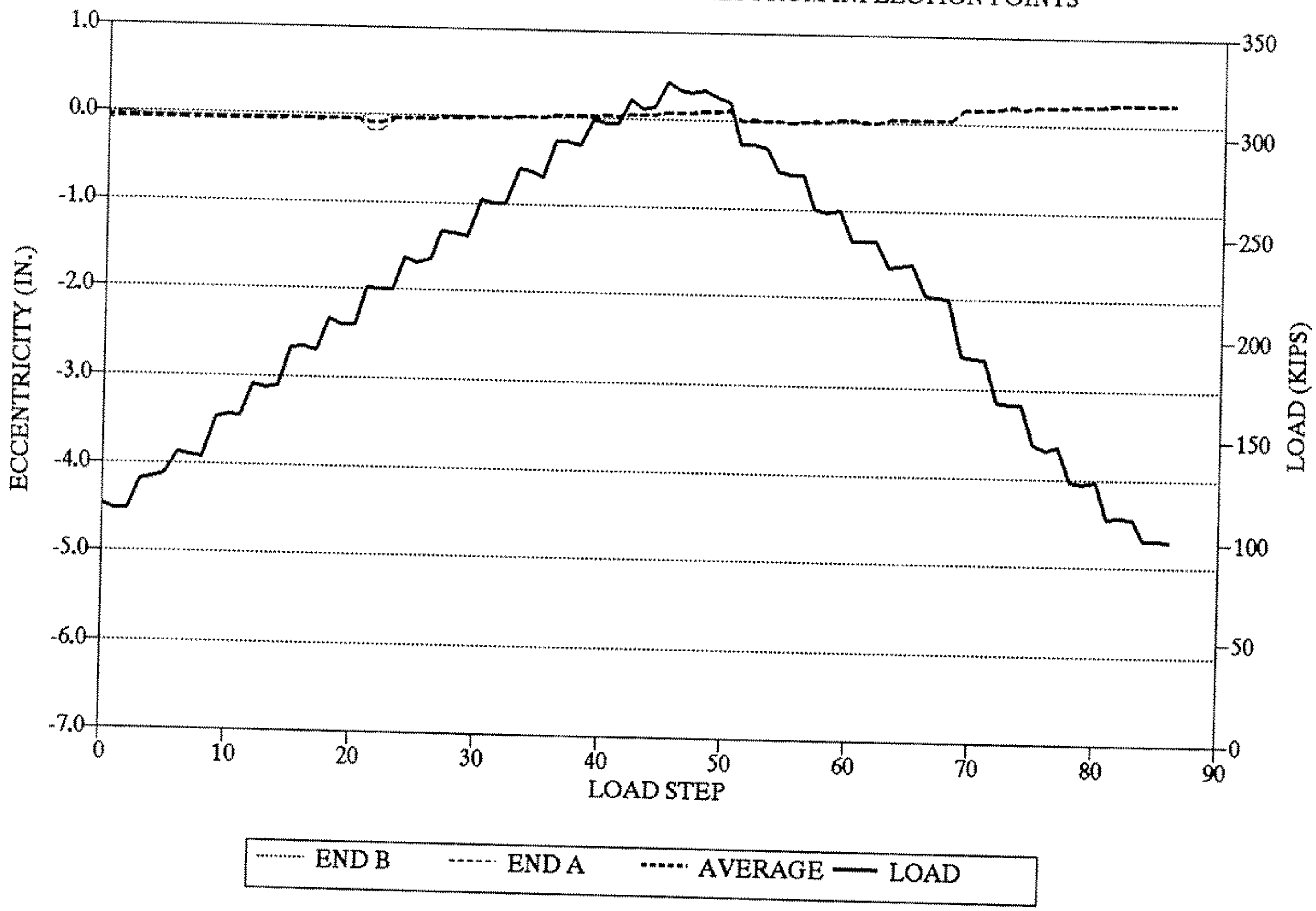


Figure A-7. LOAD AND ECCENTRICITY VS. LOAD STEP

SPECIMEN 01: Y ECCENTRICITIES FROM INFLECTION POINTS

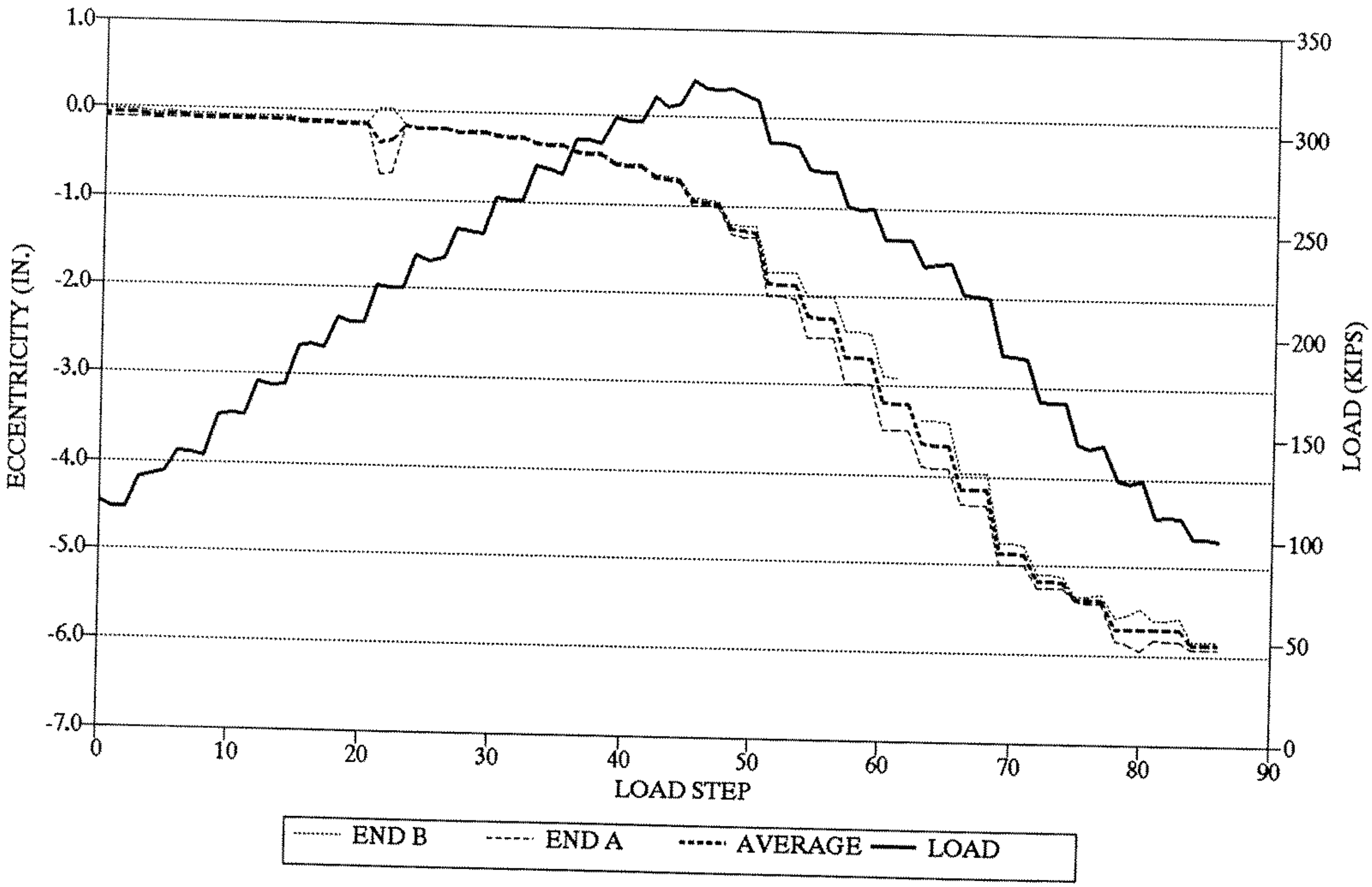


Figure A-8. LOAD AND ECCENTRICITY VS. LOAD STEP

SPECIMEN 01: X ECCENTRICITIES FROM END MOMENTS

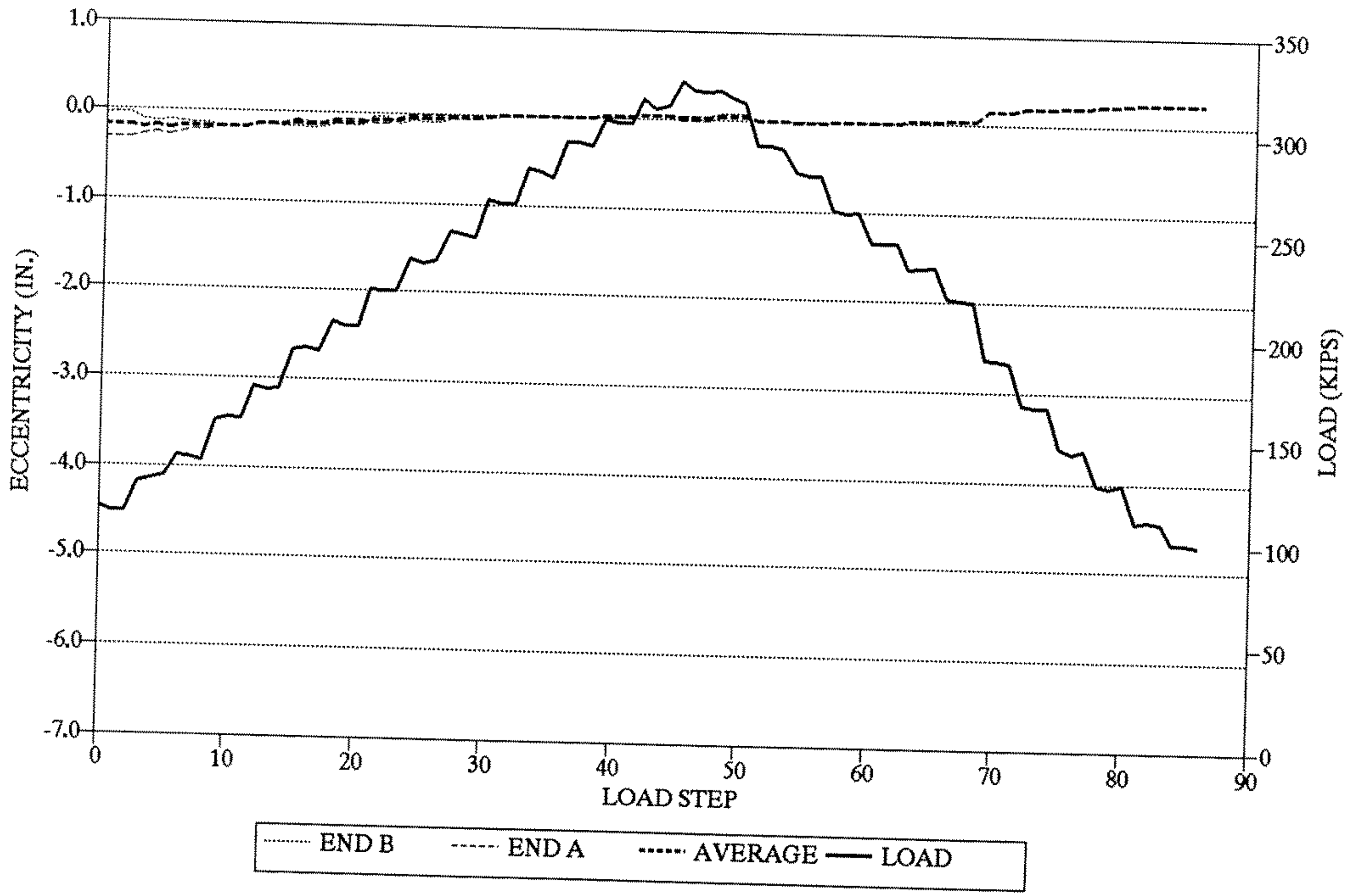


Figure A-9. LOAD AND ECCENTRICITY VS. LOAD STEP

SPECIMEN 01: Y ECCENTRICITIES FROM END MOMENTS

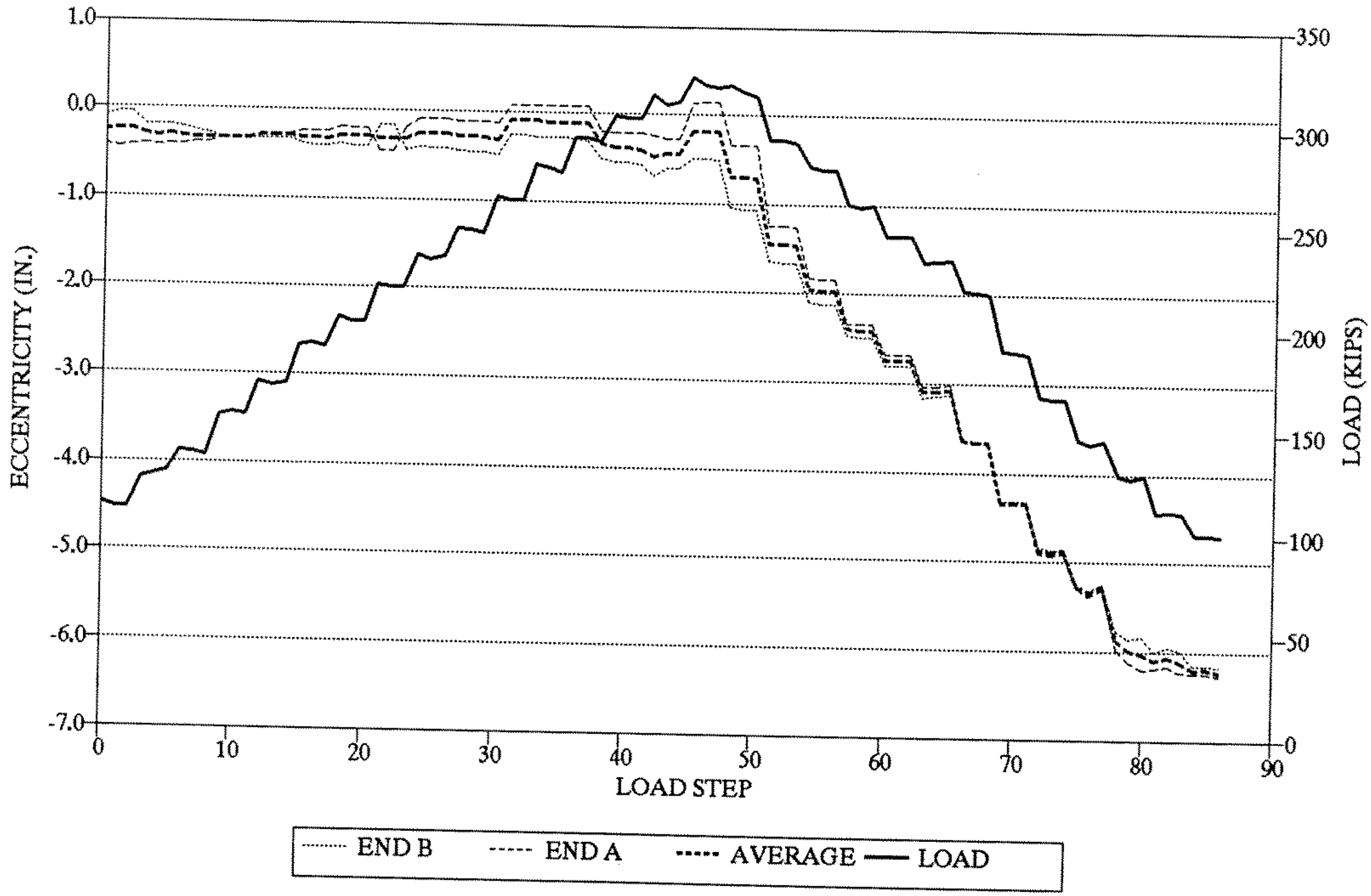


Figure A-10. END ROTATION AND LOAD VS. LOAD STEP
SPECIMEN 01

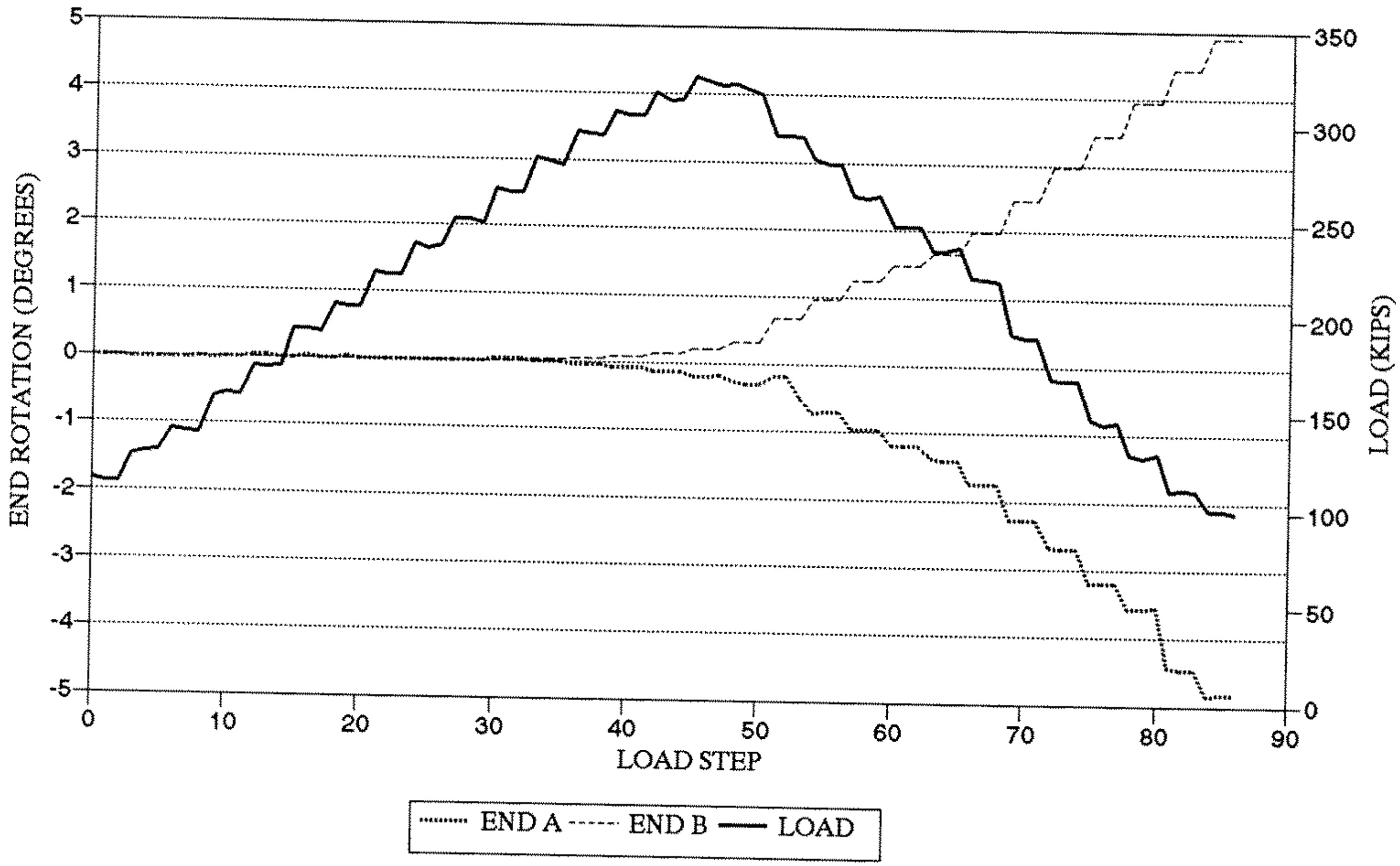


Figure A-11. EFFECTIVE LENGTH VS. LOAD STEP
SPECIMEN 02

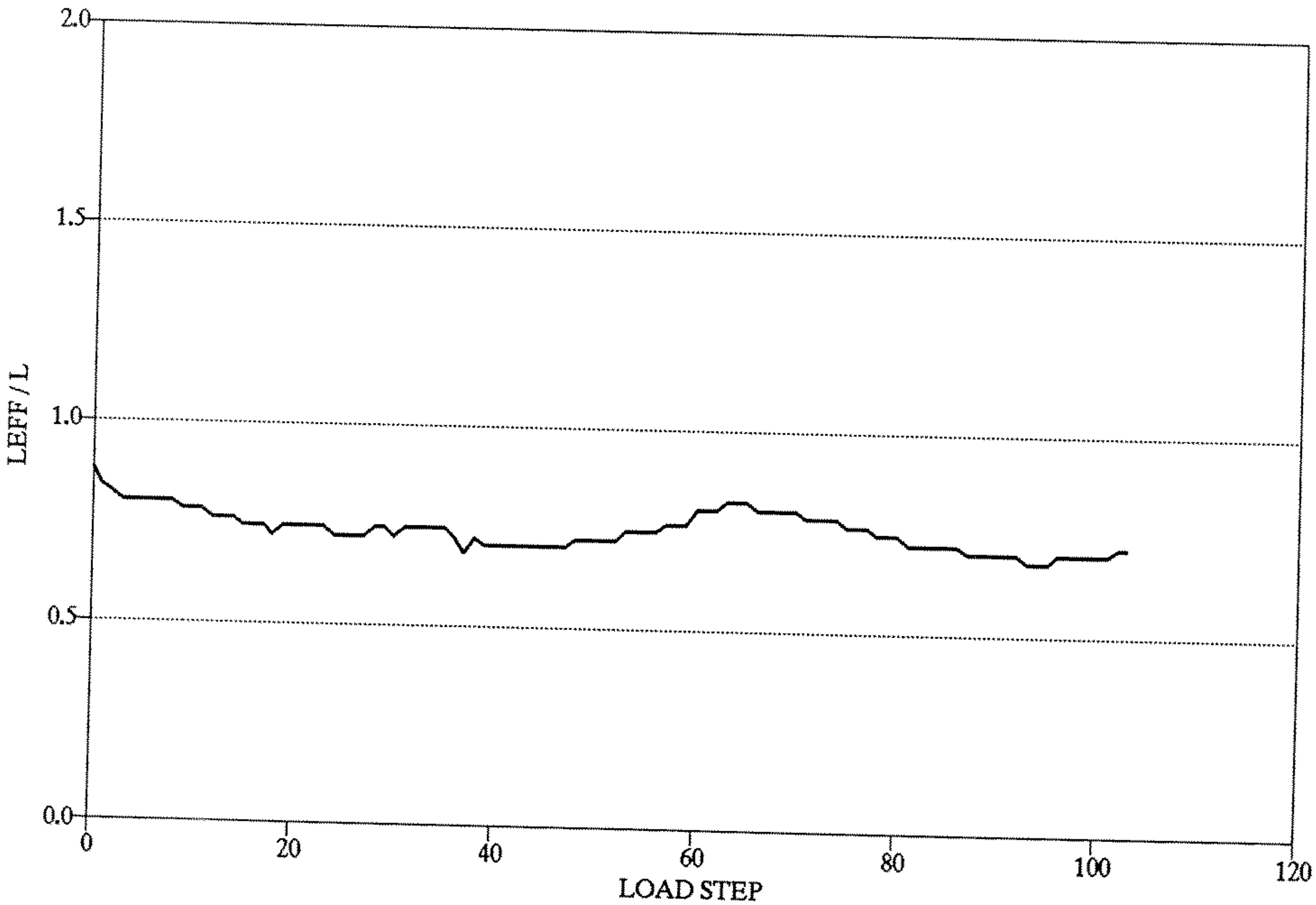


Figure A-12. LOAD AND DEFLECTION VS. LOAD STEP
SPECIMEN 02

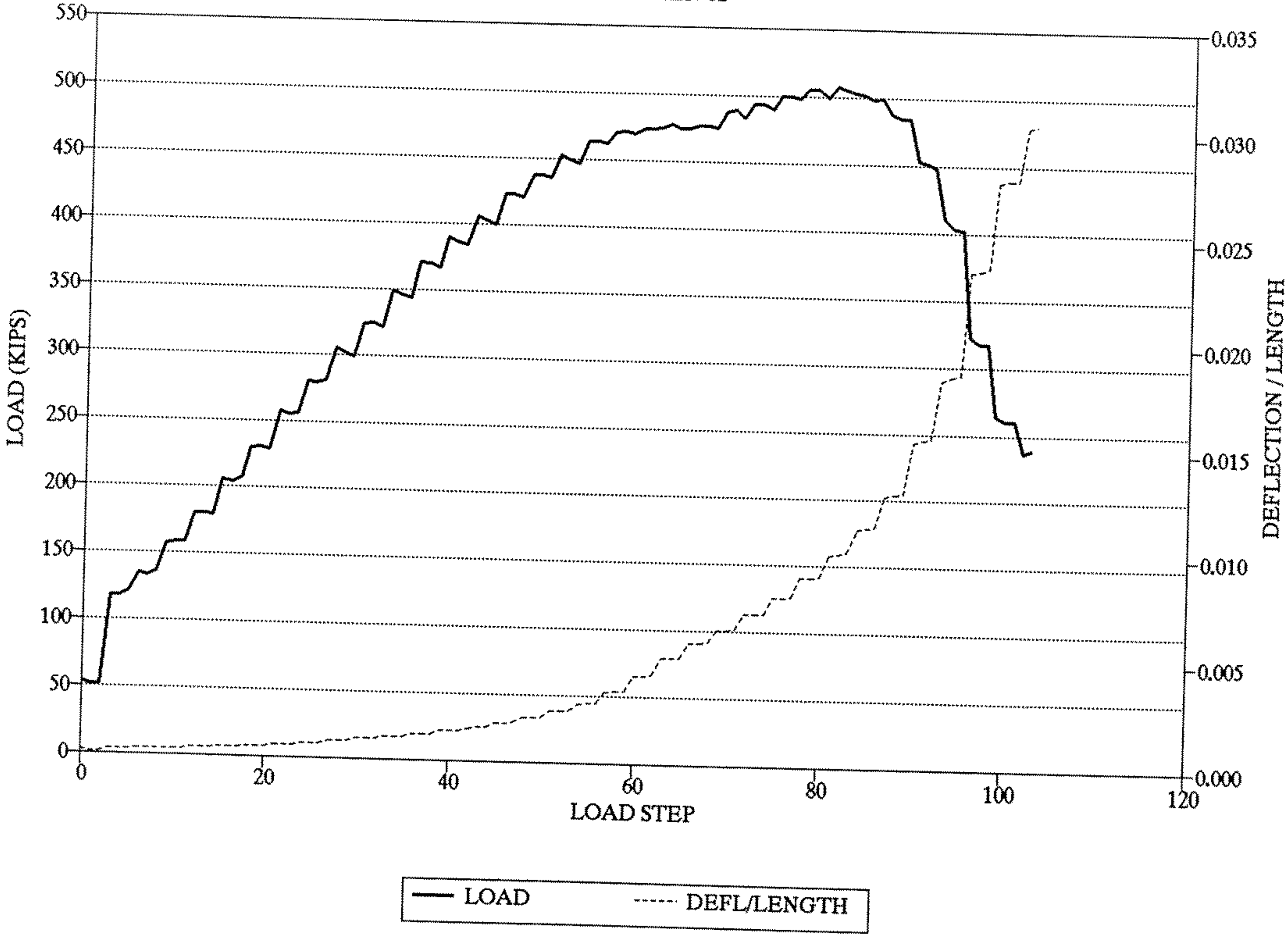


Figure A-13. LOAD VS. CHORD SHORTENING
SPECIMEN 02

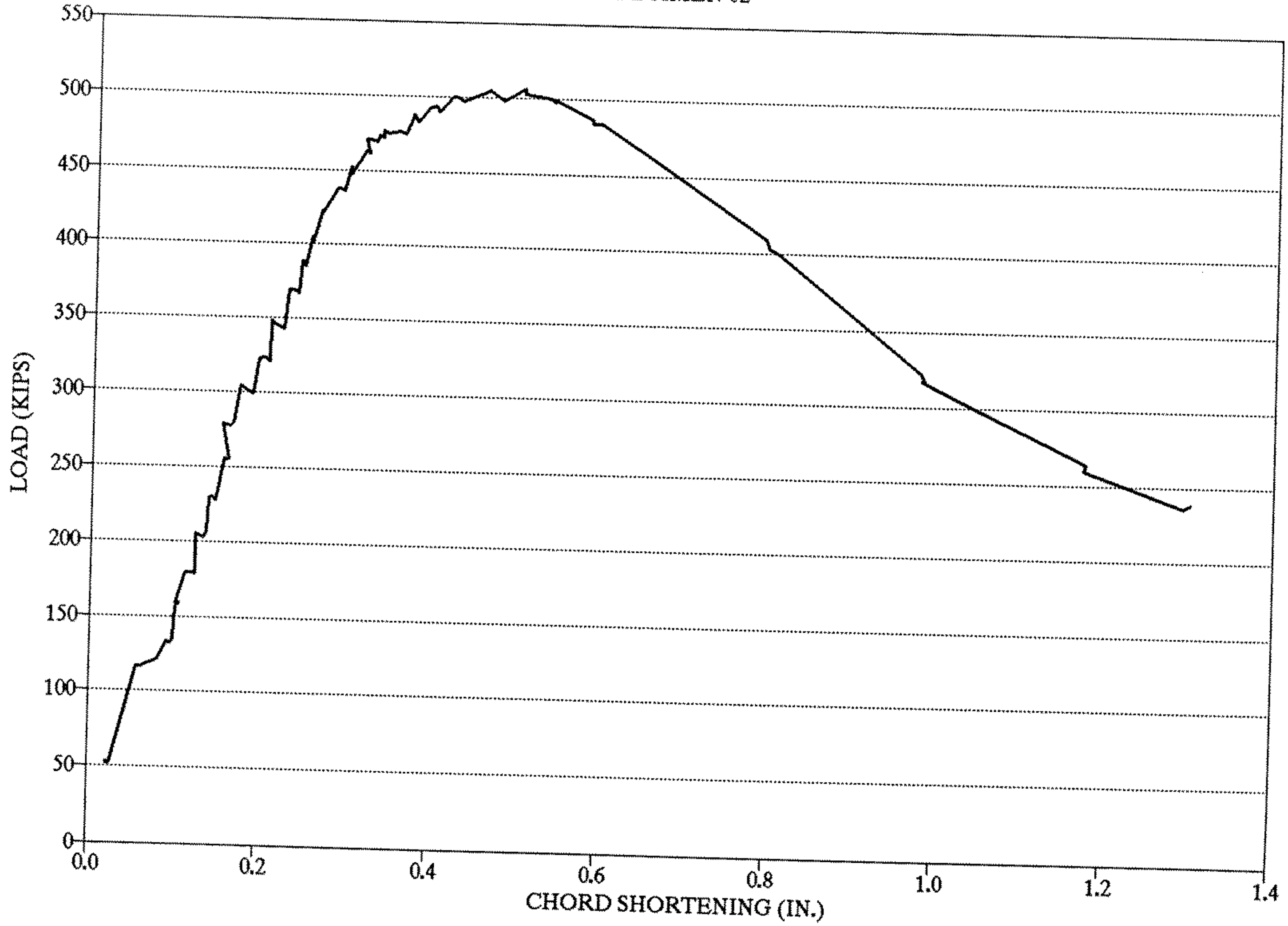


Figure A-14. HORIZONTAL DISPLACEMENTS
SPECIMEN 02

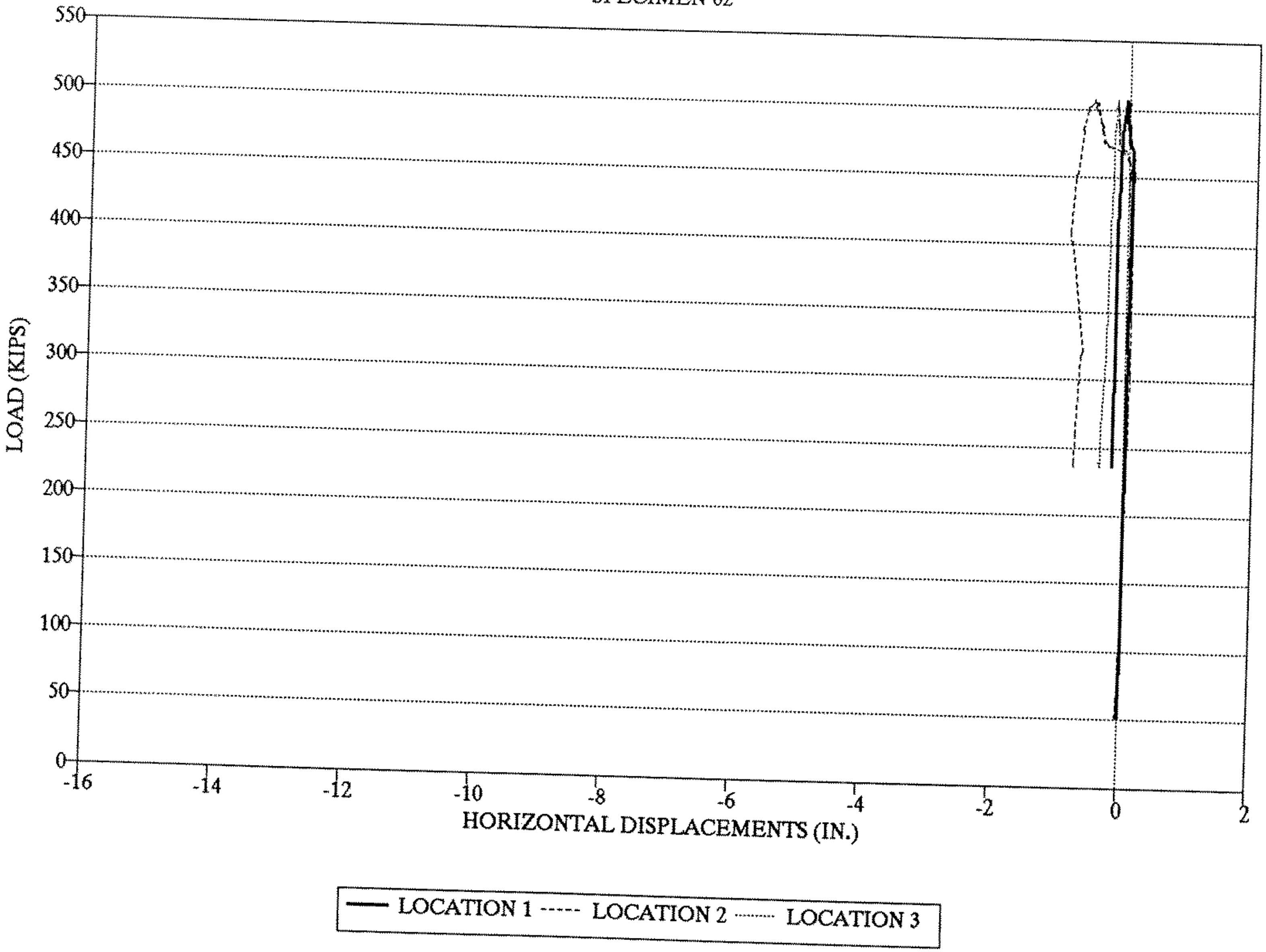


Figure A-15. VERTICAL DISPLACEMENTS
SPECIMEN 02

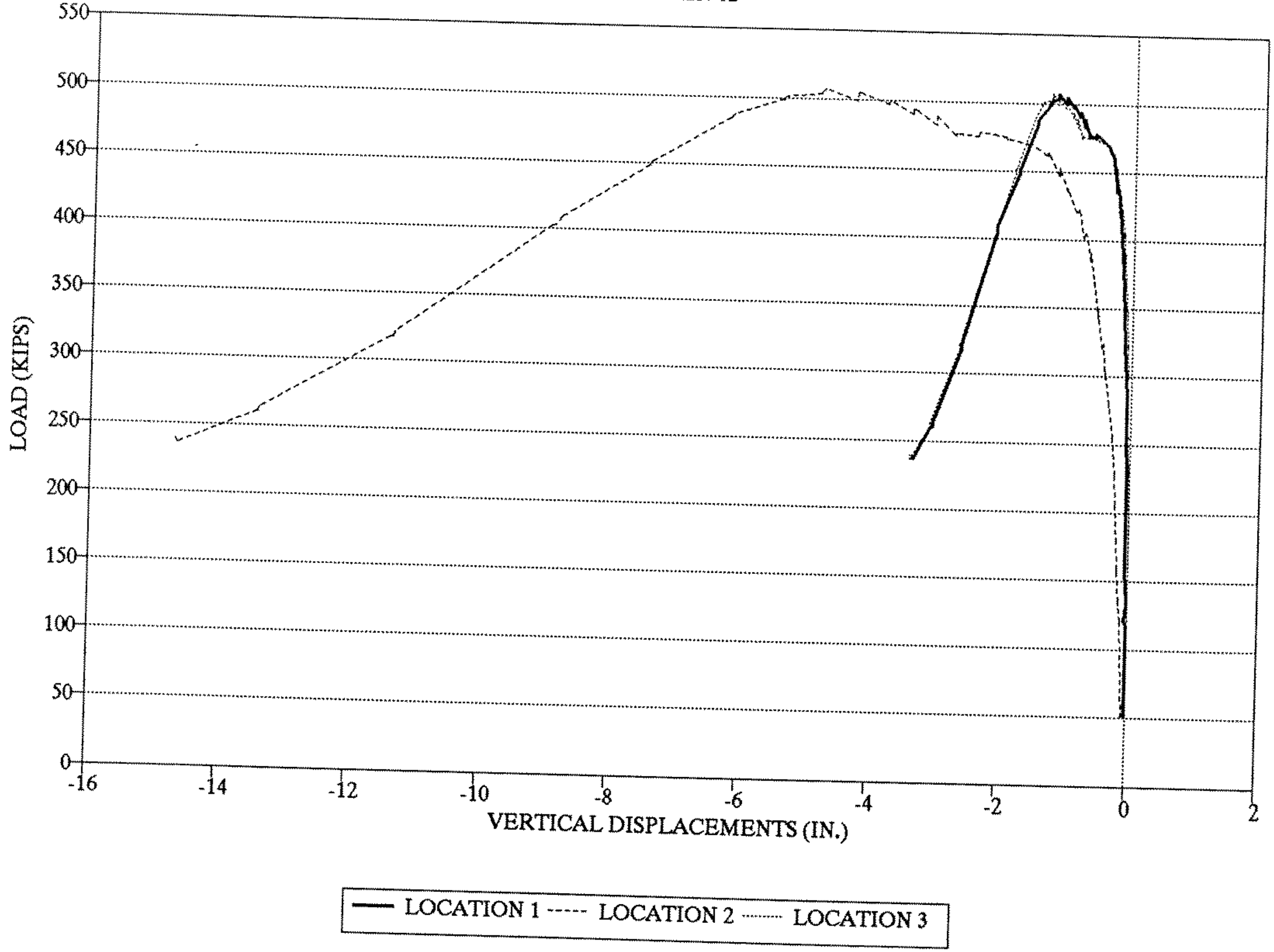


Figure A-16. LOAD AND ECCENTRICITY VS. LOAD STEP

SPECIMEN 02: X ECCENTRICITIES FROM INFLECTION POINTS

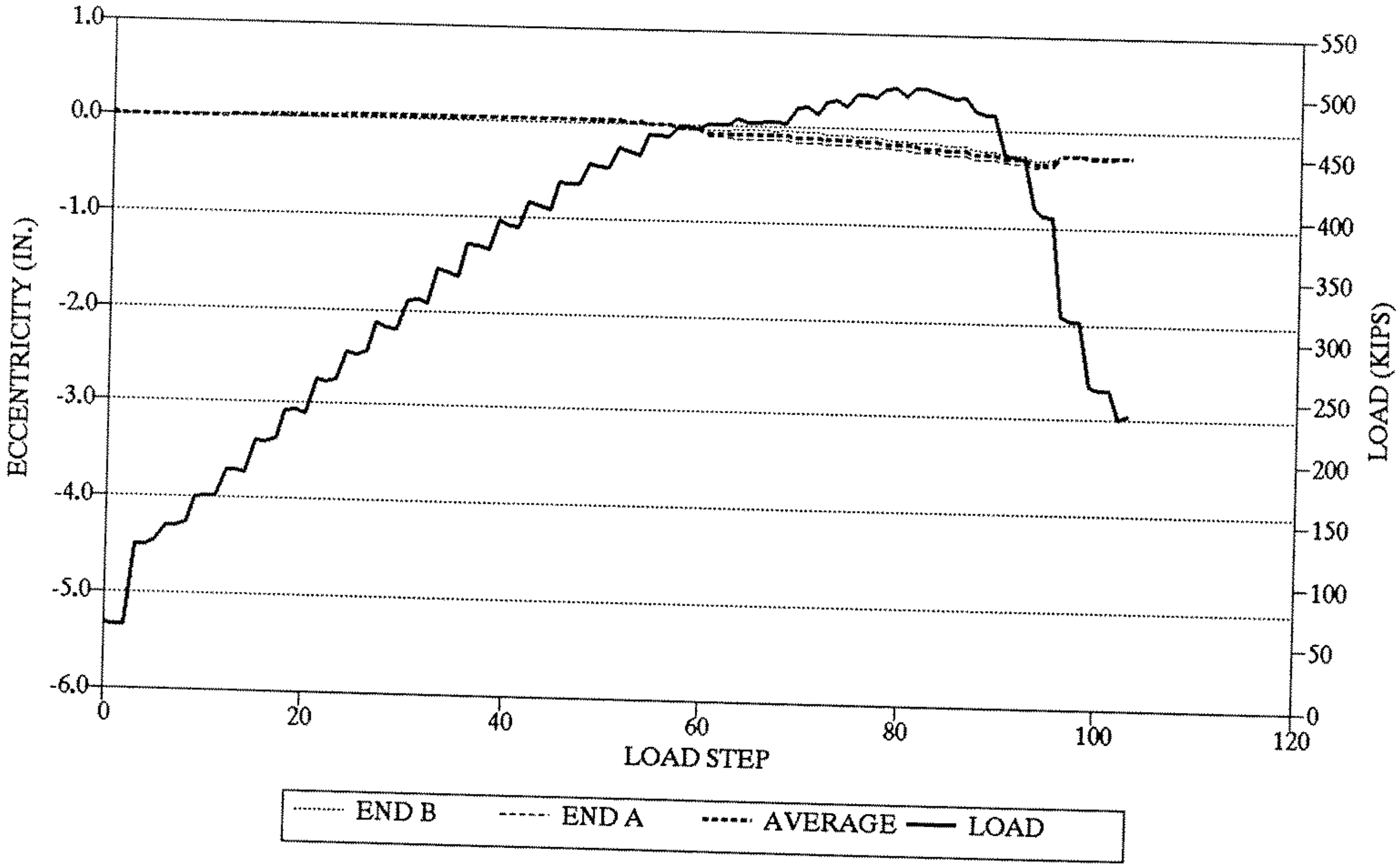


Figure A-17. LOAD AND ECCENTRICITY VS. LOAD STEP

SPECIMEN 02: Y ECCENTRICITIES FROM INFLECTION POINTS

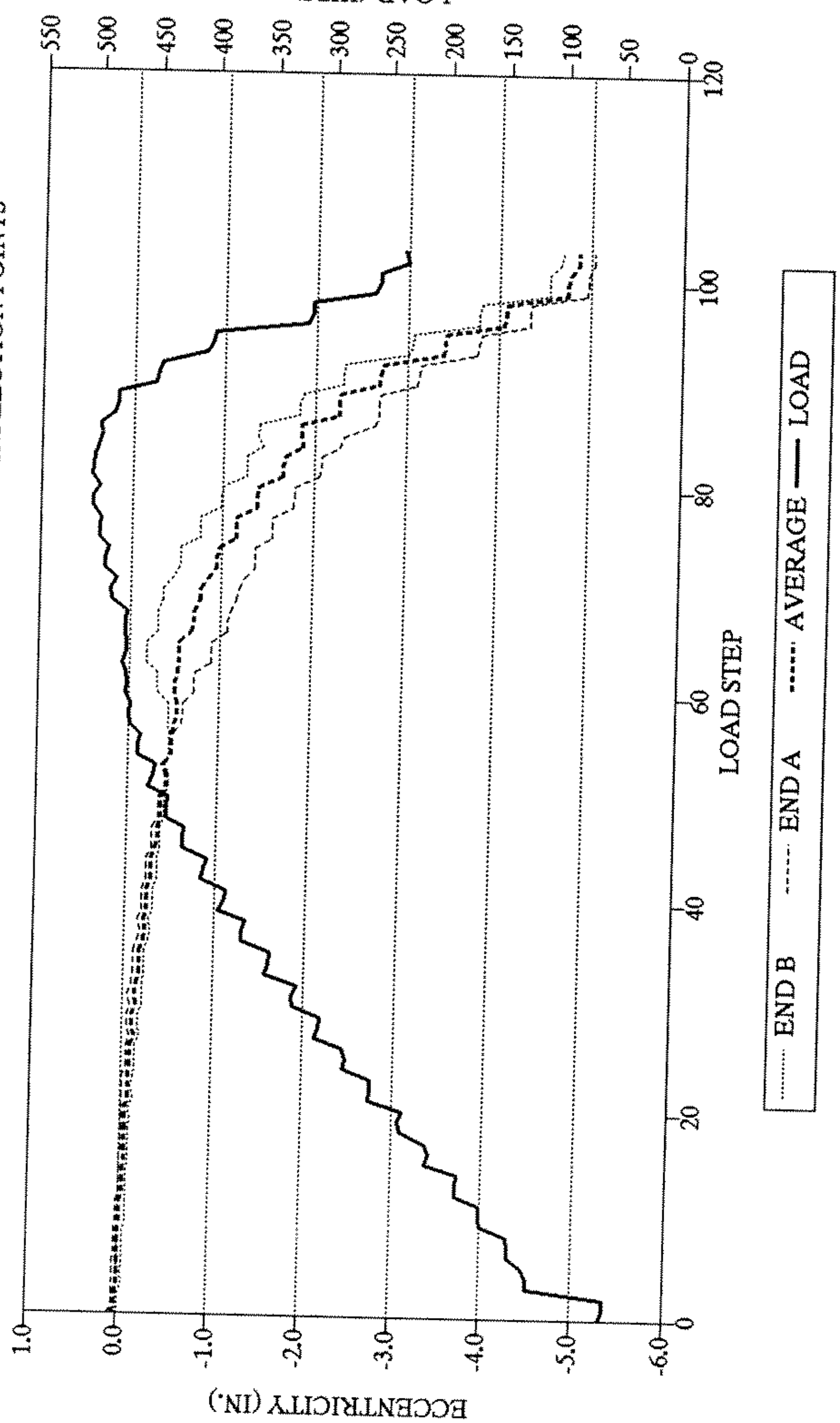


Figure A-18. LOAD AND ECCENTRICITY VS. LOAD STEP

SPECIMEN 02: X ECCENTRICITIES FROM END MOMENTS

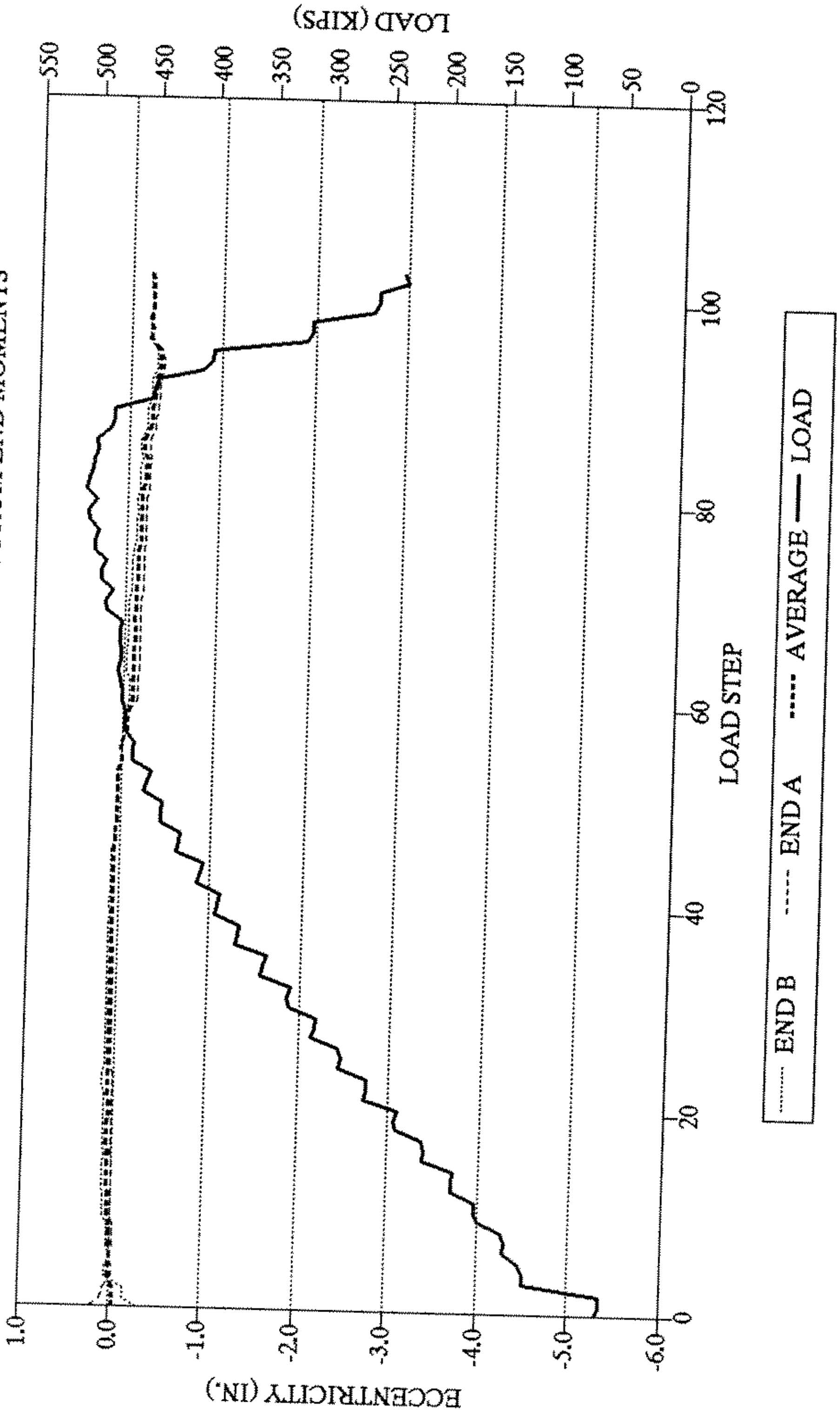


Figure A-19. LOAD AND ECCENTRICITY VS. LOAD STEP

SPECIMEN 02: Y ECCENTRICITIES FROM END MOMENTS

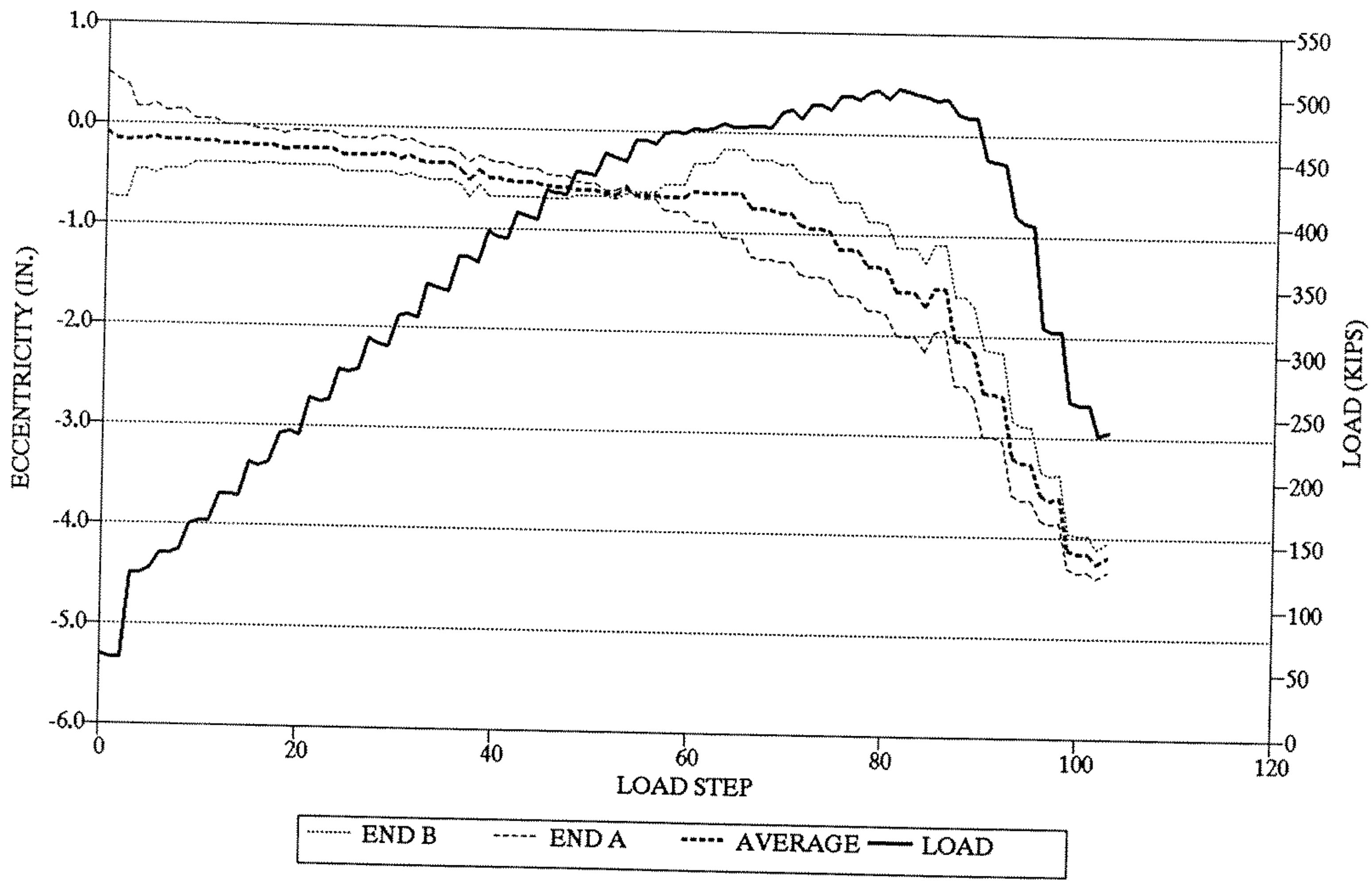


Figure A-20. END ROTATION AND LOAD VS. LOAD STEP
SPECIMEN 02

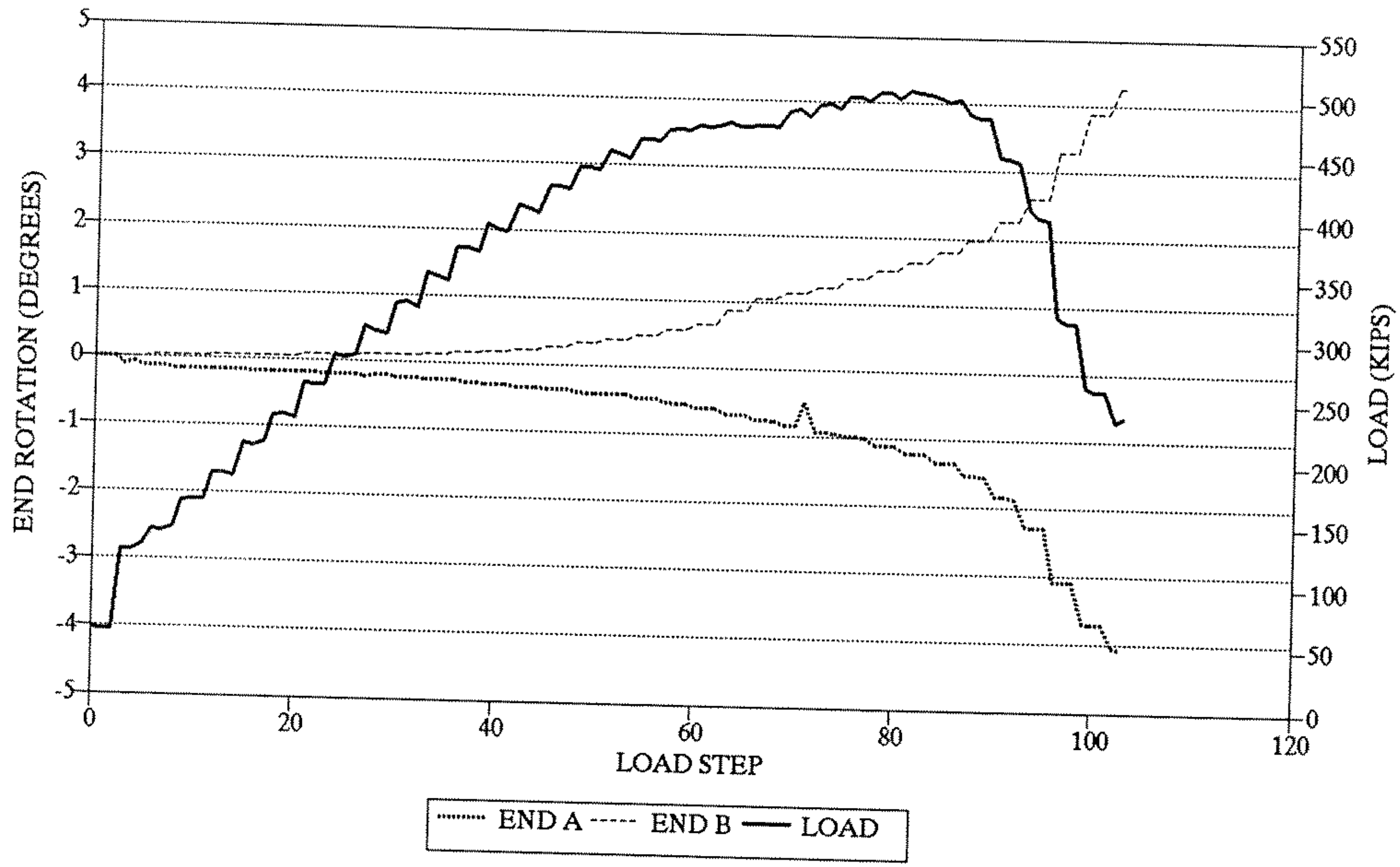


Figure A-21. EFFECTIVE LENGTH VS. LOAD STEP
SPECIMEN 03

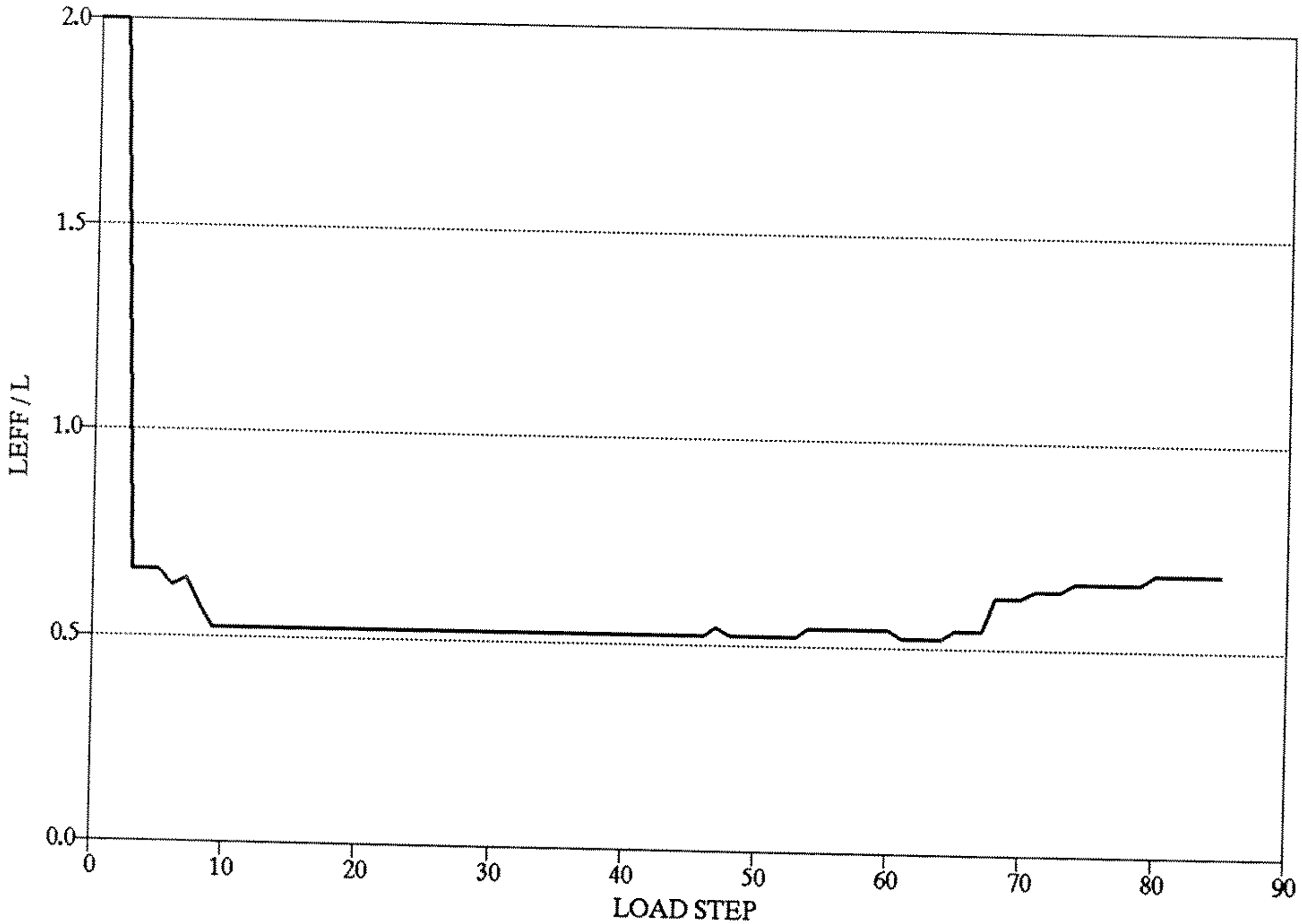


Figure A-22. LOAD AND DEFLECTION VS. LOAD STEP
SPECIMEN 03

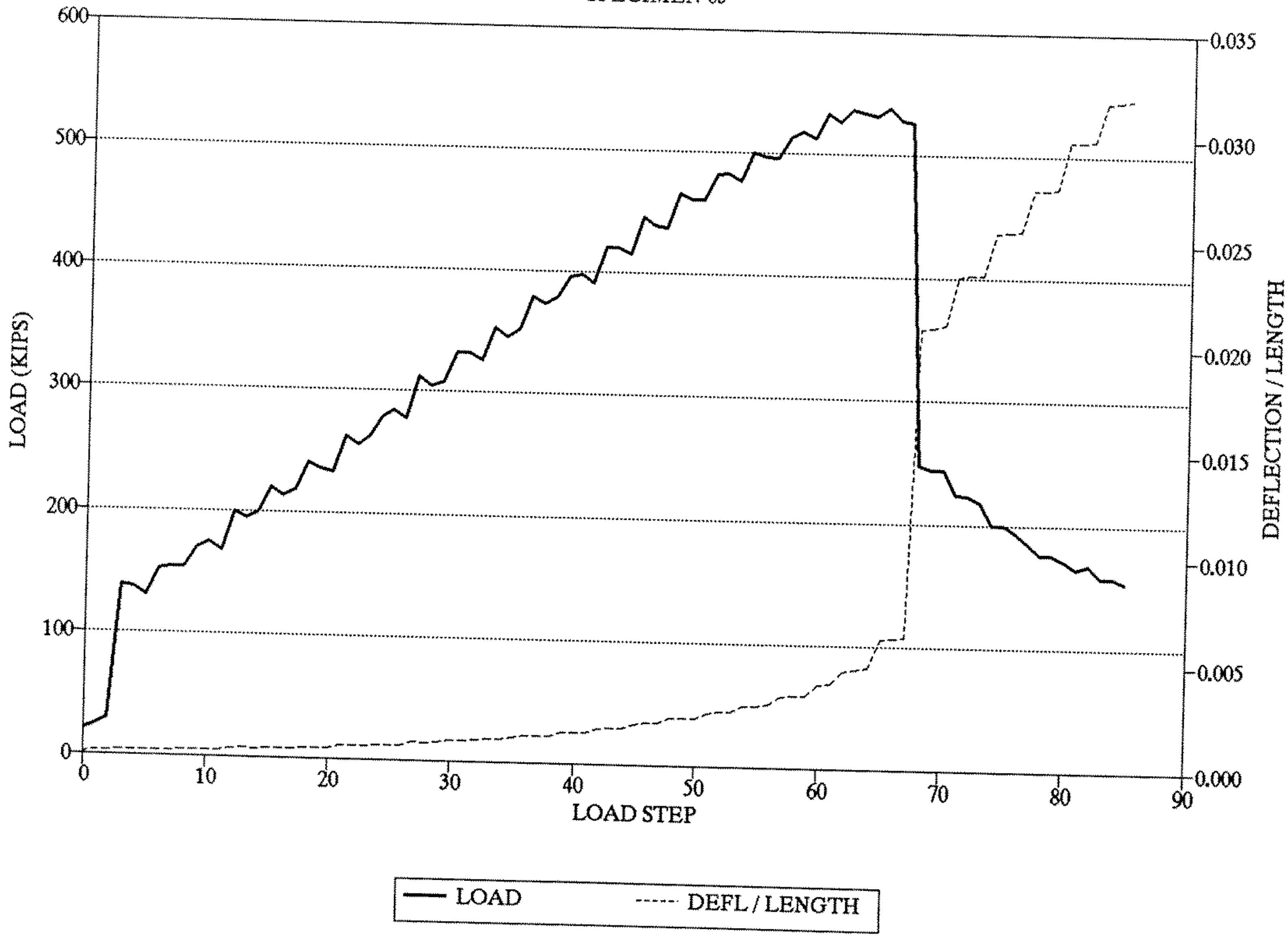


Figure A-23. LOAD VS. CHORD SHORTENING
SPECIMEN 03

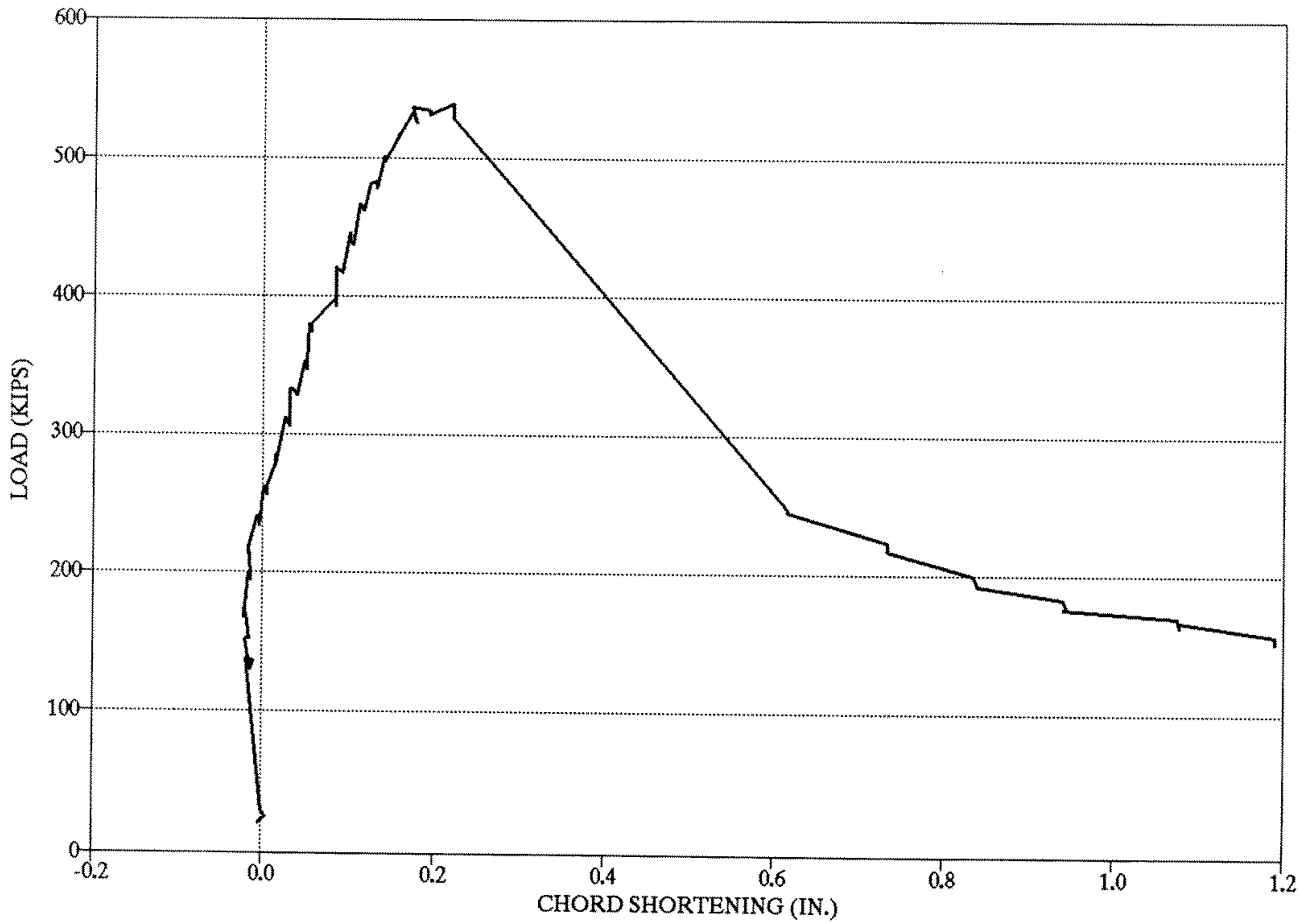


Figure A-24. HORIZONTAL DISPLACEMENTS
SPECIMEN 03

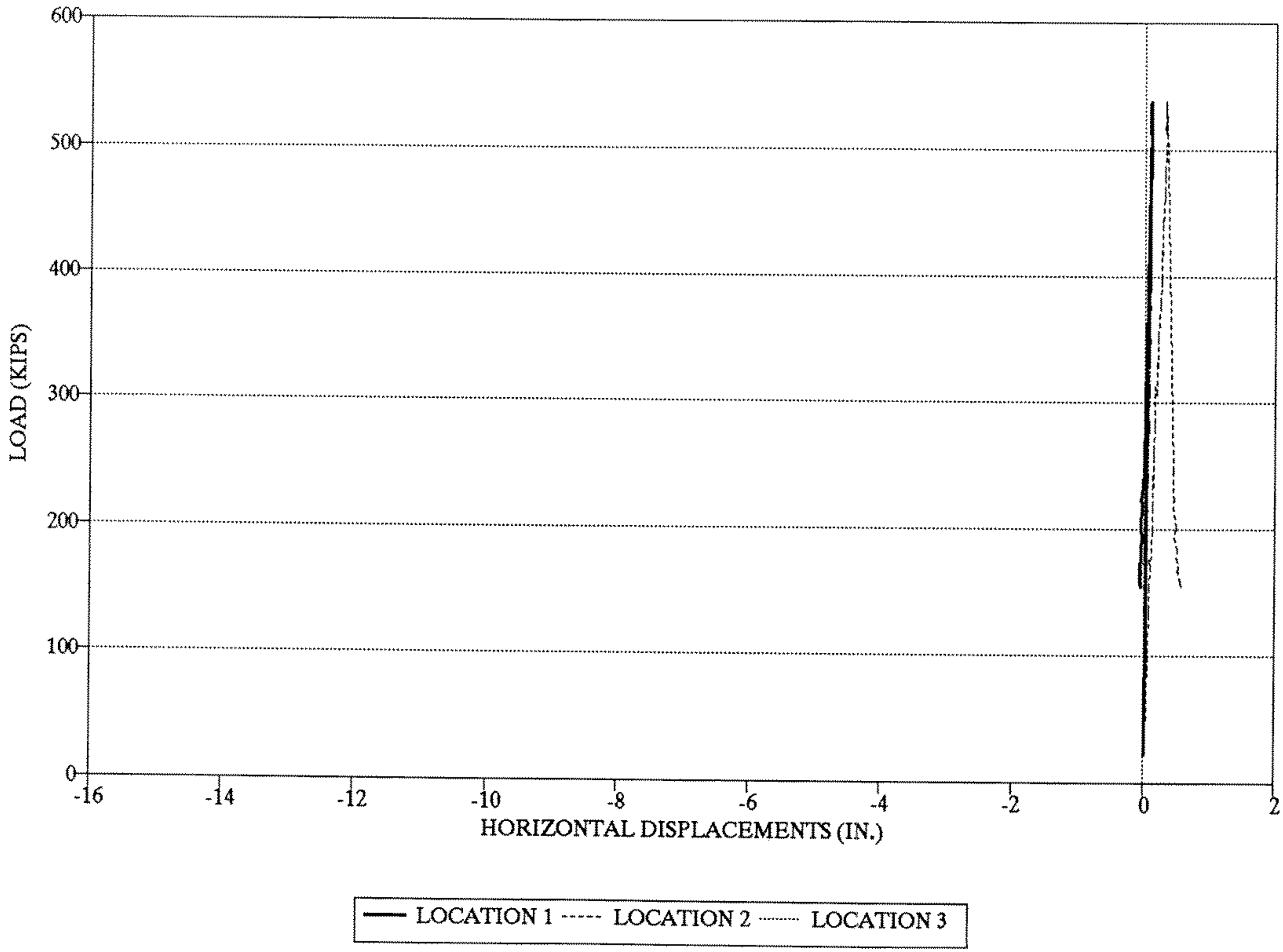


Figure A-25. VERTICAL DISPLACEMENTS
SPECIMEN 03

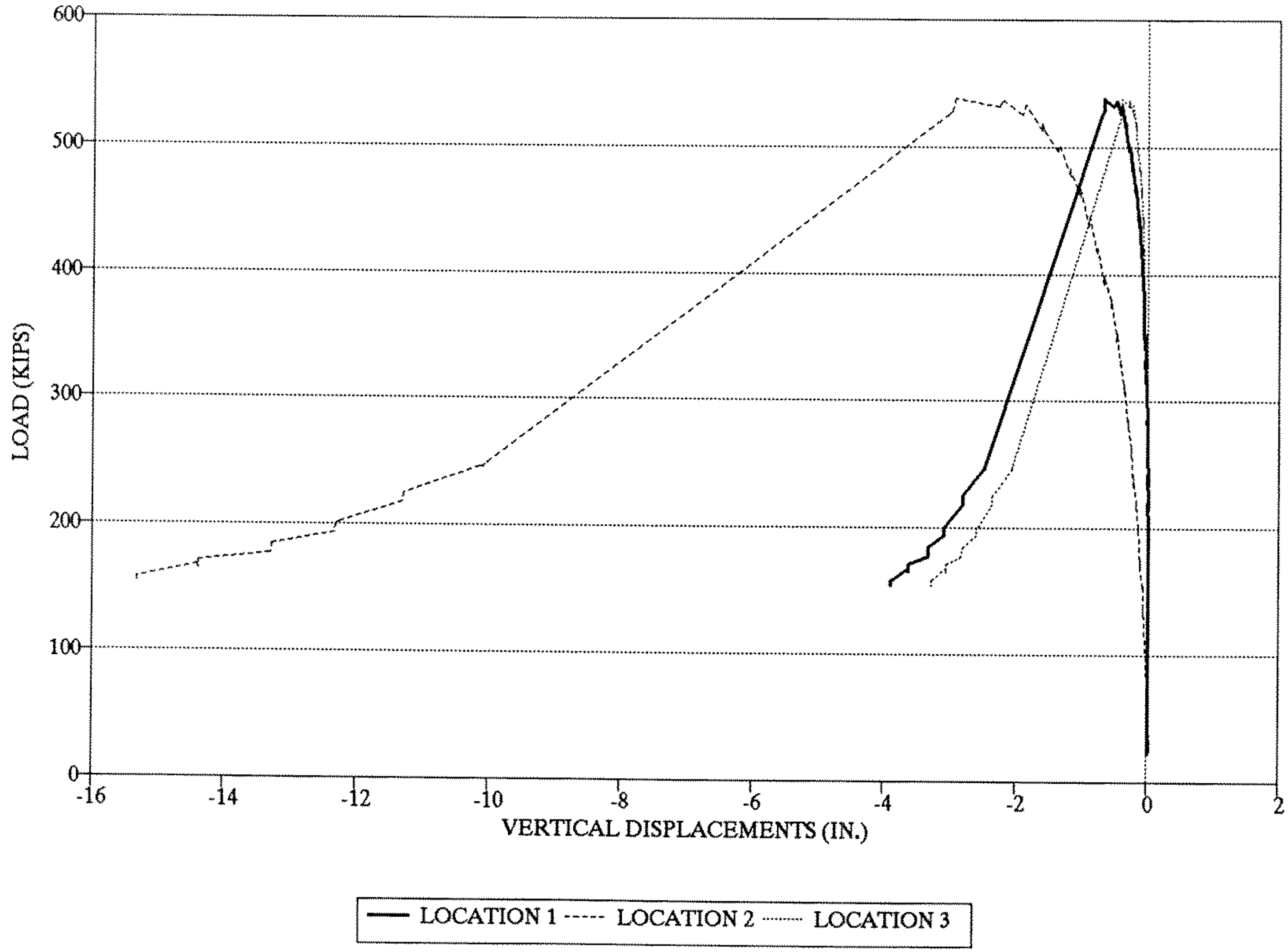


Figure A-26. LOAD AND ECCENTRICITY VS. LOAD STEP

SPECIMEN 03: X ECCENTRICITIES FROM INFLECTION POINTS

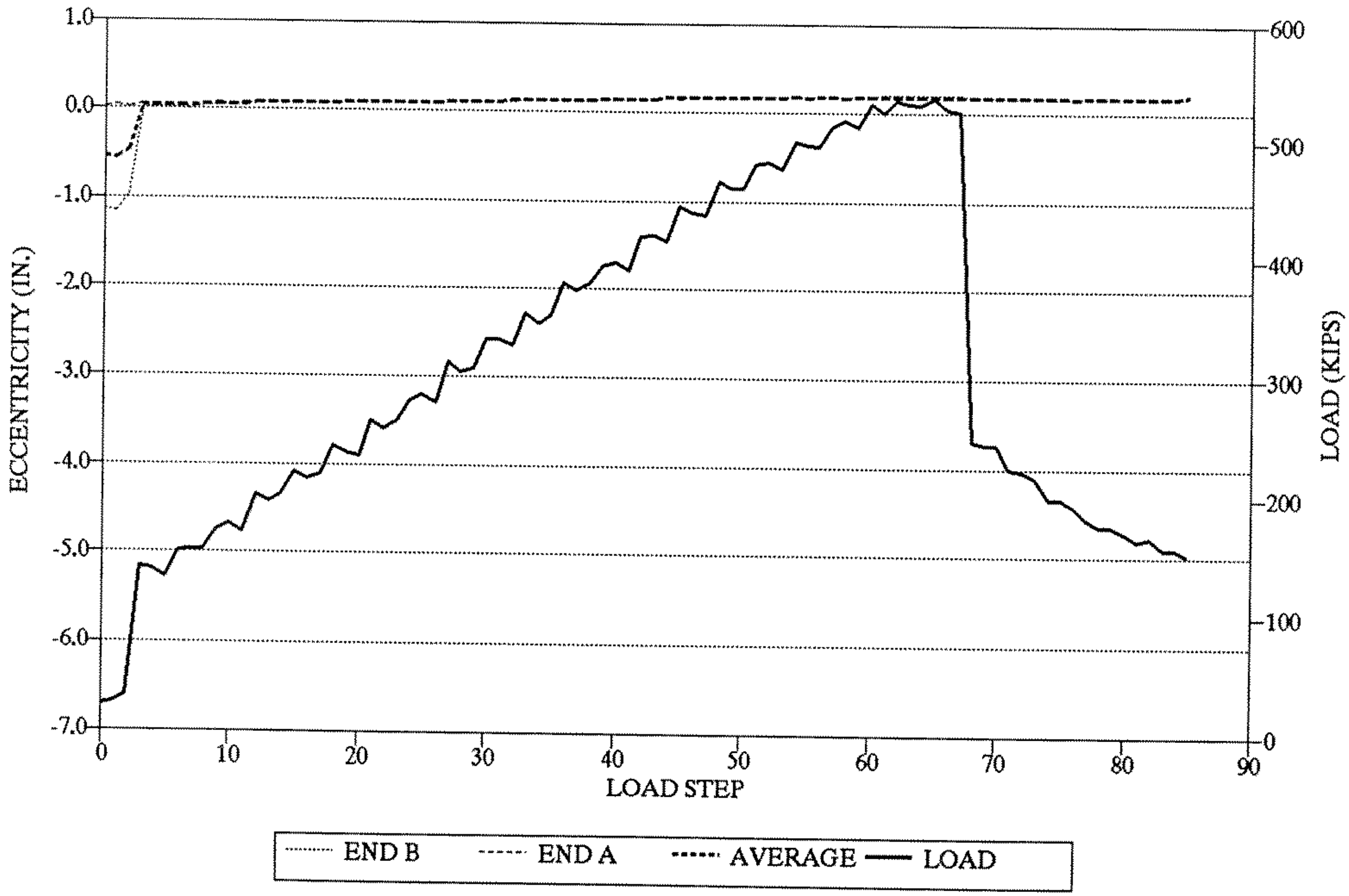


Figure A-27. LOAD AND ECCENTRICITY VS. LOAD STEP

SPECIMEN 03: Y ECCENTRICITES FROM INFLECTION POINTS

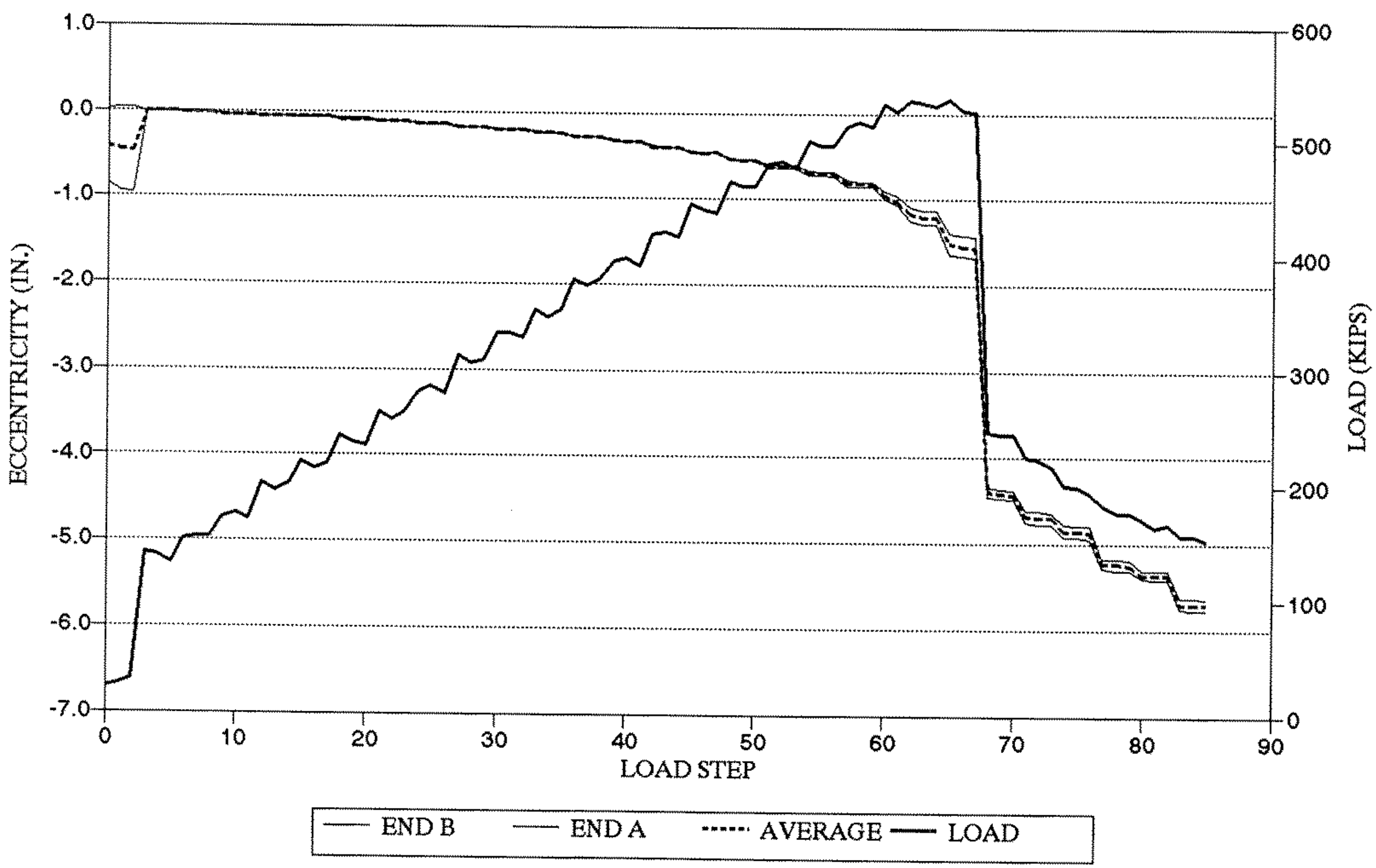


Figure A-28. LOAD AND ECCENTRICITY VS. LOAD STEP

SPECIMEN 03: X ECCENTRICITIES FROM END MOMENTS

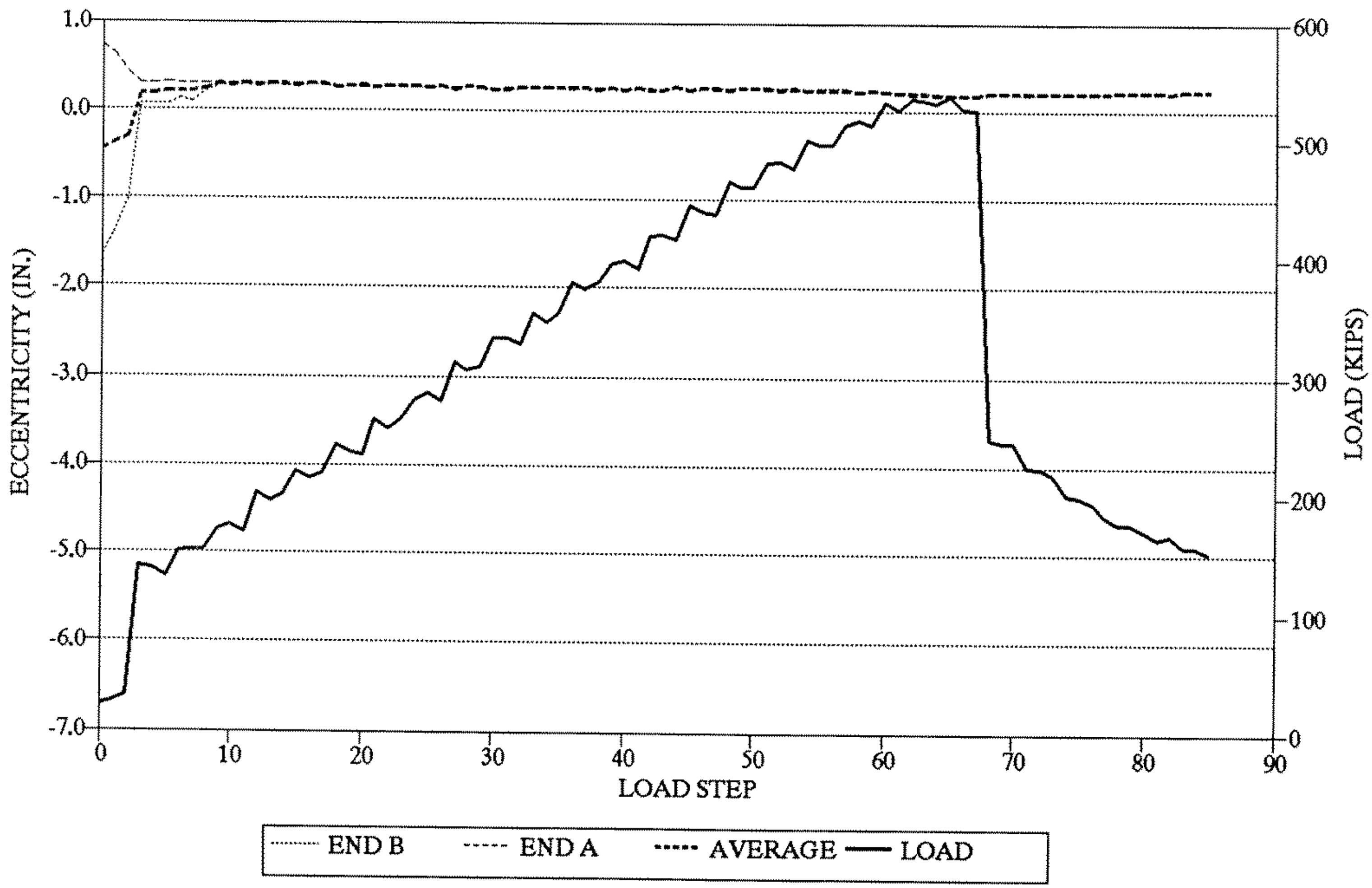


Figure A-29. LOAD AND ECCENTRICITY VS. LOAD STEP

SPECIMEN 03: Y ECCENTRICITIES FROM END MOMENTS

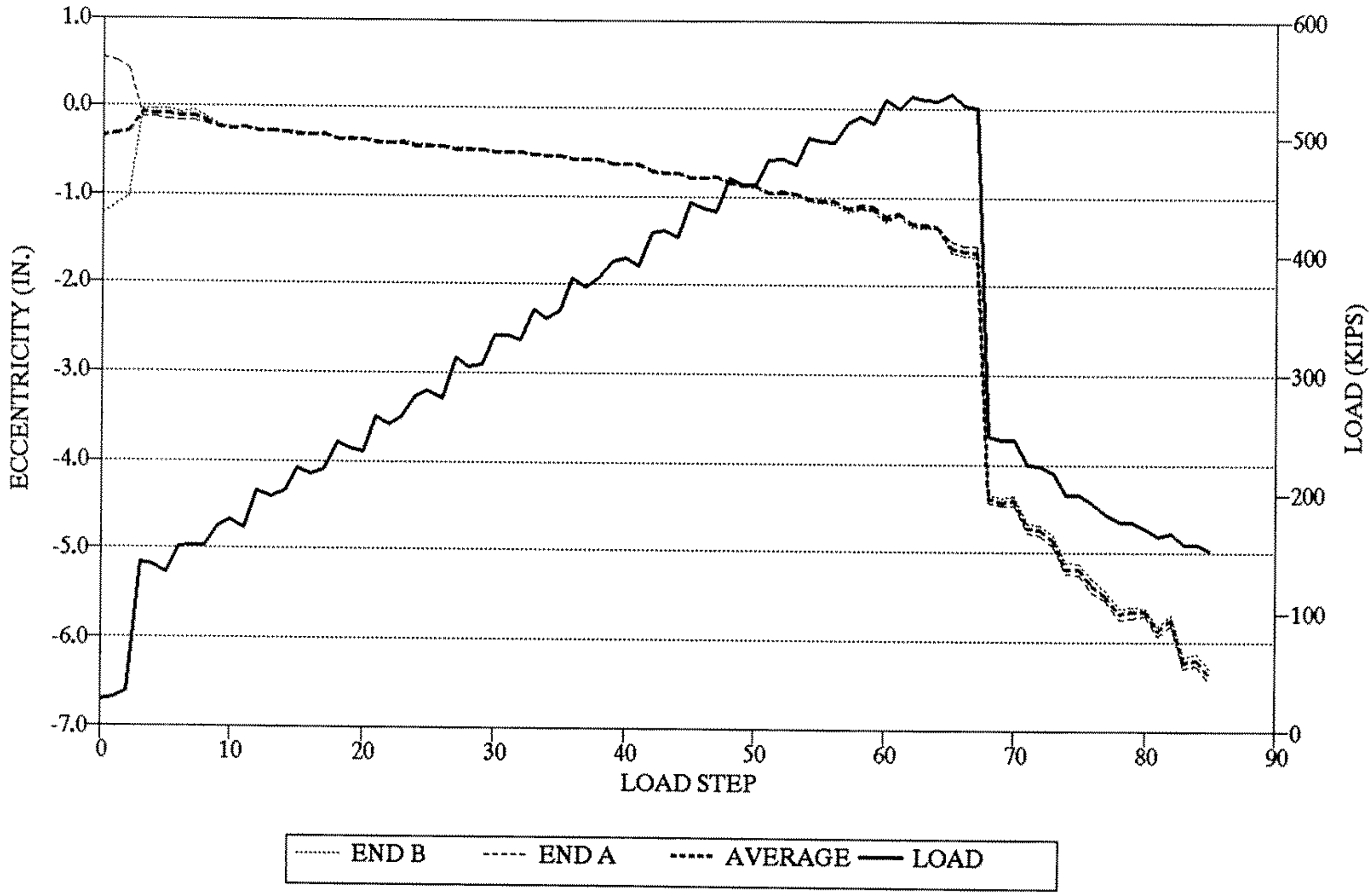


Figure A-30. END ROTATION AND LOAD VS. LOAD STEP
SPECIMEN 03

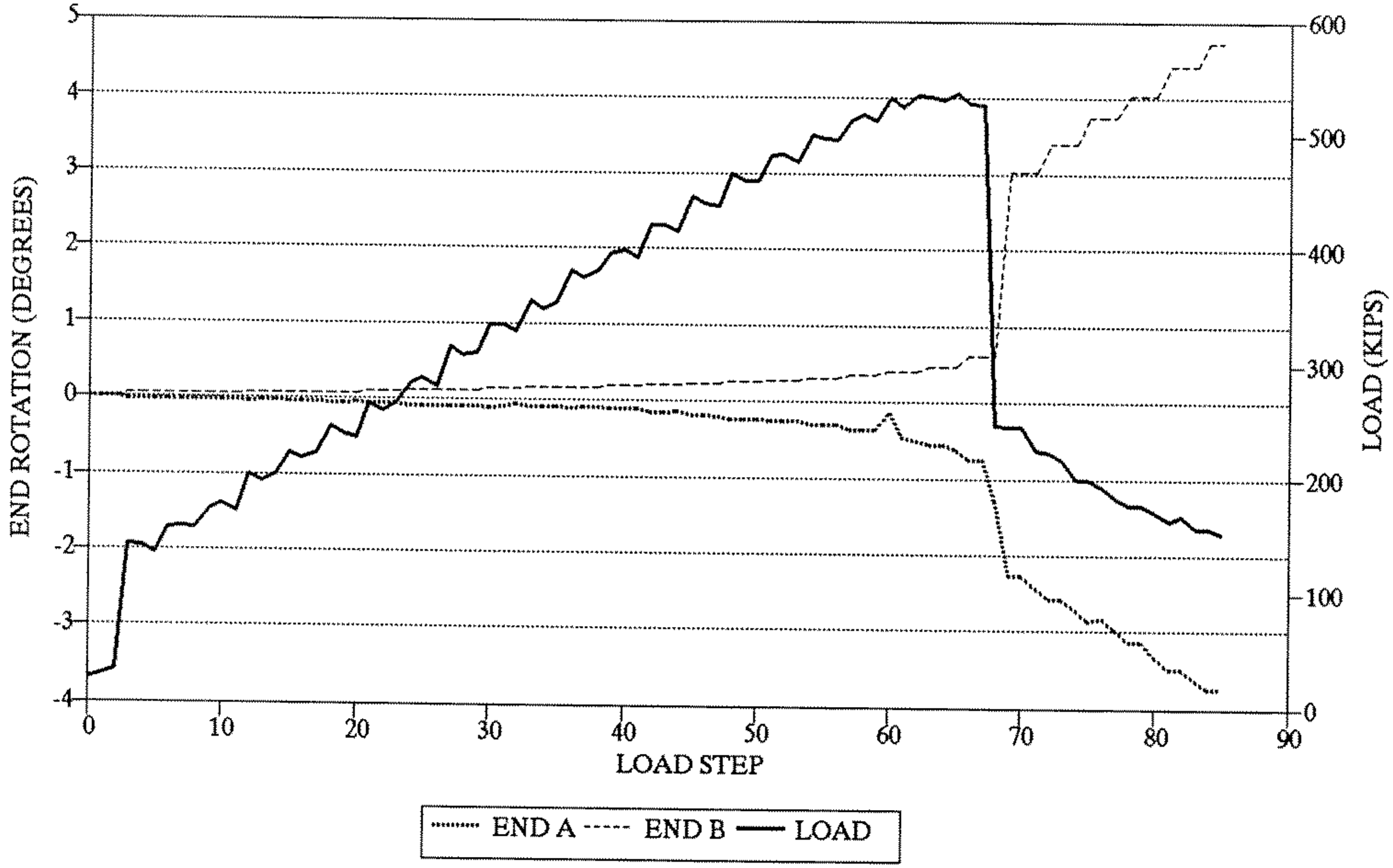


Figure A-31. EFFECTIVE LENGTH VS. LOAD STEP
SPECIMEN 04

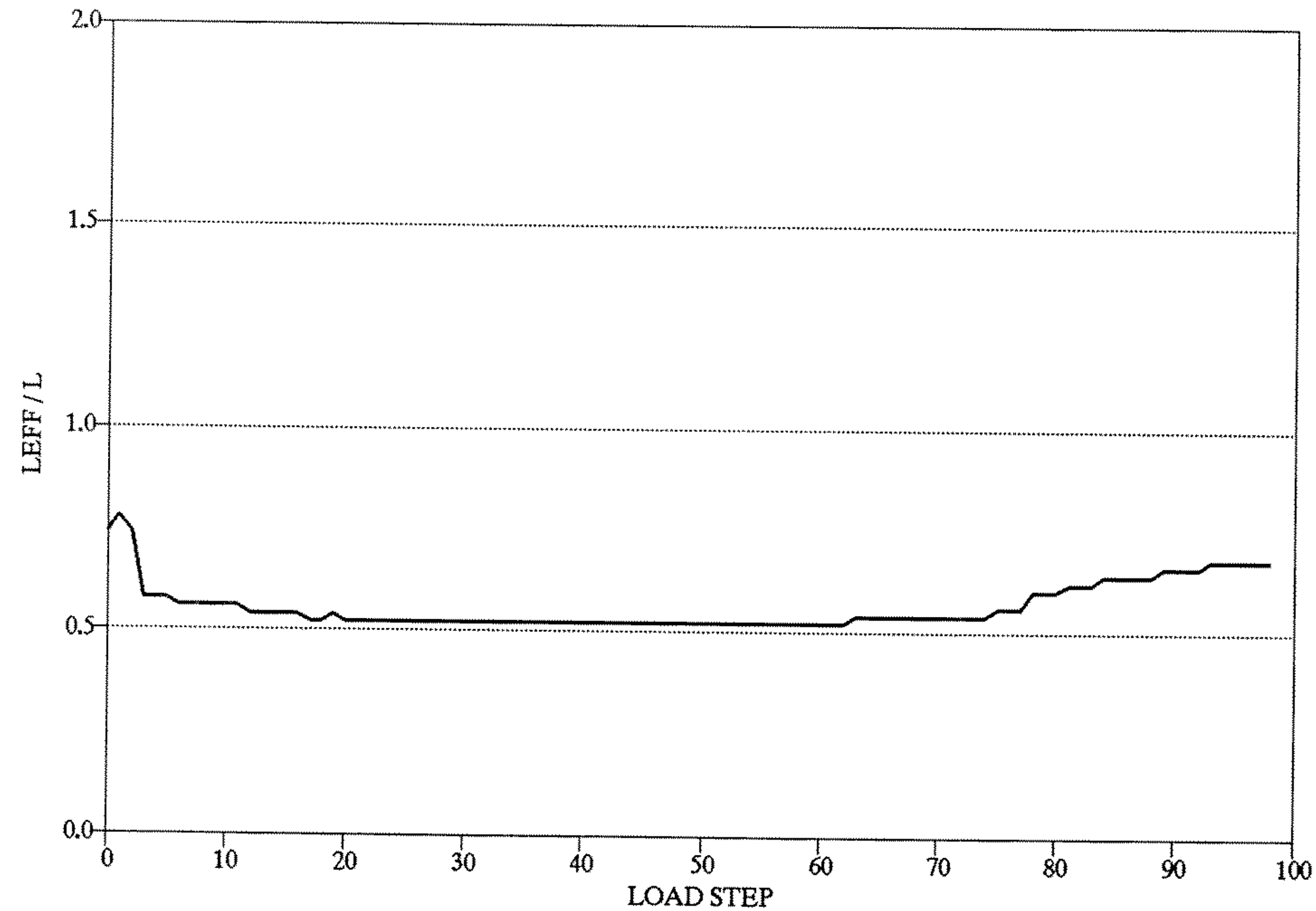


Figure A-32. LOAD AND DEFLECTION VS. LOAD STEP
SPECIMEN 04

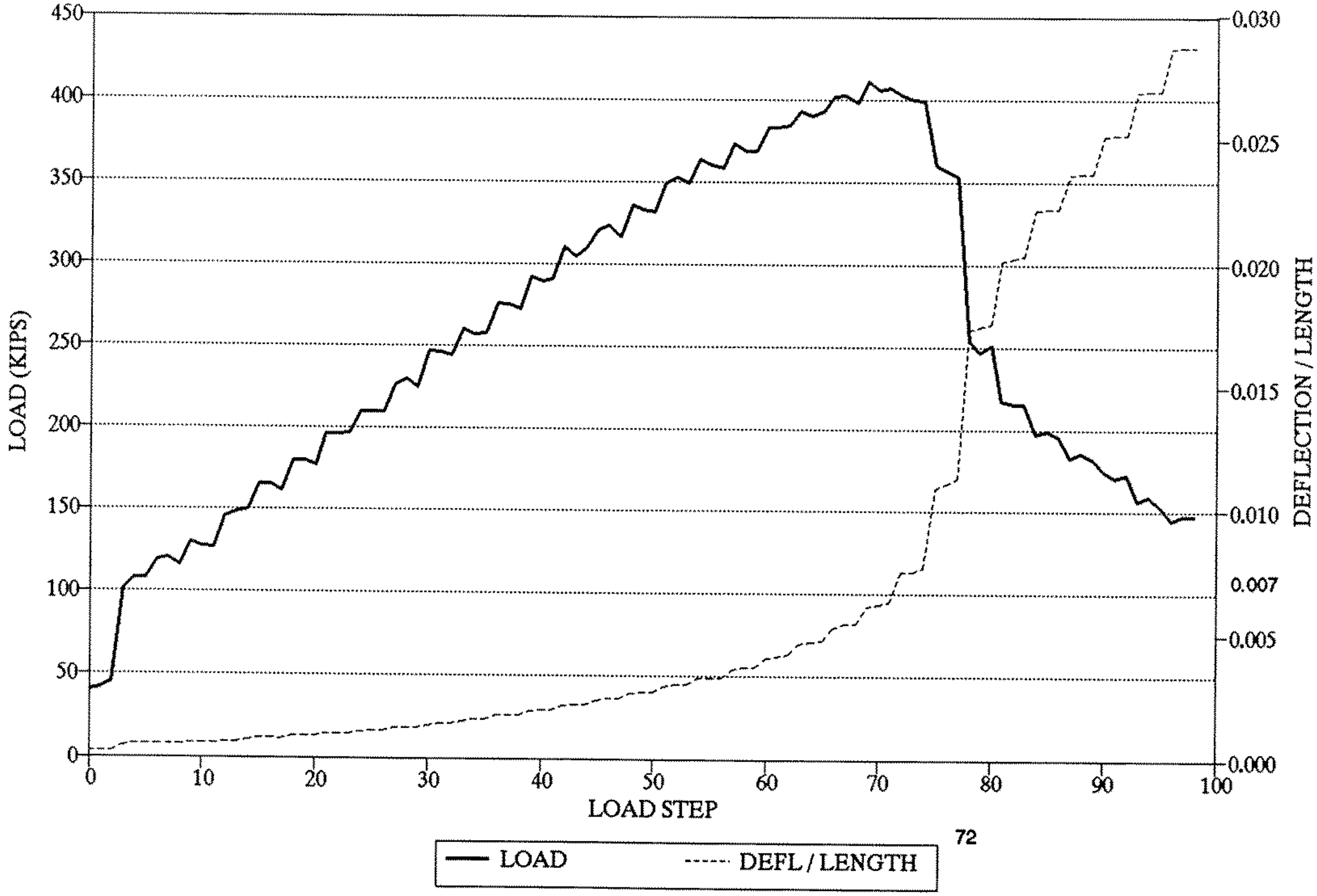


Figure A-33. LOAD VS. CHORD SHORTENING
SPECIMEN 04

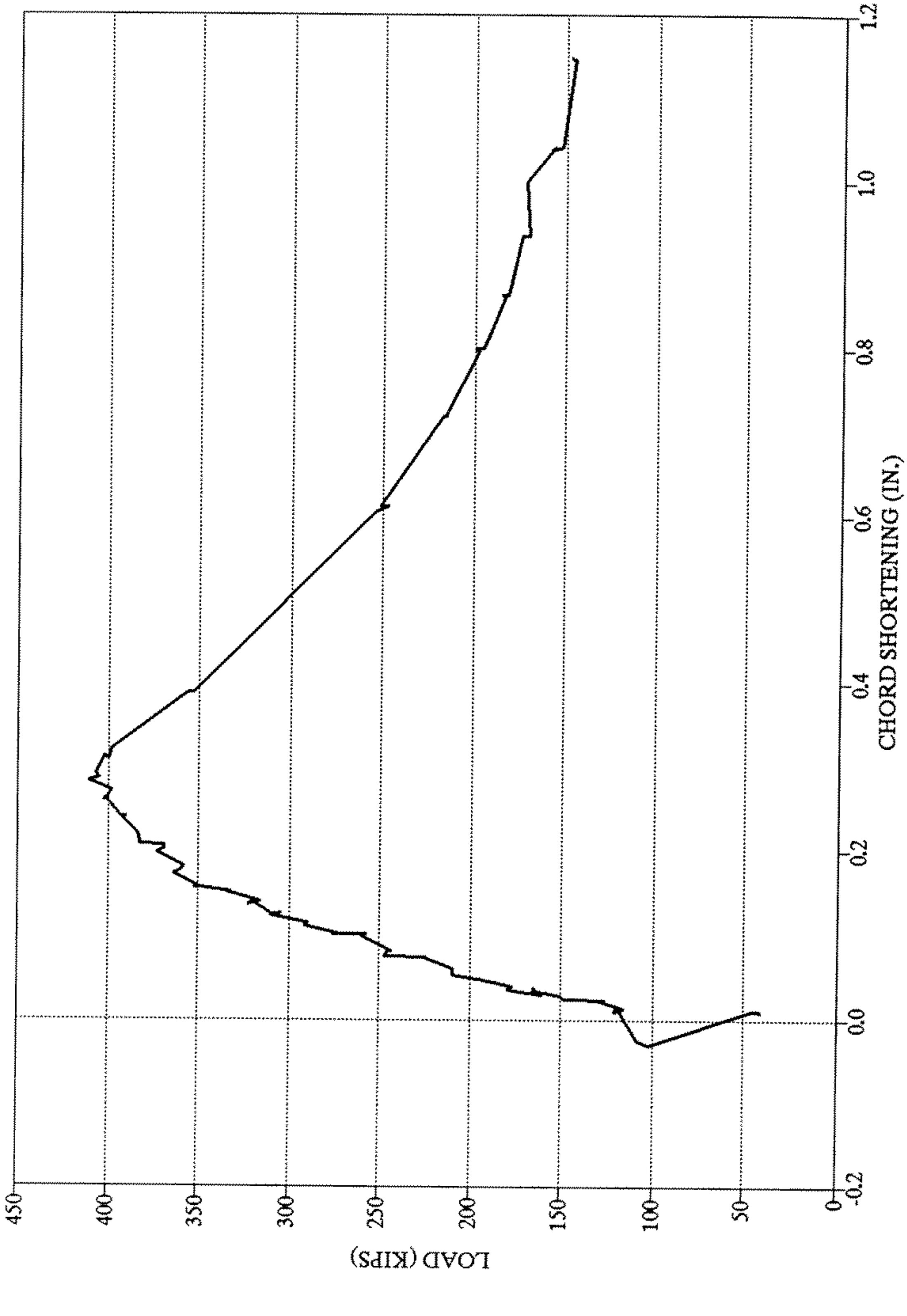


Figure A-34. HORIZONTAL DISPLACEMENTS
SPECIMEN 04

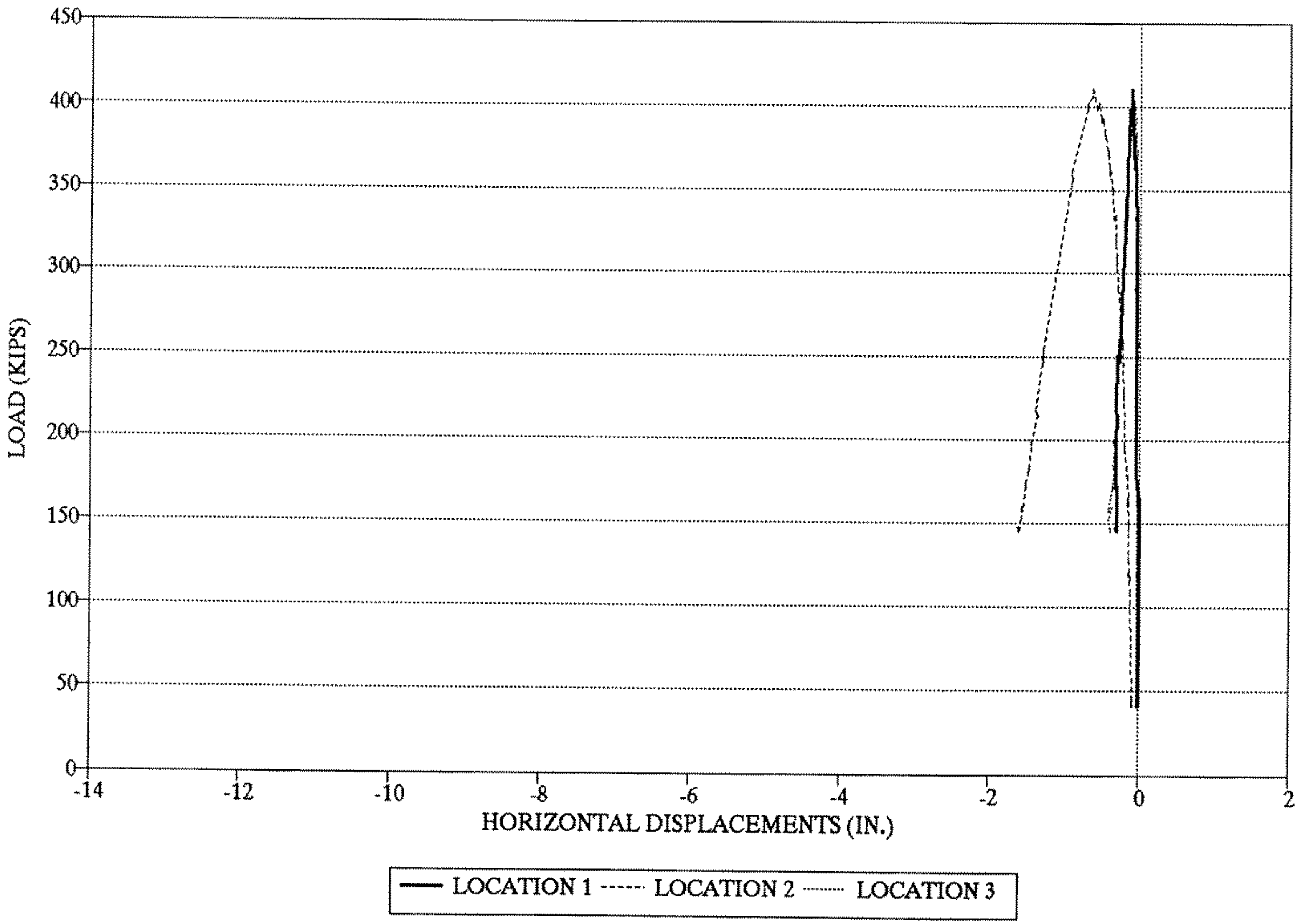


Figure A-35. VERTICAL DISPLACEMENTS
SPECIMEN 04

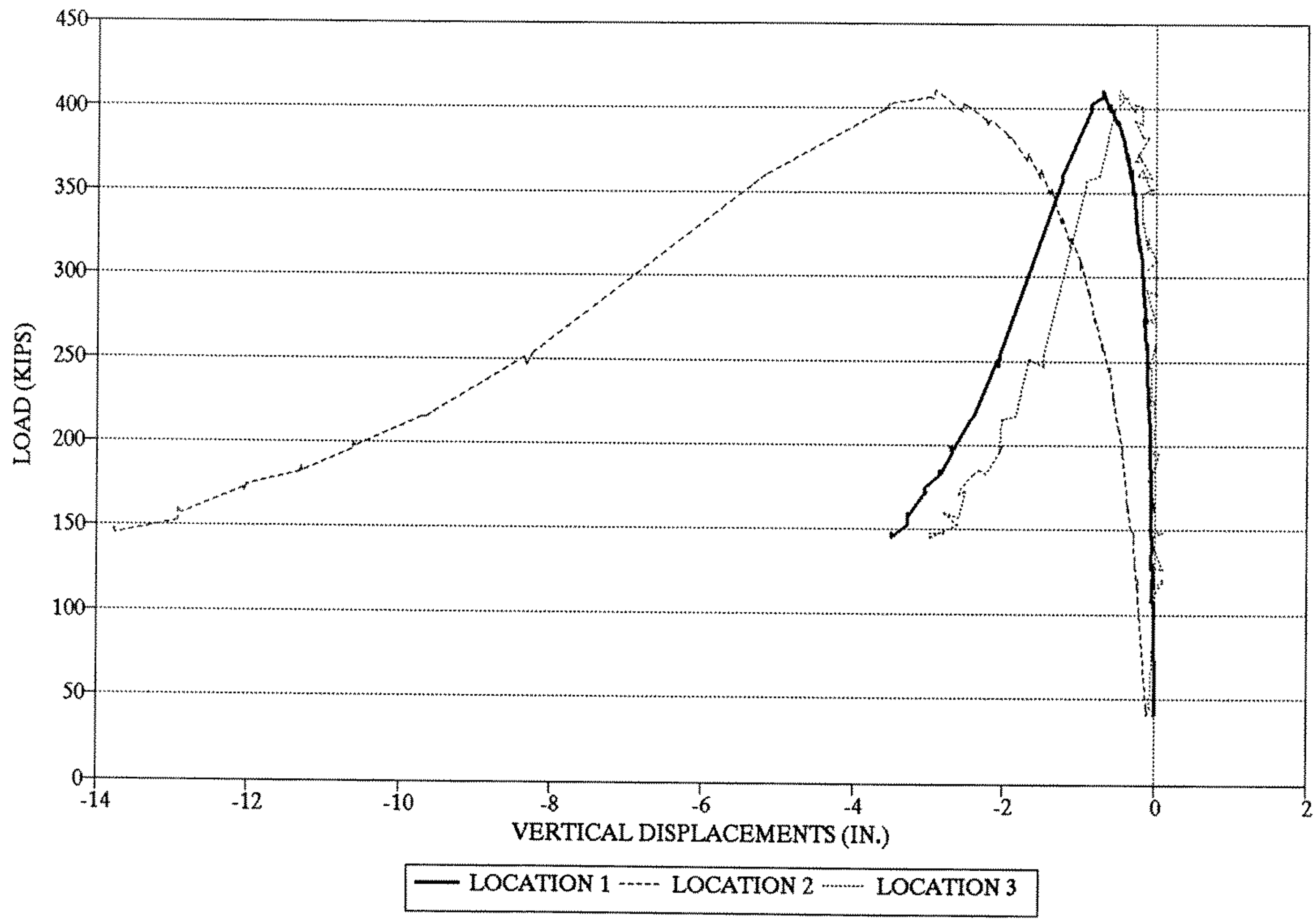


Figure A-36. LOAD AND ECCENTRICITY VS. LOAD STEP

SPECIMEN 04: X ECCENTRICITIES FROM INFLECTION POINTS

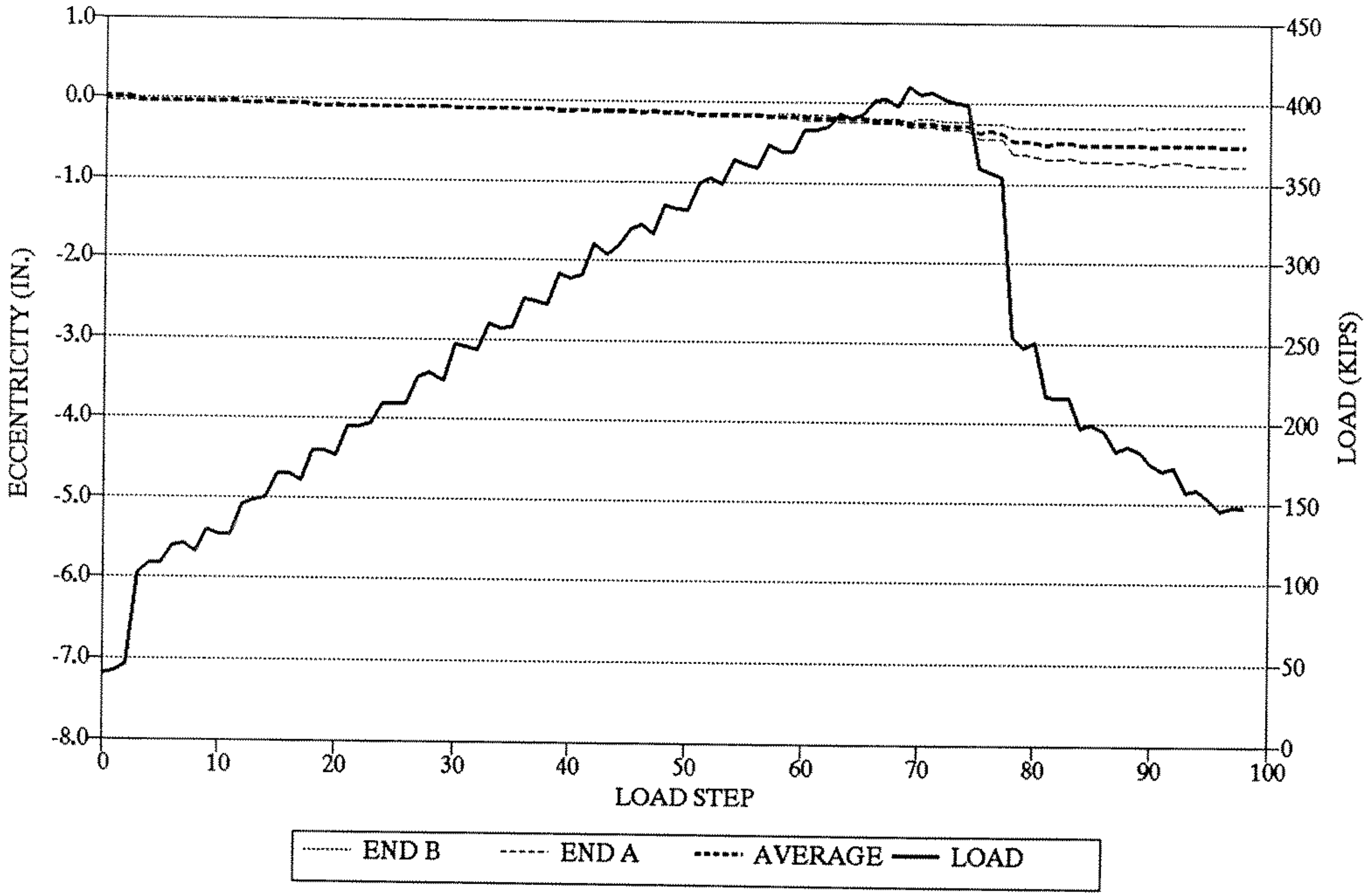


Figure A-37. LOAD AND ECCENTRICITY VS. LOAD STEP

SPECIMEN 04: Y ECCENTRICITIES FROM INFLECTION POINTS

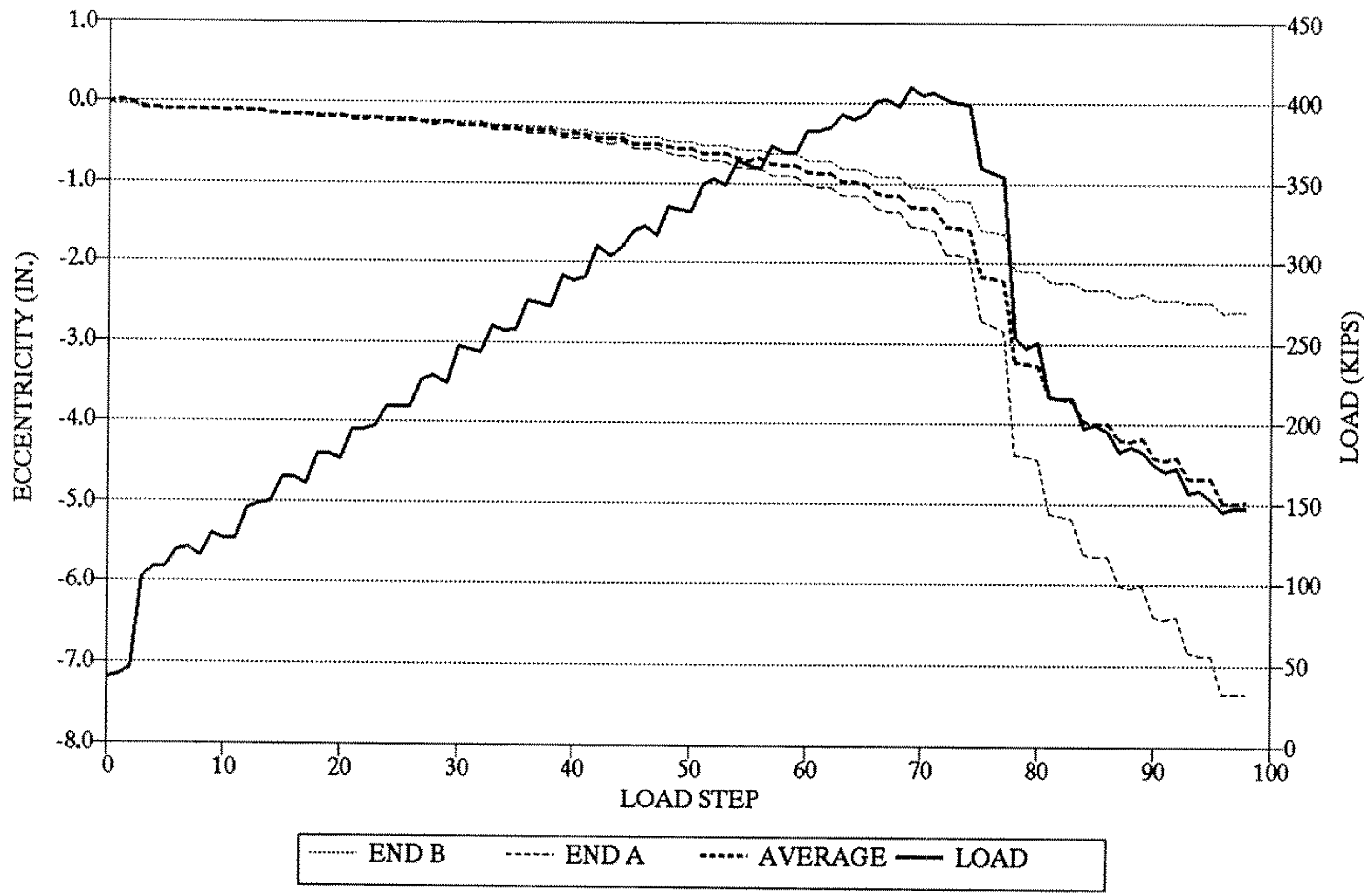


Figure A-38. LOAD AND ECCENTRICITY VS. LOAD STEP

SPECIMEN 04: X ECCENTRICITIES FROM END MOMENTS

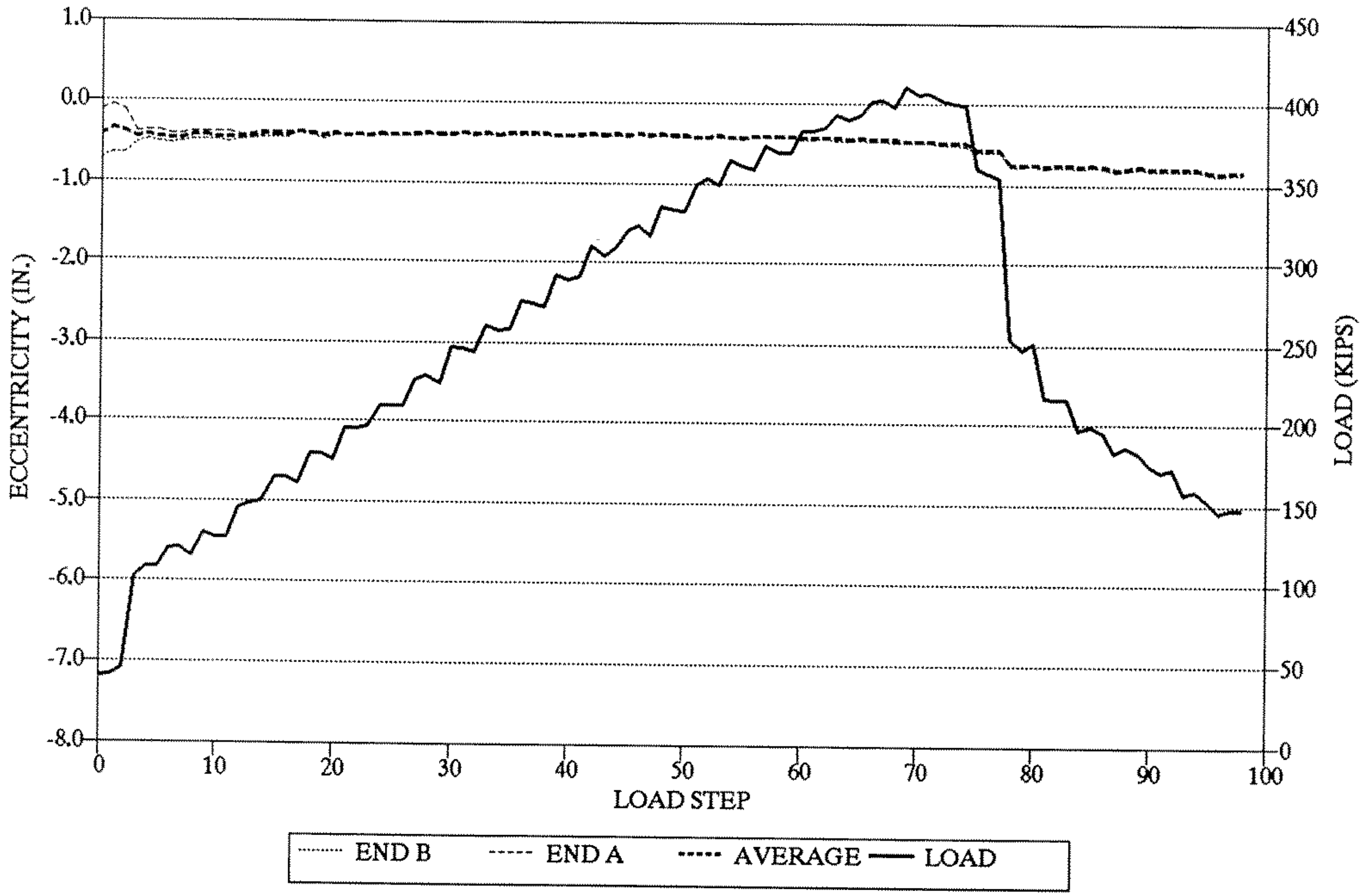


Figure A-39. LOAD AND ECCENTRICITY VS. LOAD STEP

SPECIMEN 04: Y ECCENTRICITIES FROM END MOMENTS

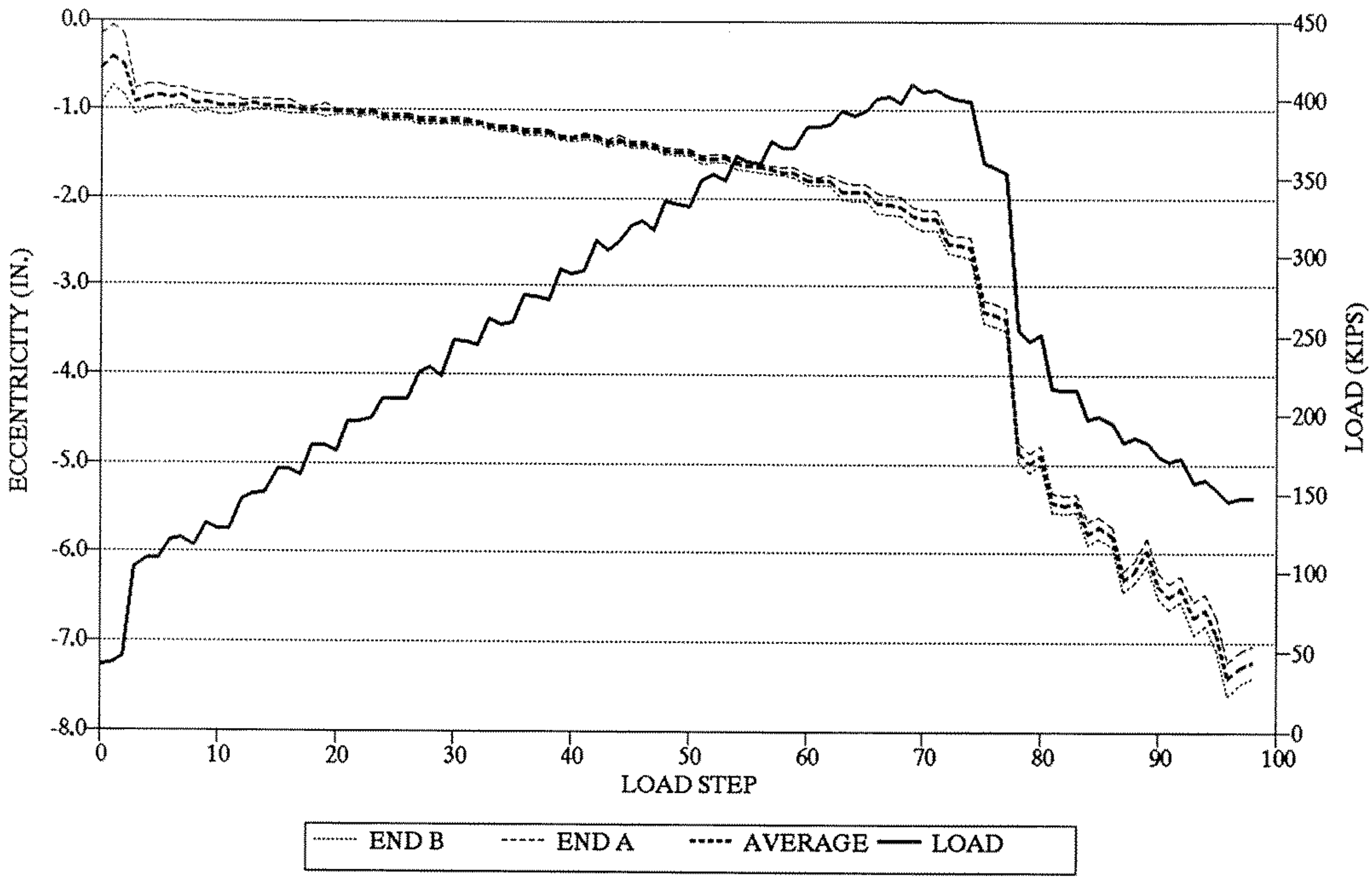


Figure A-40. END ROTATION AND LOAD VS. LOAD STEP
SPECIMEN 04

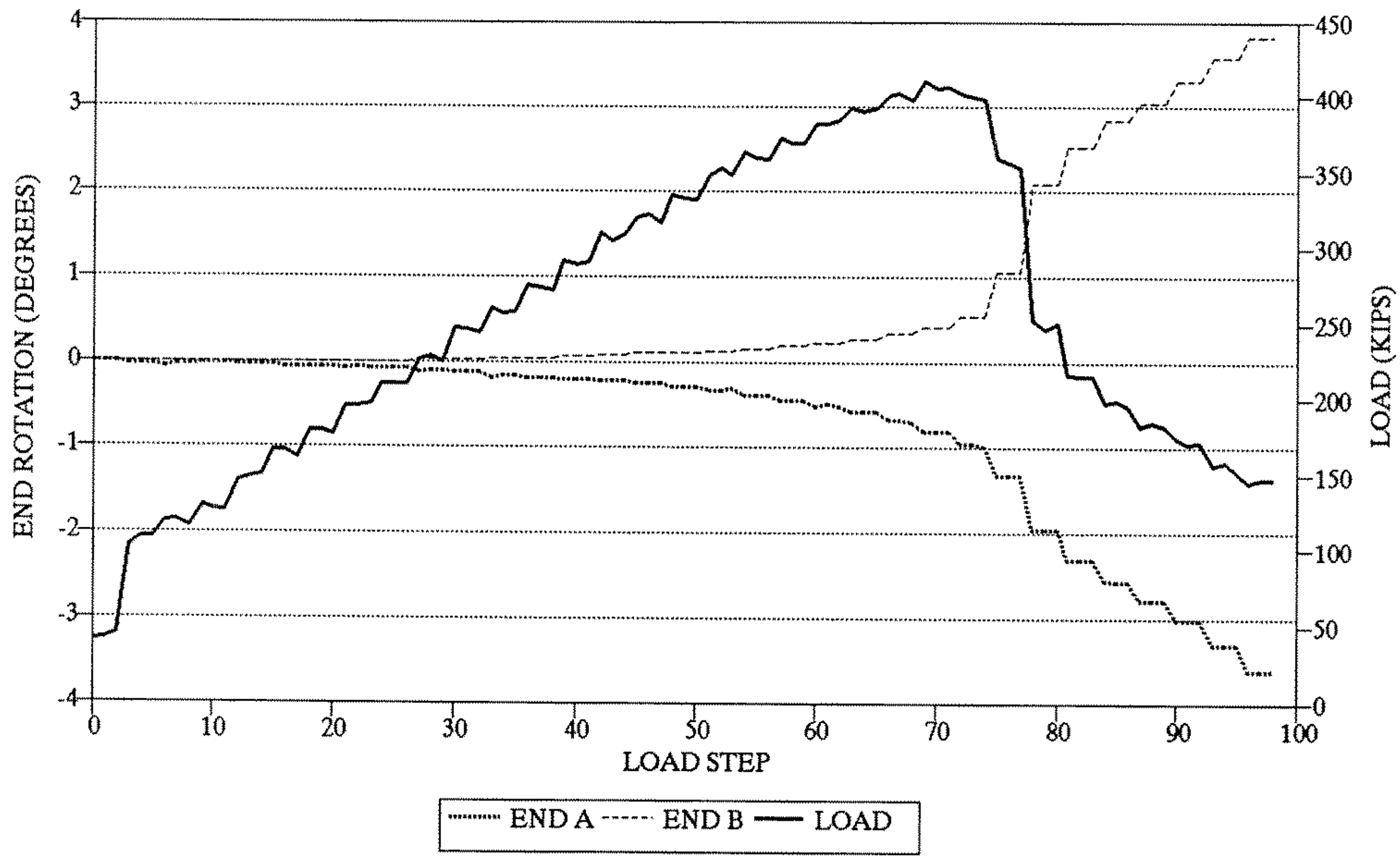


Figure A-41. EFFECTIVE LENGTH VS. LOAD STEP
SPECIMEN 05

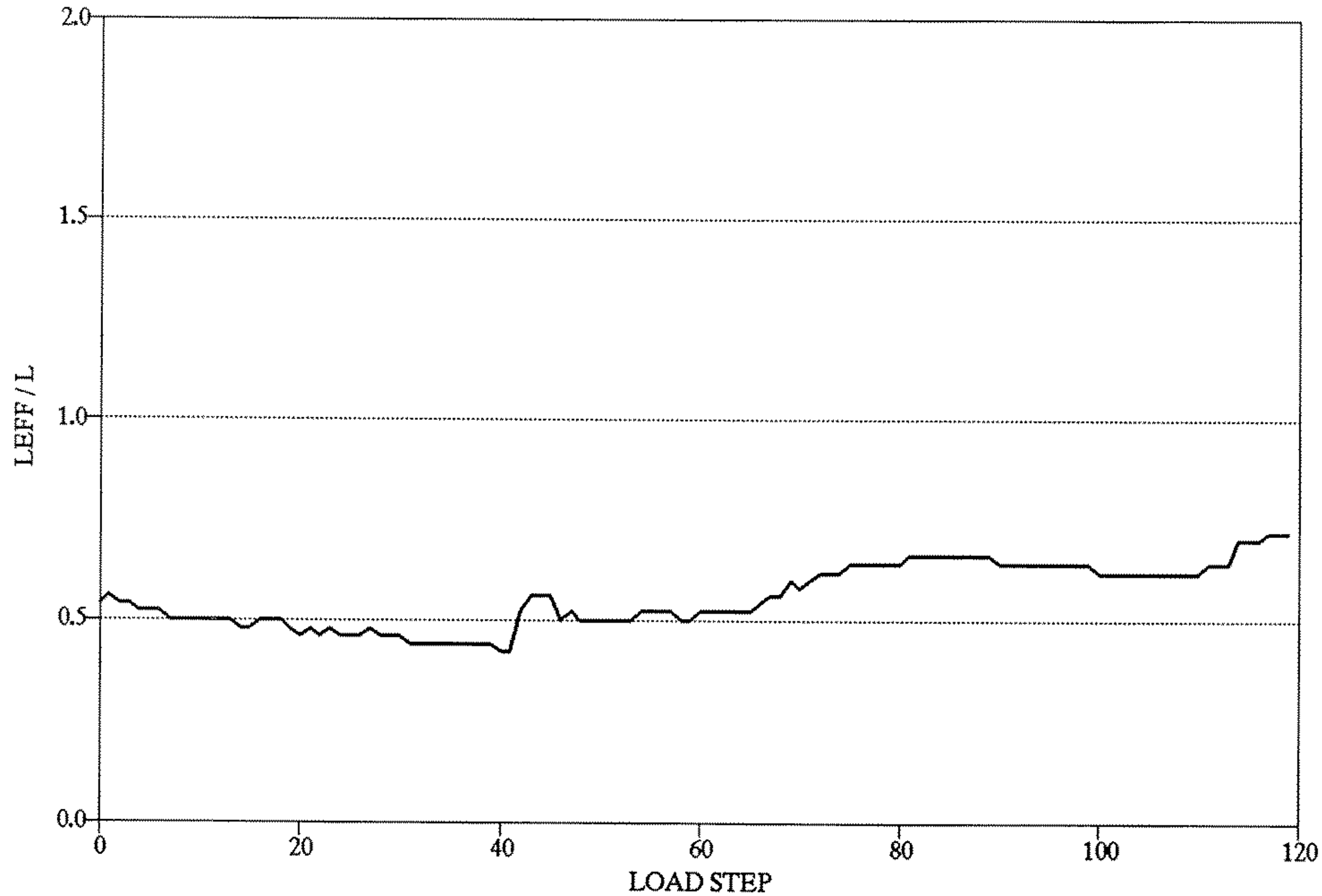


Figure A-42. LOAD AND DEFLECTION VS. LOAD STEP
SPECIMEN 05

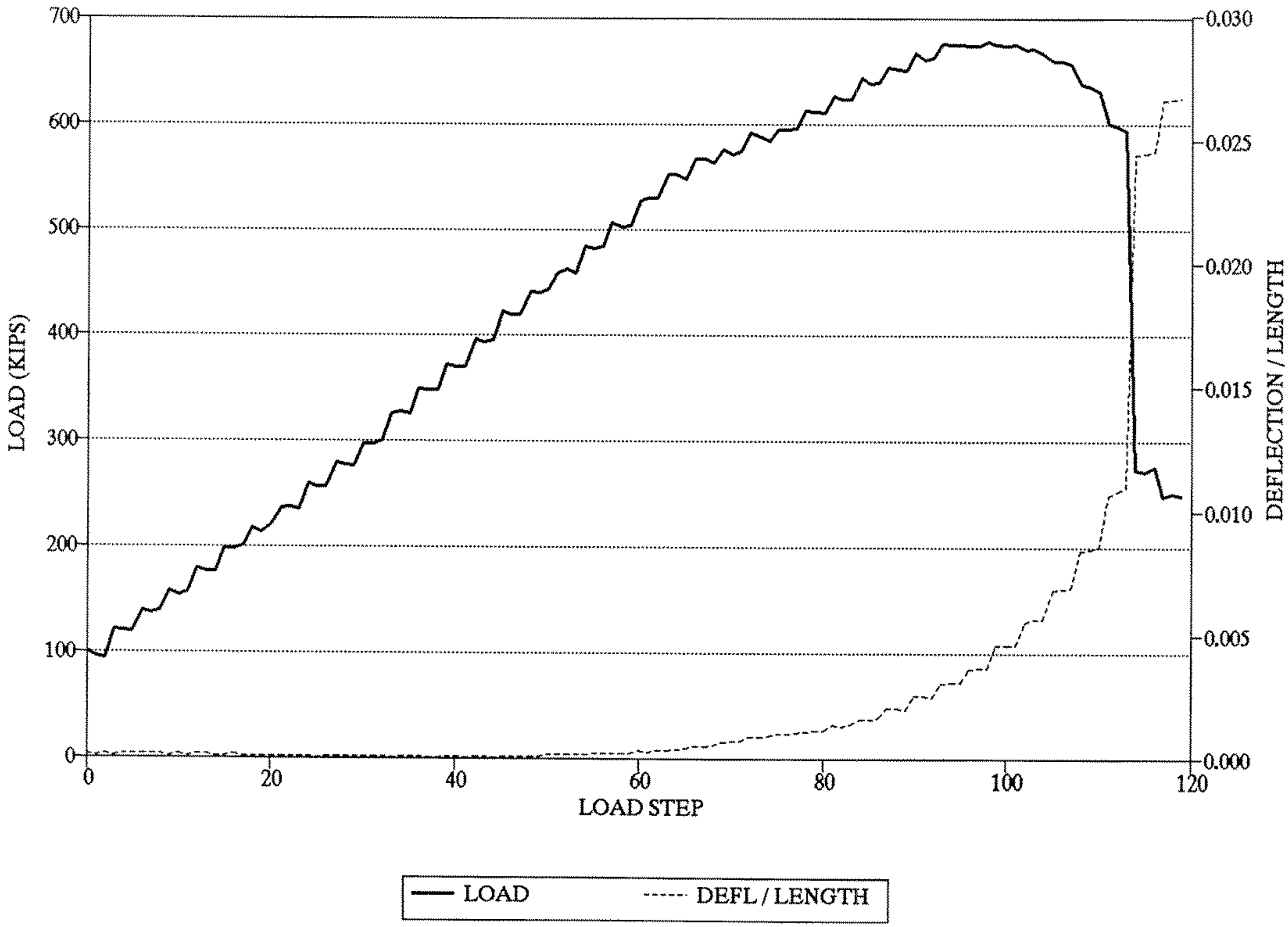


Figure A-43. LOAD VS. CHORD SHORTENING
SPECIMEN 05

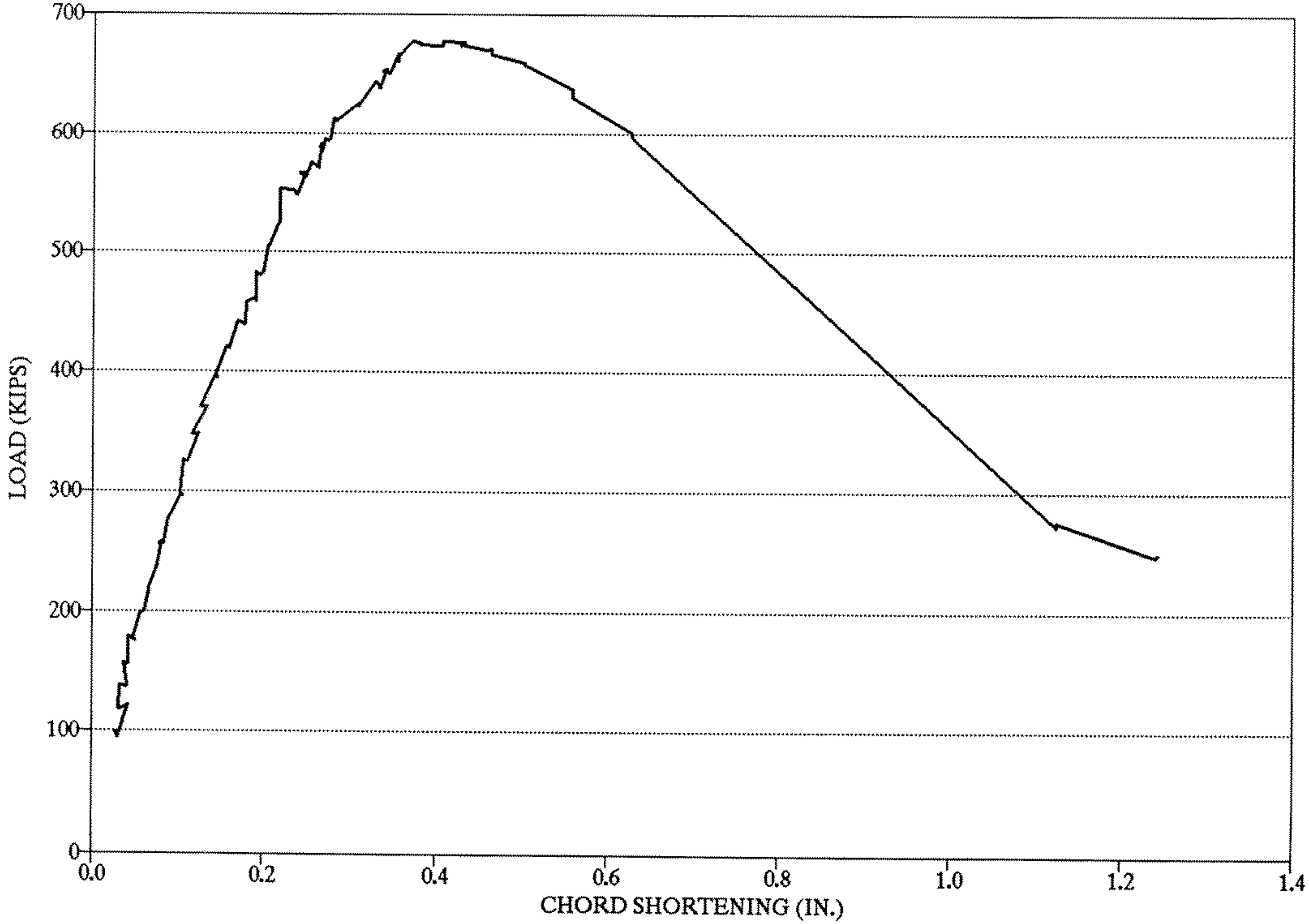


Figure A-44. HORIZONTAL DISPLACEMENTS
SPECIMEN 05

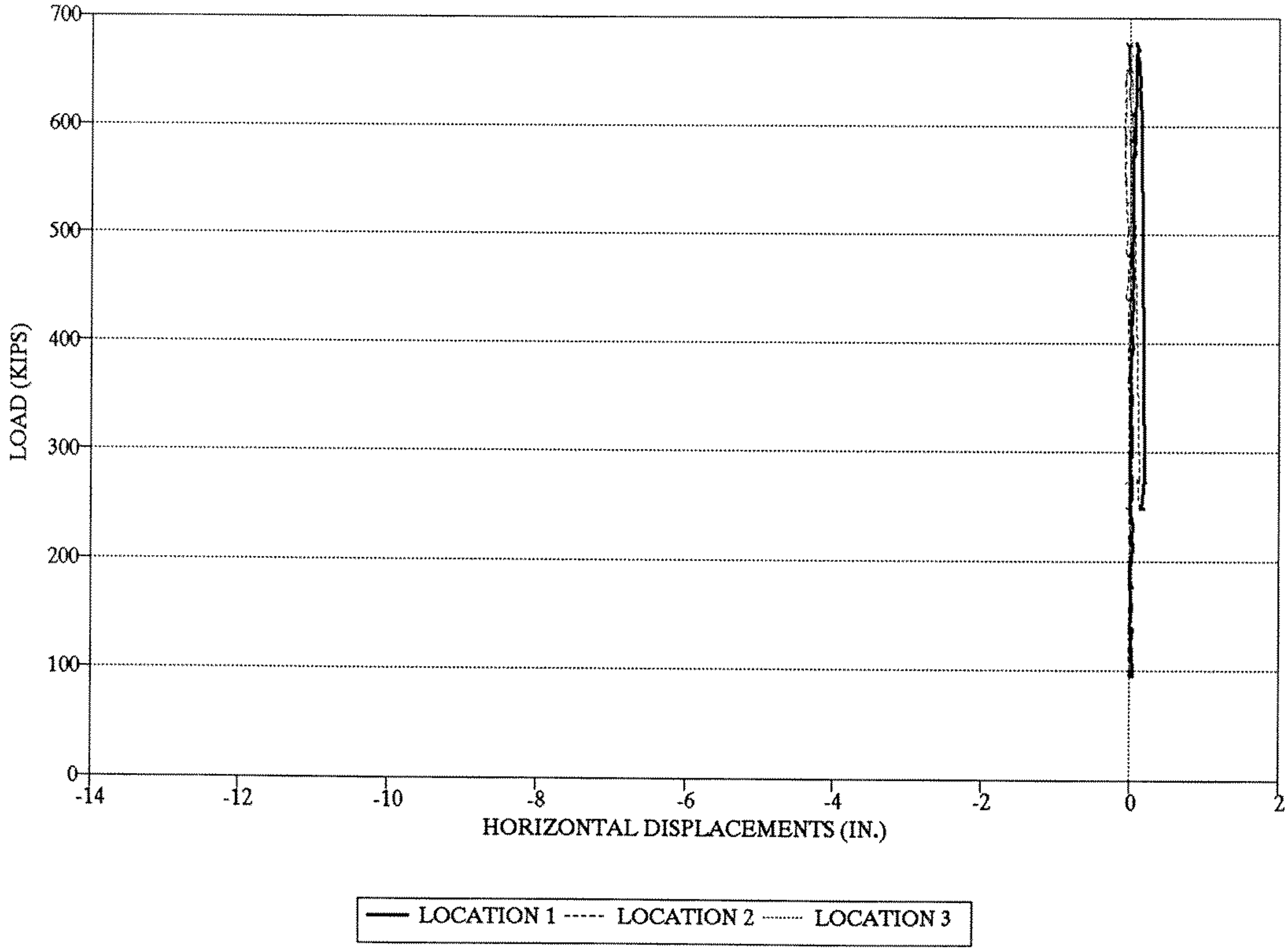


Figure A-45. VERTICAL DISPLACEMENTS
SPECIMEN 05

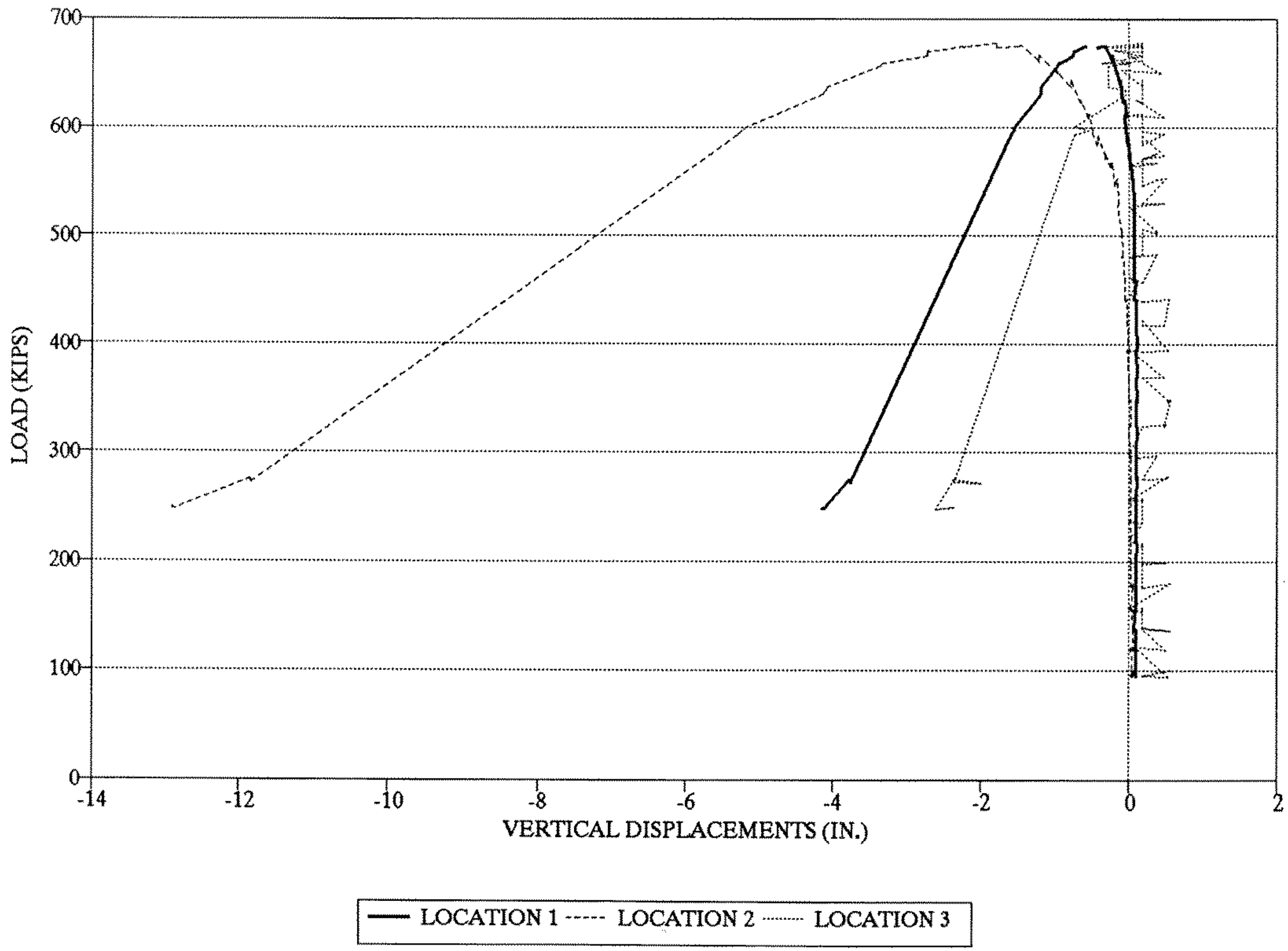


Figure A-46. LOAD AND ECCENTRICITY VS. LOAD STEP

SPECIMEN 05: X ECCENTRICITIES FROM INFLECTION POINTS

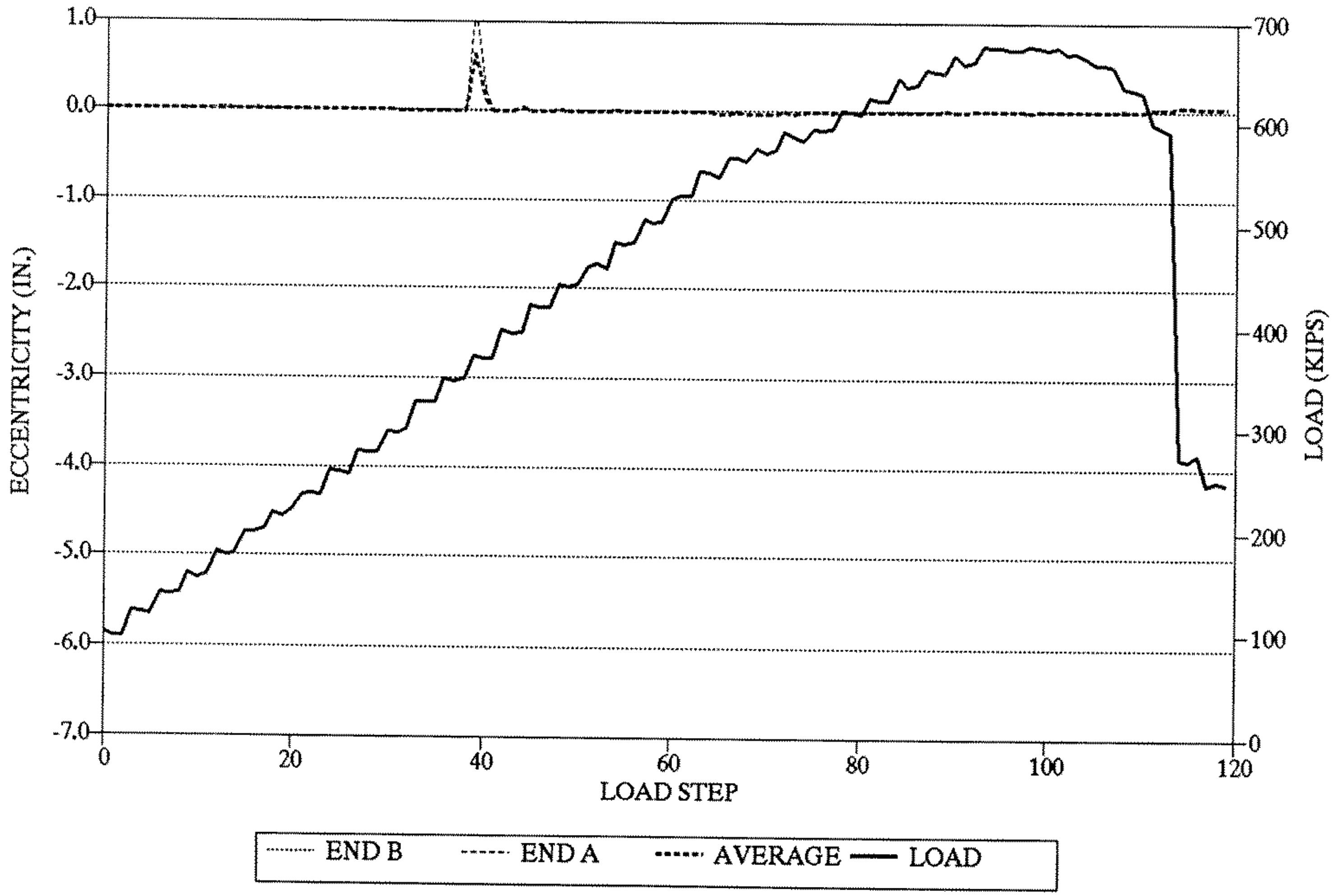


Figure A-47. LOAD AND ECCENTRICITY VS. LOAD STEP

SPECIMEN 05: Y ECCENTRICITIES FROM INFLECTION POINTS

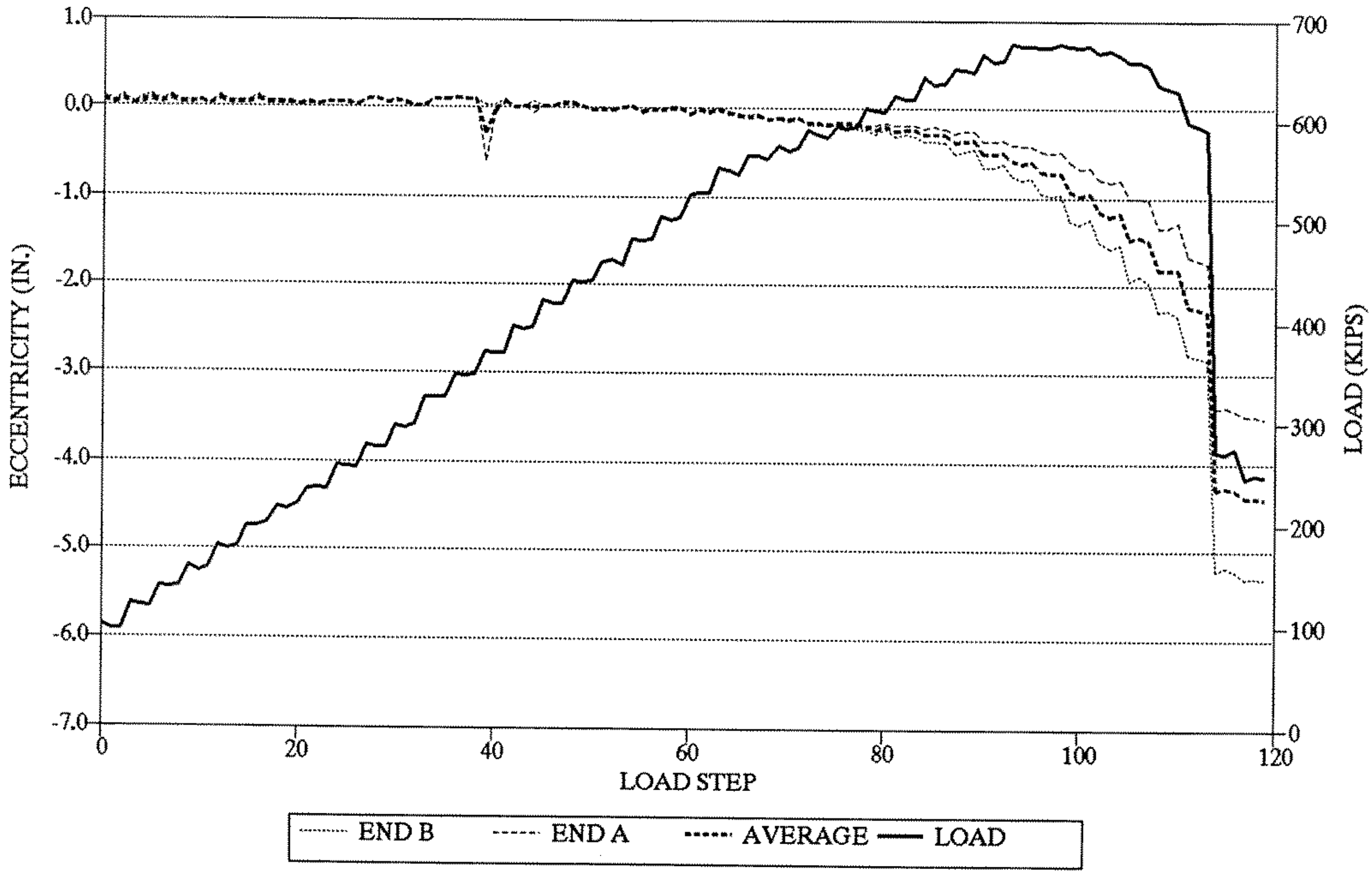


Figure A-48. LOAD AND ECCENTRICITY VS. LOAD STEP

SPECIMEN 05: X ECCENTRICITIES FROM END MOMENTS

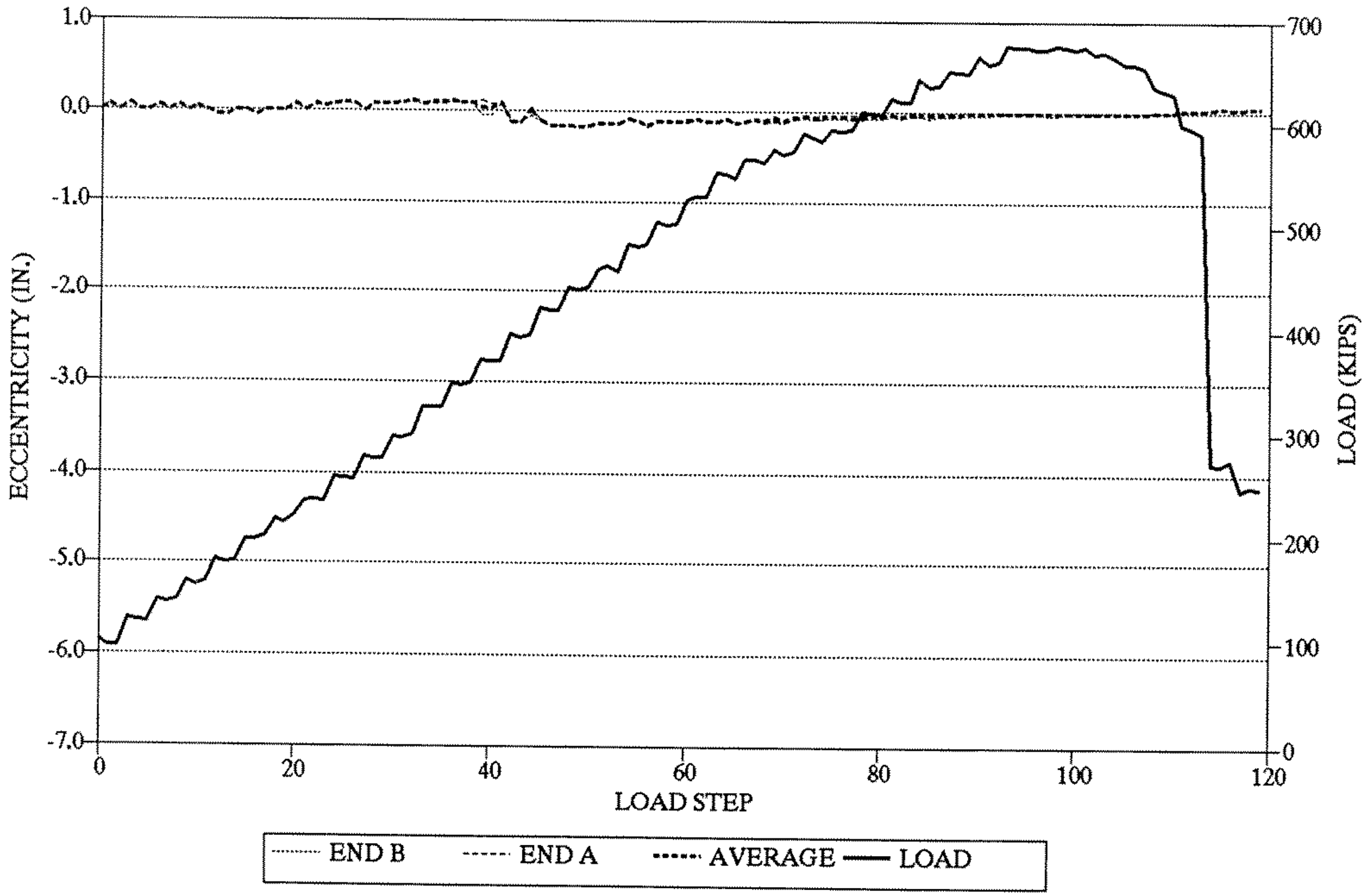


Figure A-49. LOAD AND ECCENTRICITY VS. LOAD STEP

SPECIMEN 05: Y ECCENTRICITIES FROM END MOMENTS

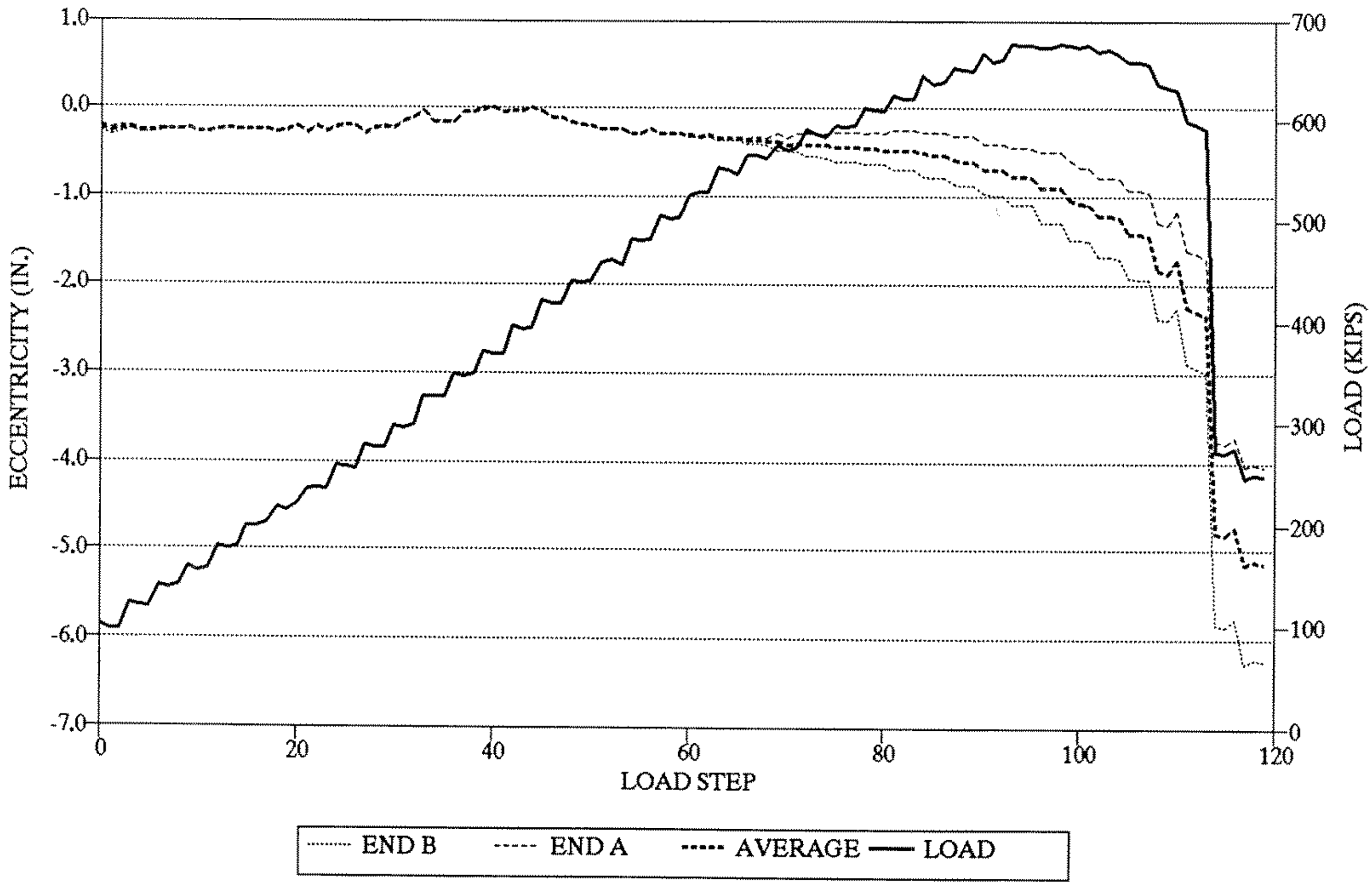


Figure A-50. END ROTATION AND LOAD VS. LOAD STEP
SPECIMEN 05

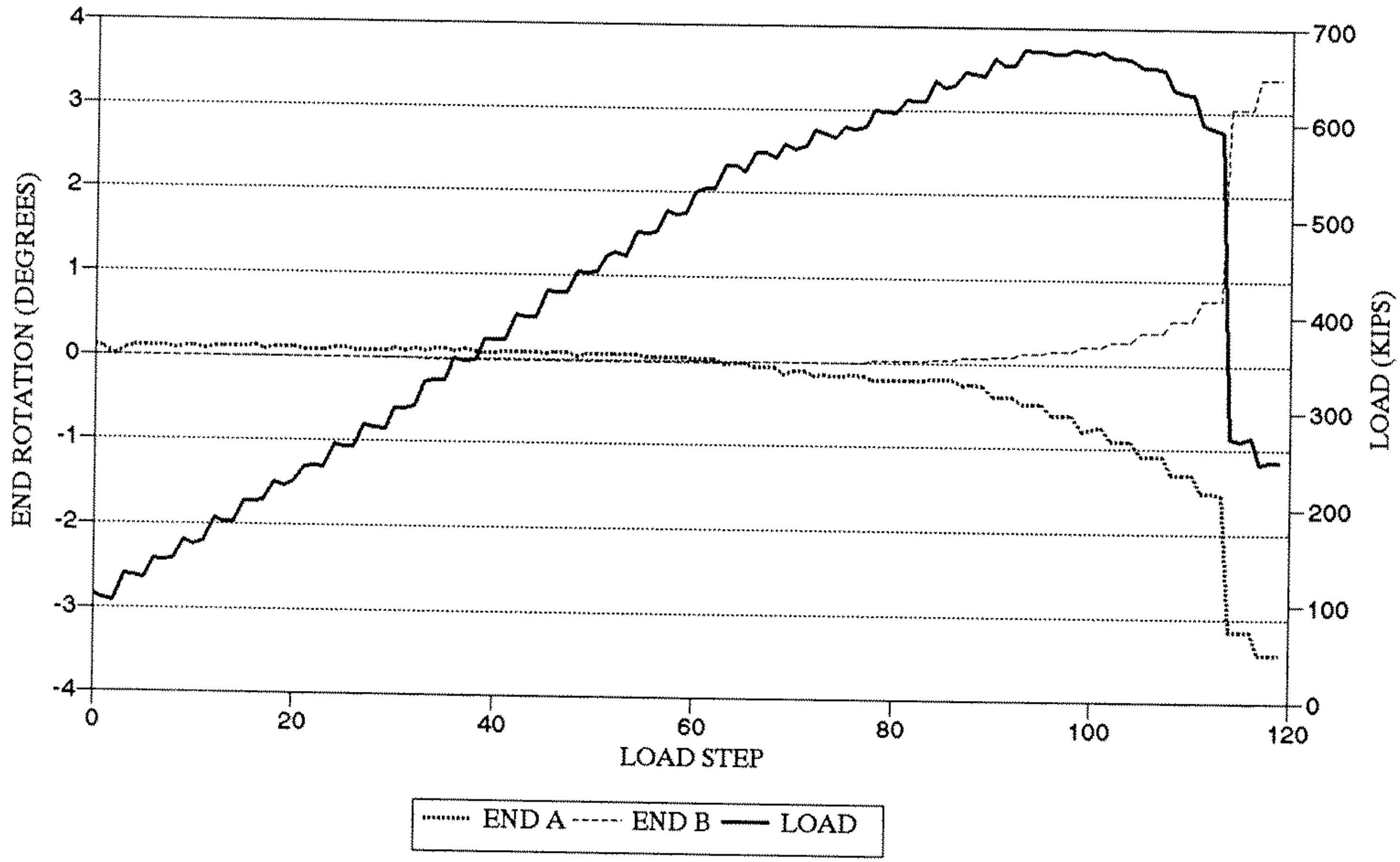


Figure A-51. EFFECTIVE LENGTH VS. LOAD STEP
SPECIMEN 06

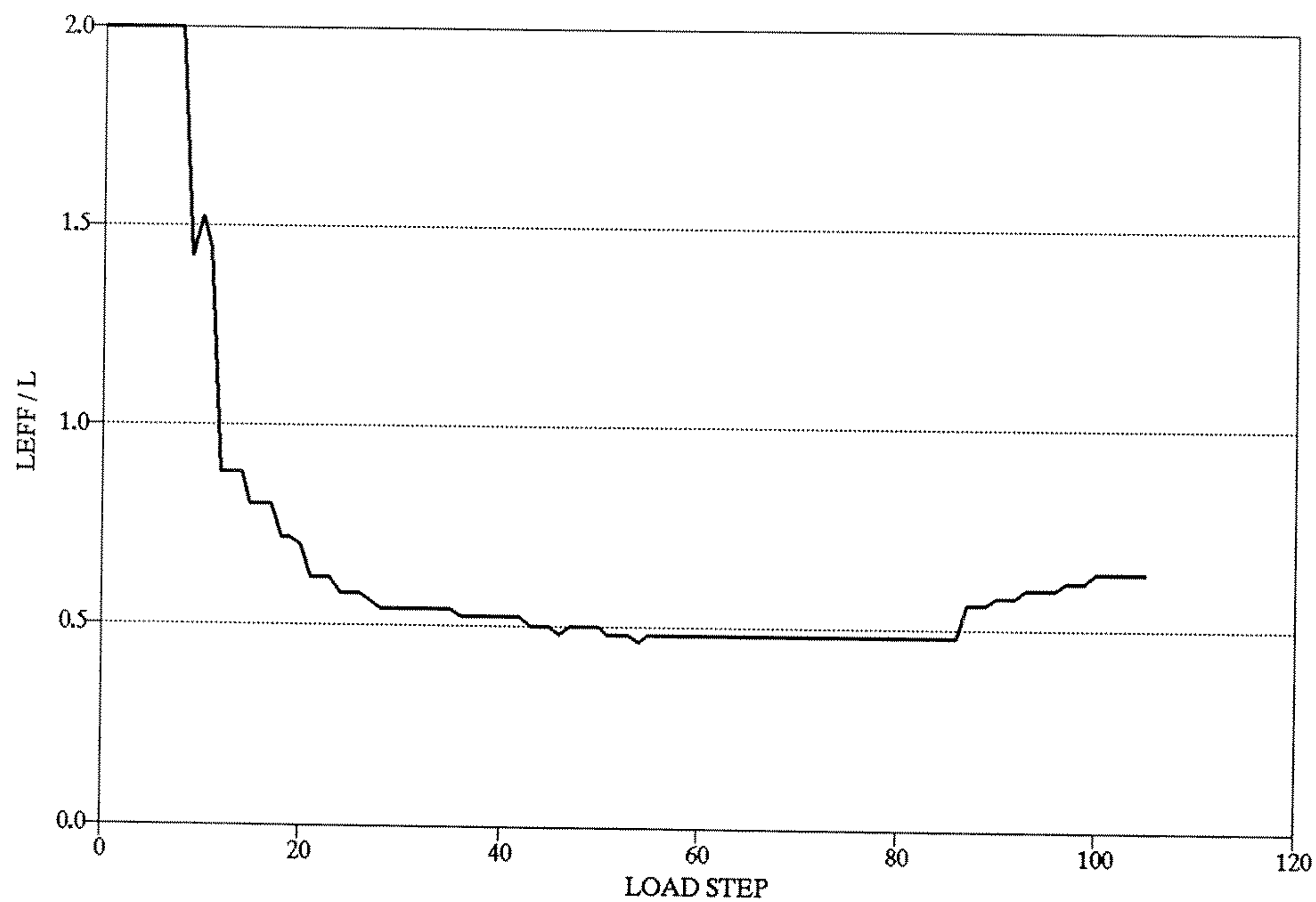


Figure A-52. LOAD AND DEFLECTION VS. LOAD STEP
SPECIMEN 06

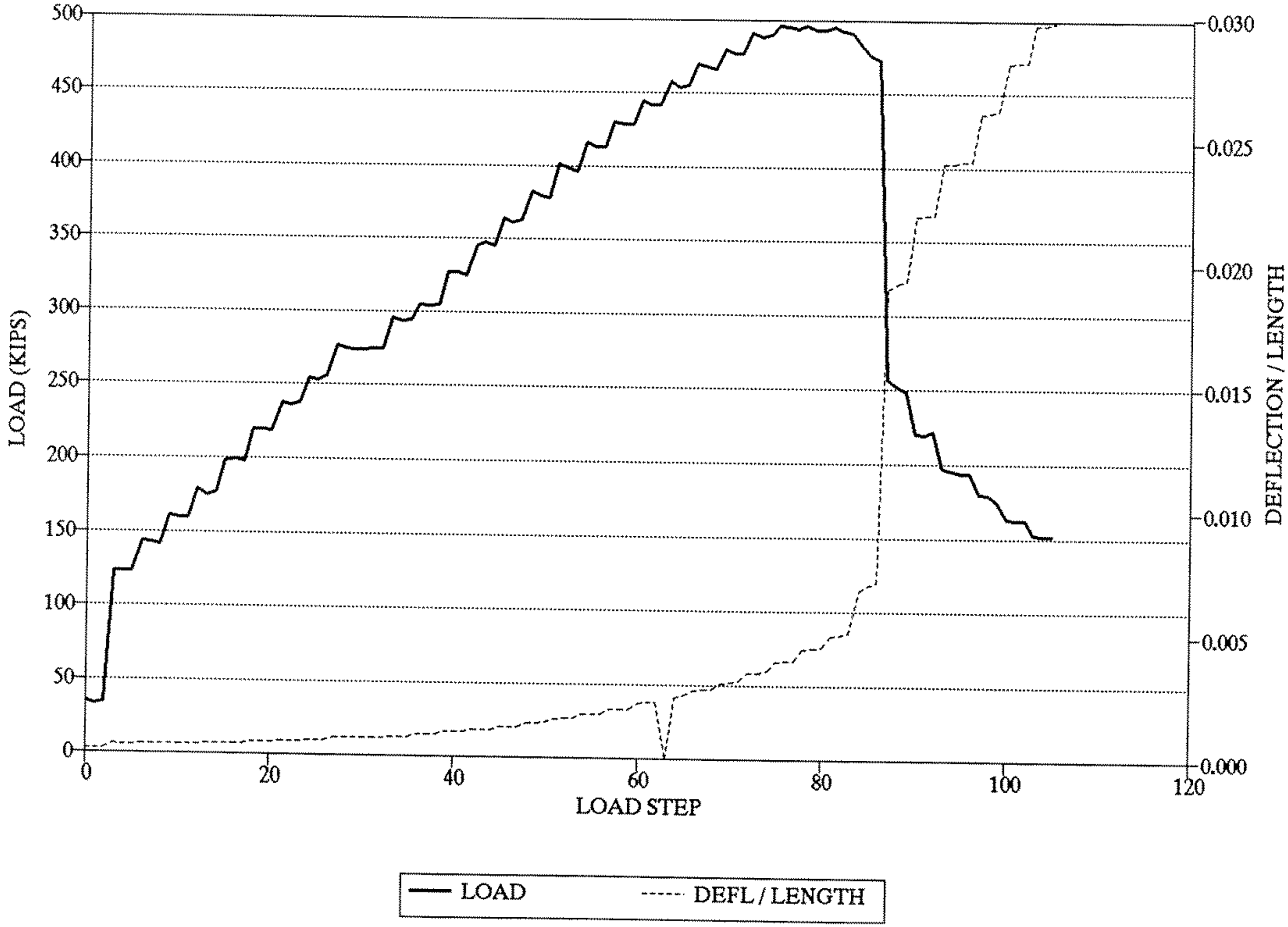


Figure A-53. LOAD VS. CHORD SHORTENING
SPECIMEN 06

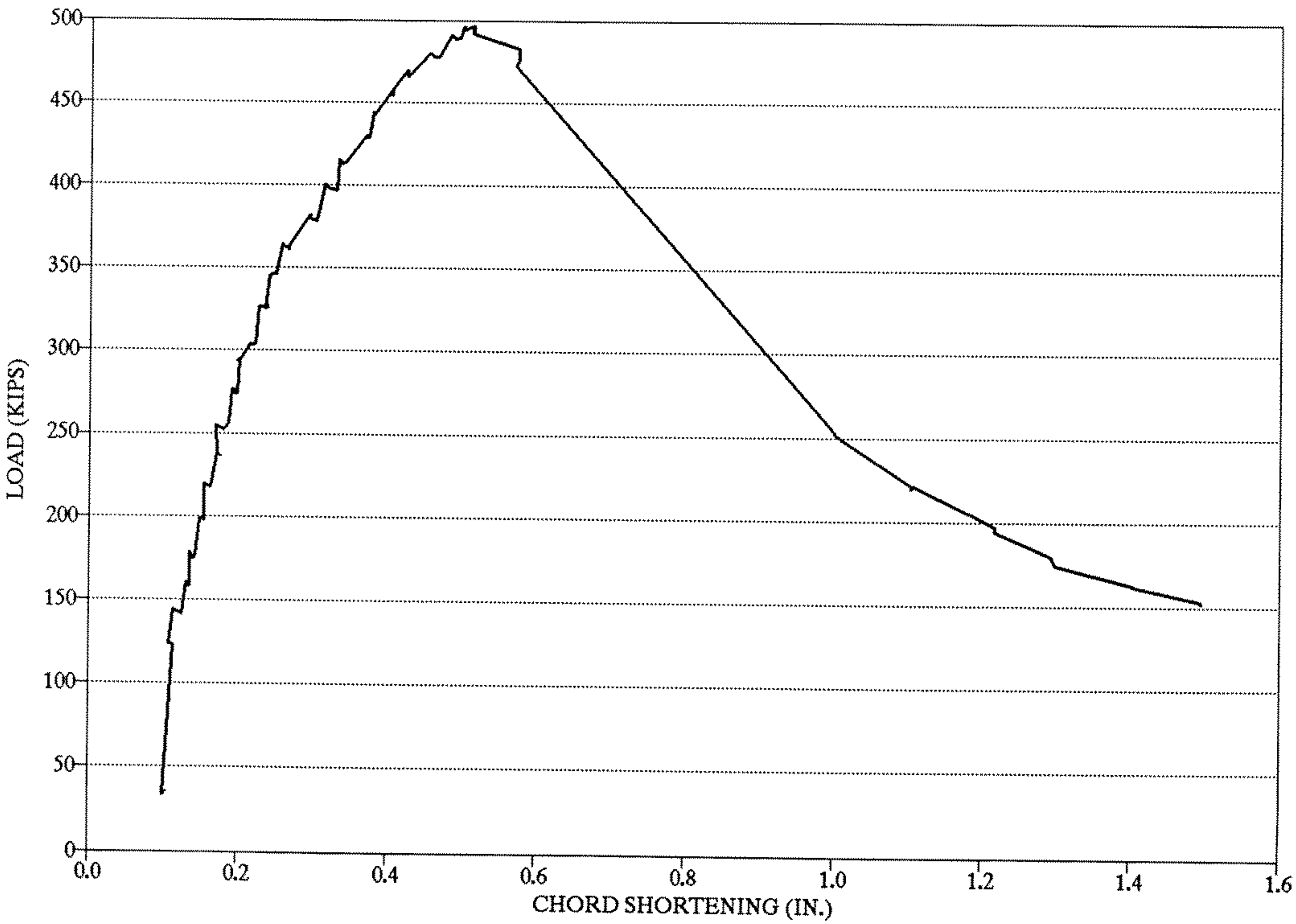


Figure A-54. HORIZONTAL DISPLACEMENTS
SPECIMEN 06

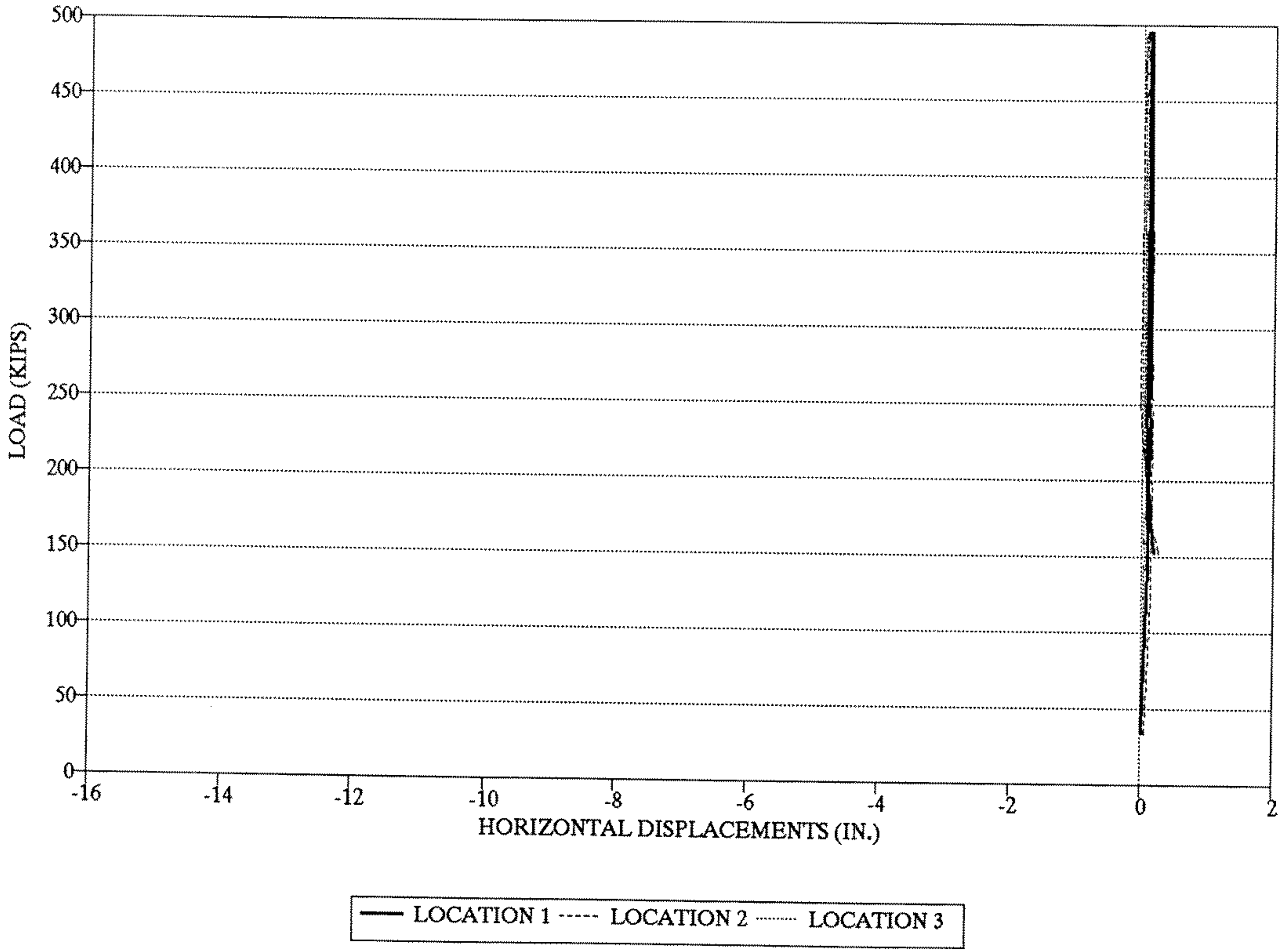


Figure A-55. VERTICAL DISPLACEMENTS
SPECIMEN 06

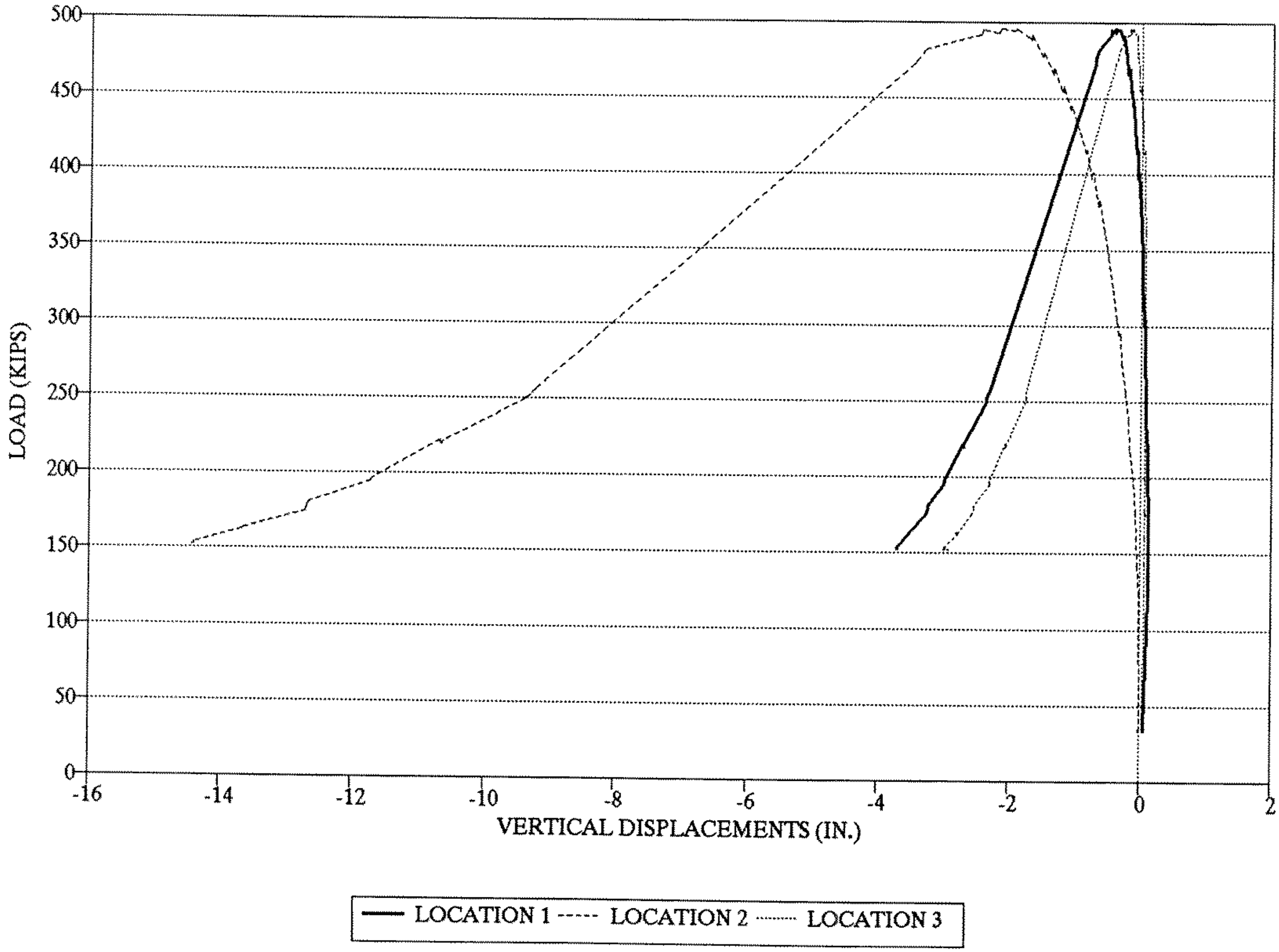


Figure A-56. LOAD AND ECCENTRICITY VS. LOAD STEP

SPECIMEN 06: X ECCENTRICITIES FROM INFLECTION POINTS

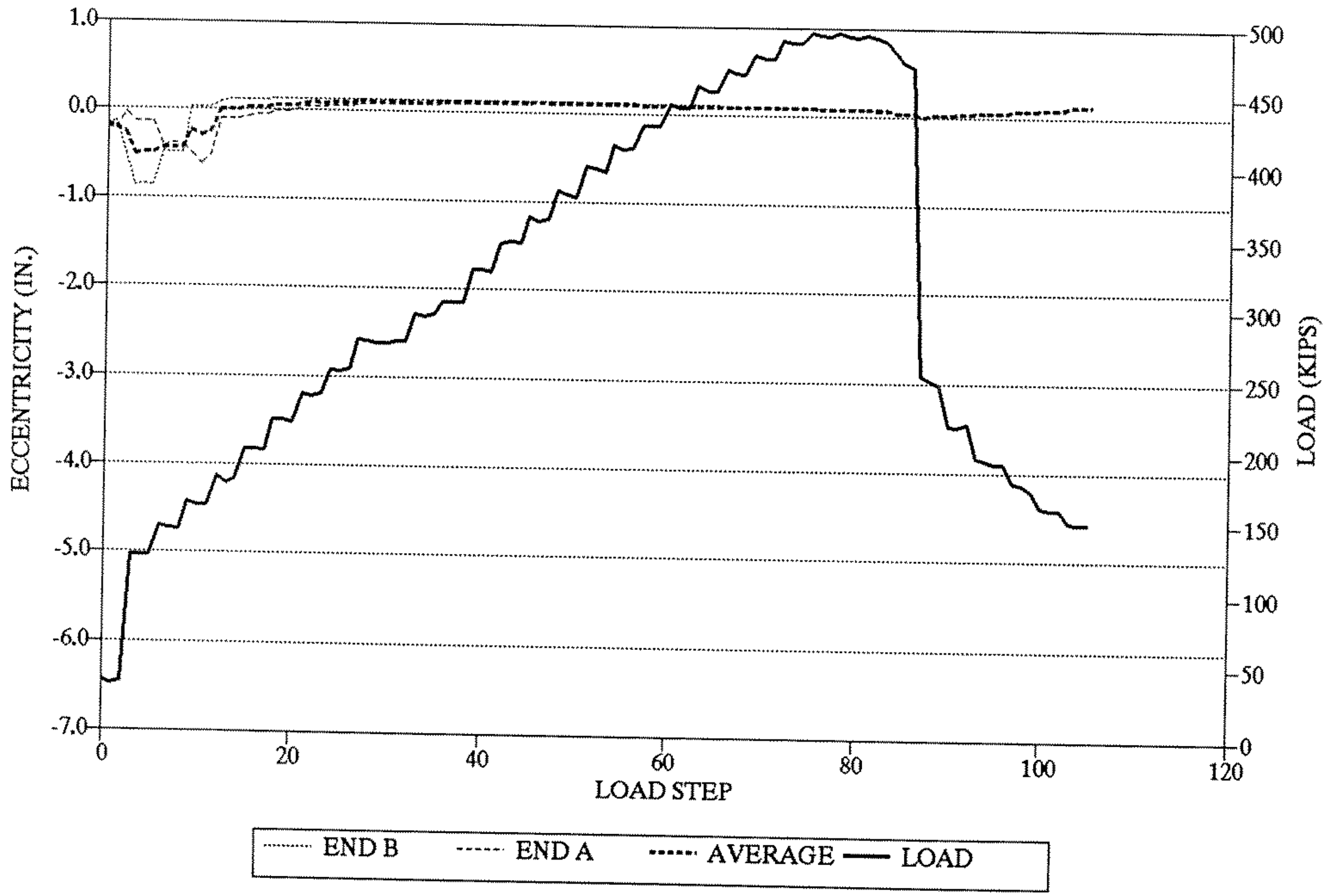


Figure A-57. LOAD AND ECCENTRICITY VS. LOAD STEP

SPECIMEN 06: Y ECCENTRICITIES FROM INFLECTION POINTS

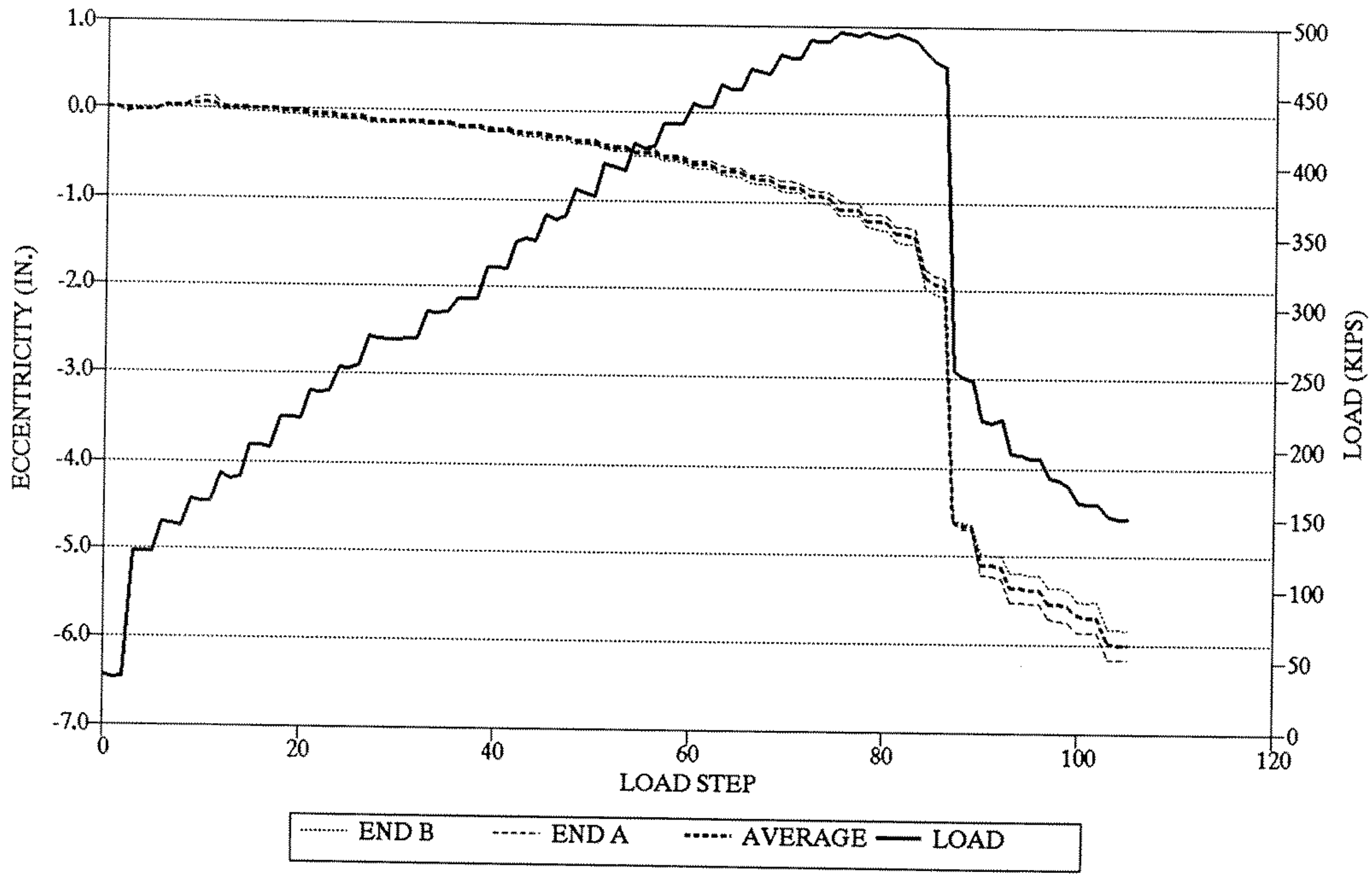


Figure A-58. LOAD AND ECCENTRICITY VS. LOAD STEP

SPECIMEN 06: X ECCENTRICITIES FROM END MOMENTS

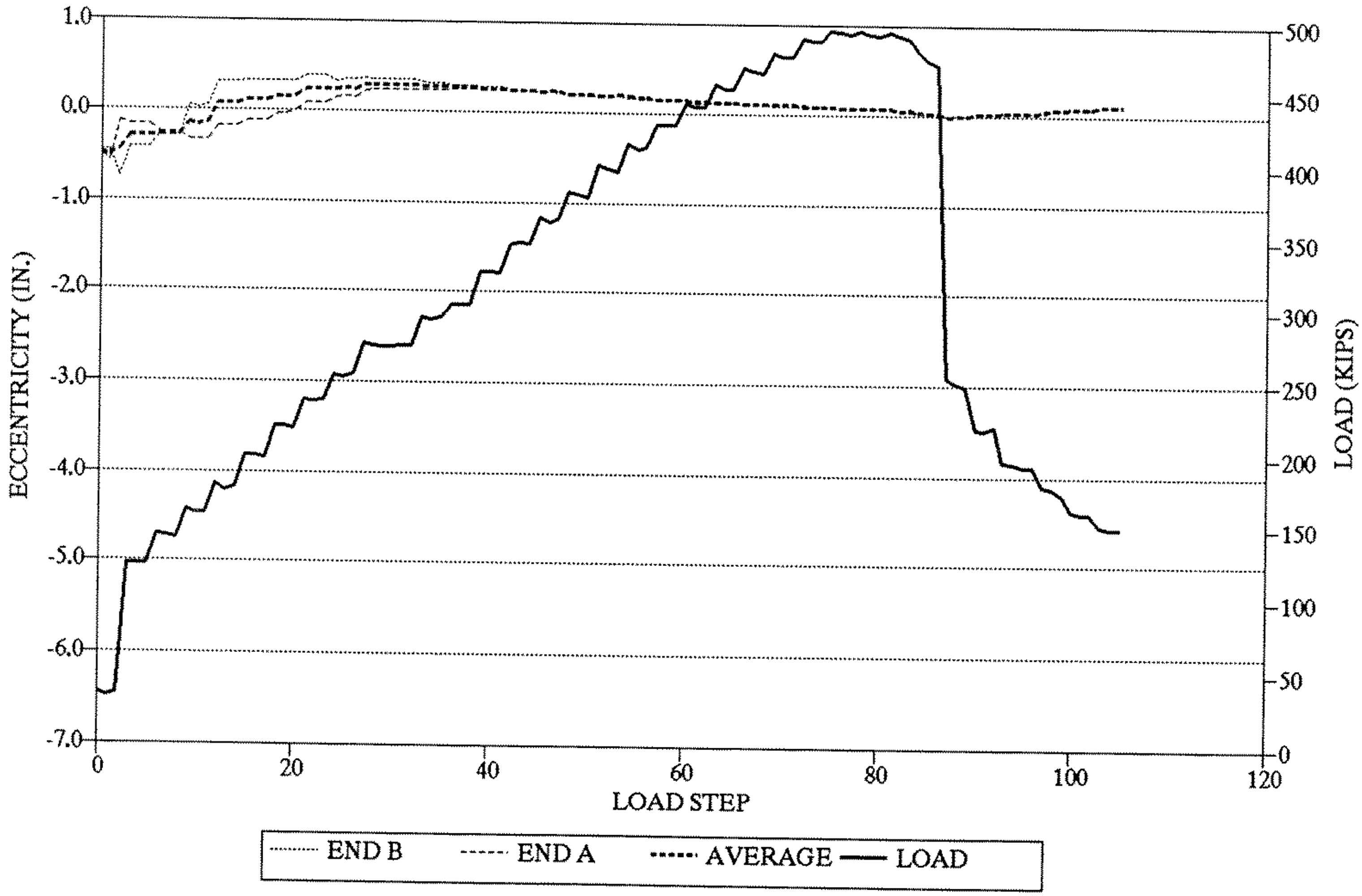


Figure A-59. LOAD AND ECCENTRICITY VS. LOAD STEP

SPECIMEN 06: Y ECCENTRICITIES FROM END MOMENTS

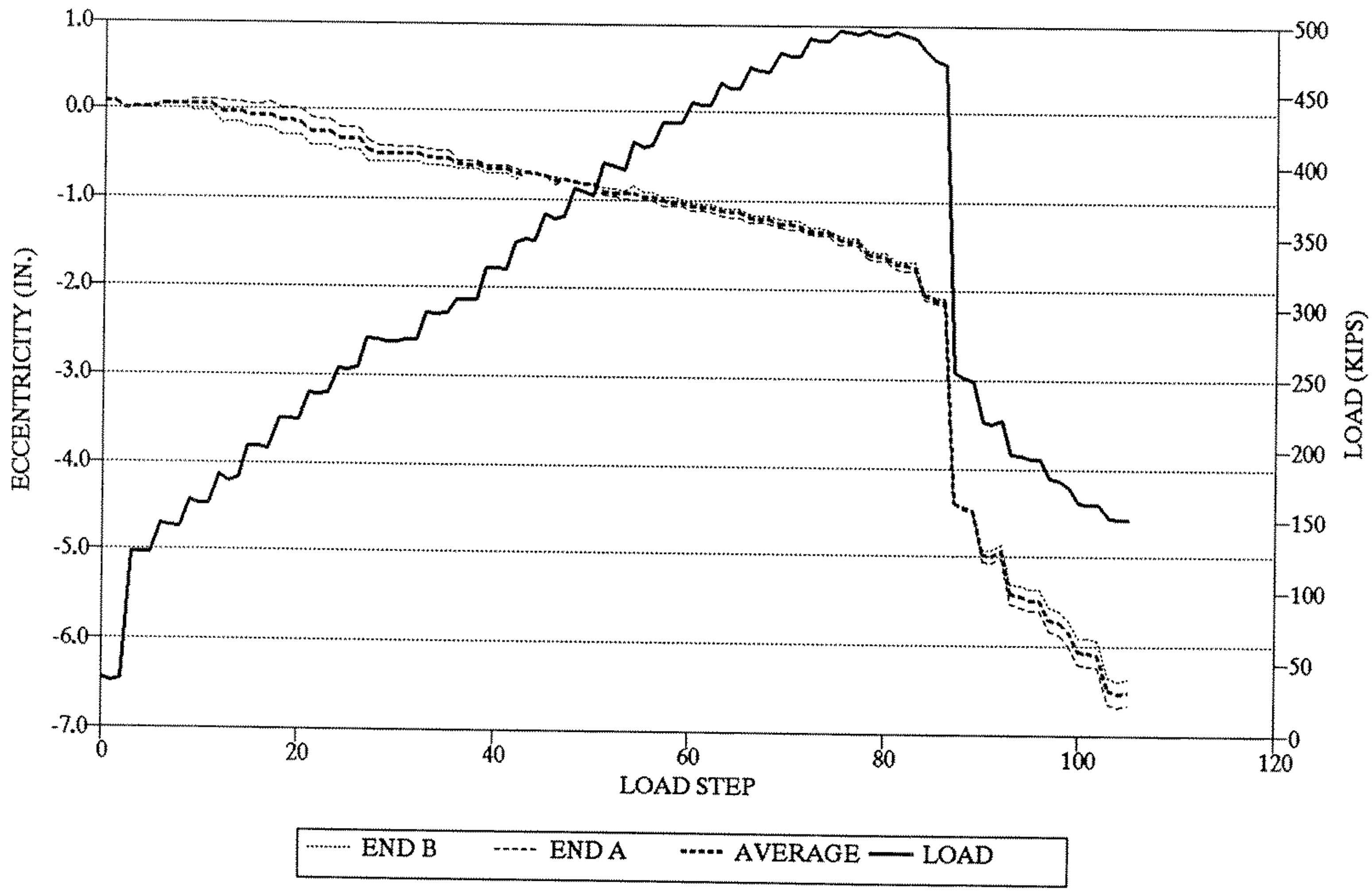


Figure A-60. END ROTATION AND LOAD VS. LOAD STEP
SPECIMEN 06

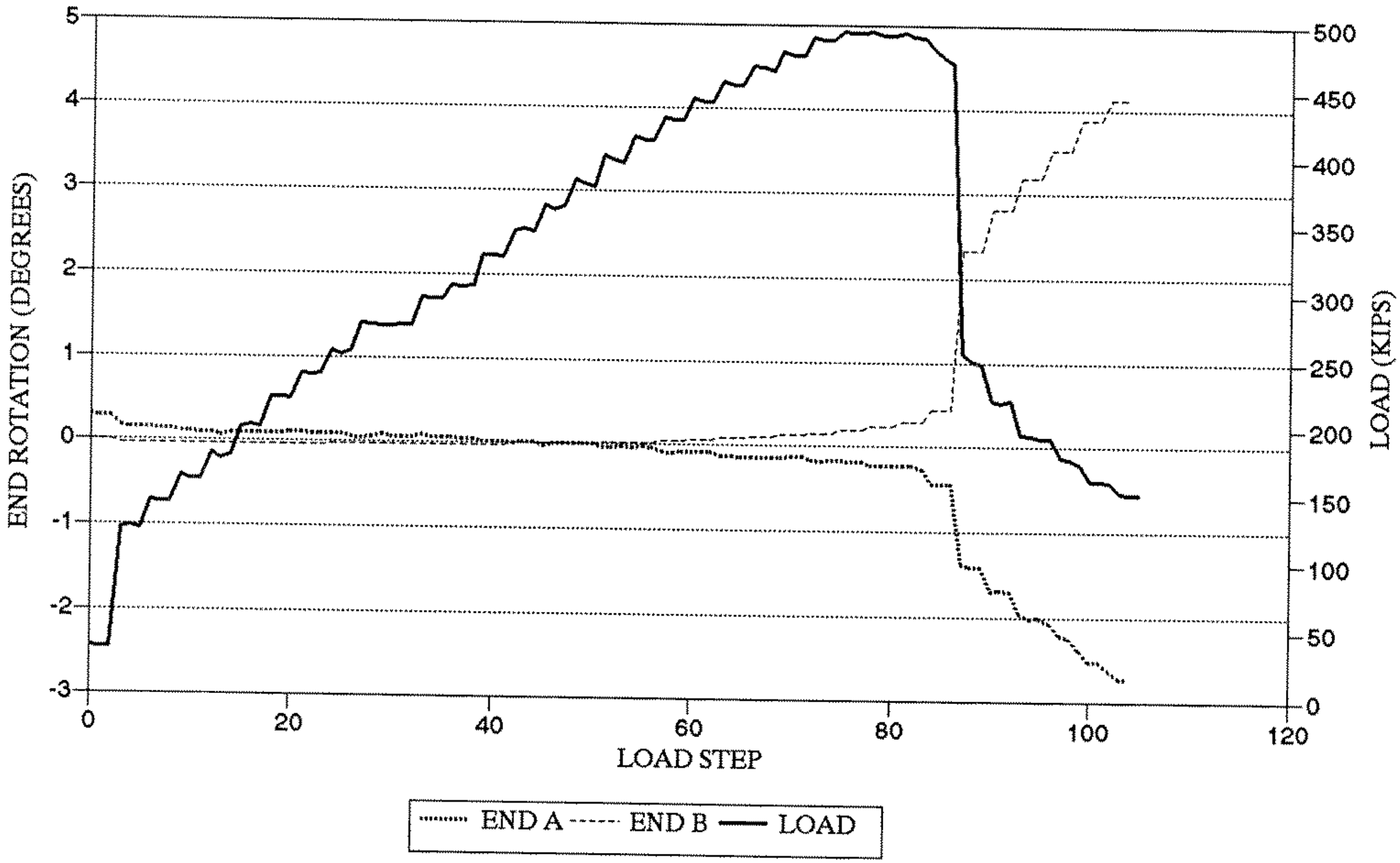


Figure A-61. EFFECTIVE LENGTH VS. LOAD STEP
SPECIMEN 07

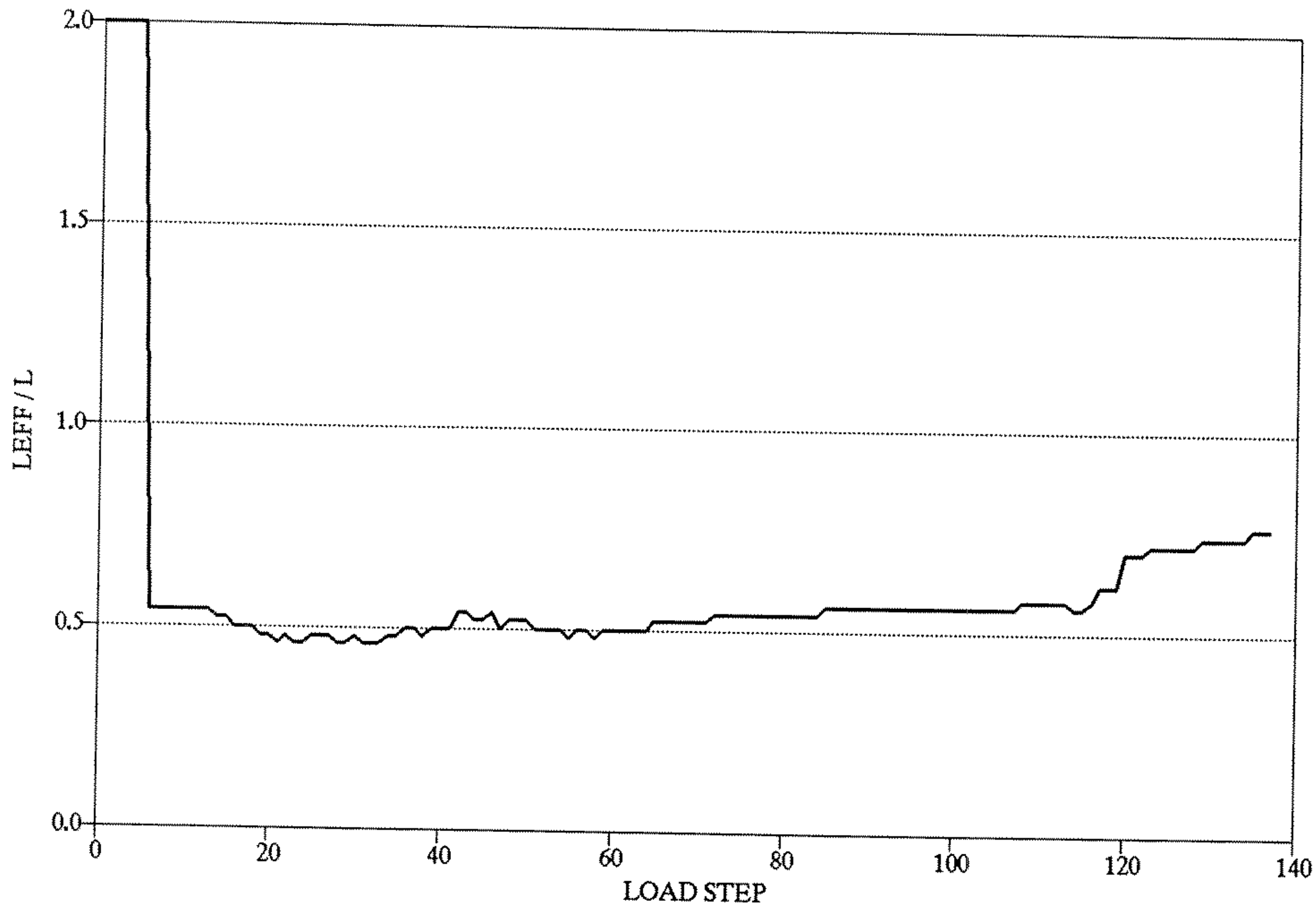


Figure A-62. LOAD AND DEFLECTION VS. LOAD STEP
SPECIMEN 07

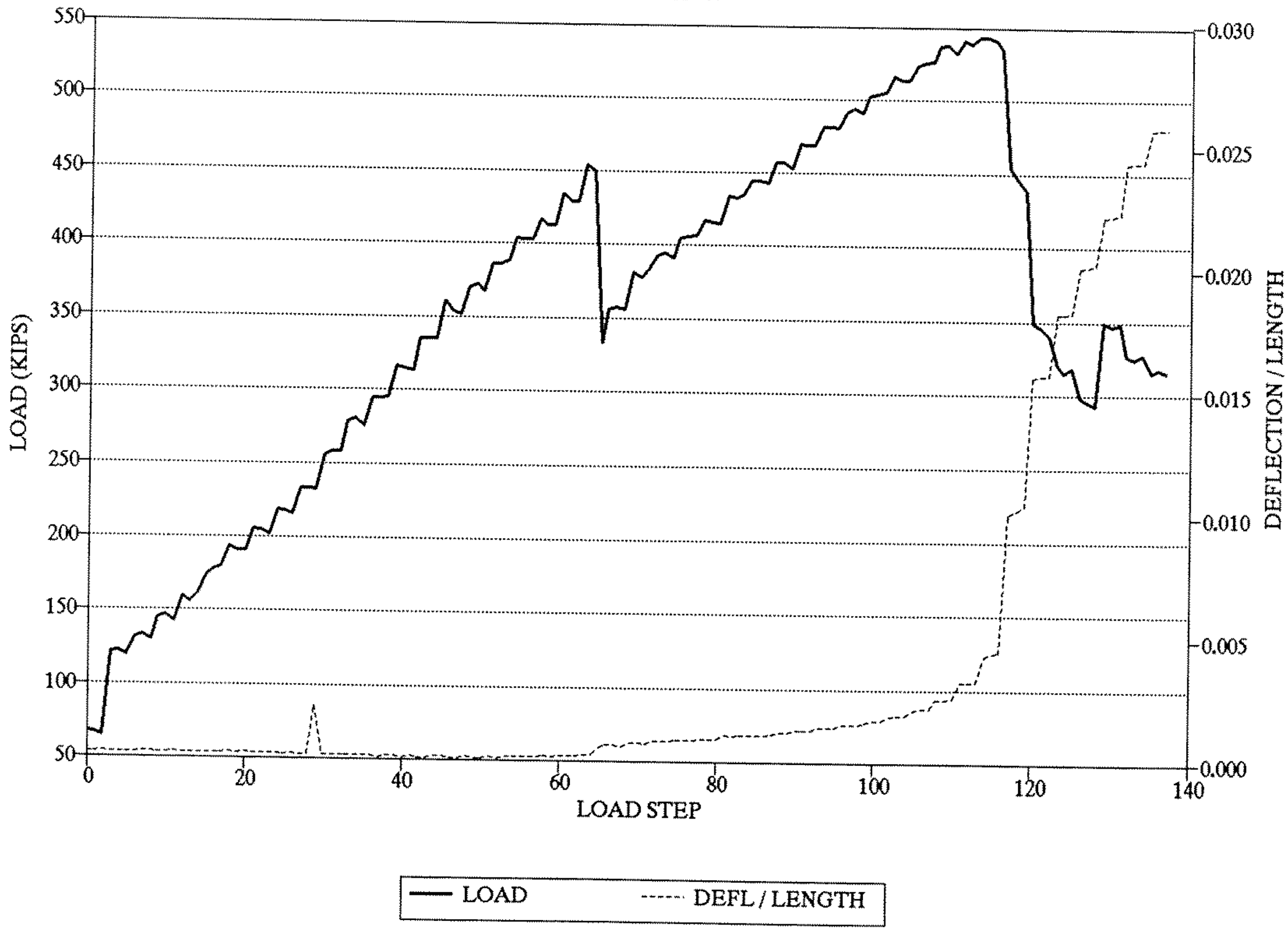


Figure A-63. LOAD VS. CHORD SHORTENING
SPECIMEN 07

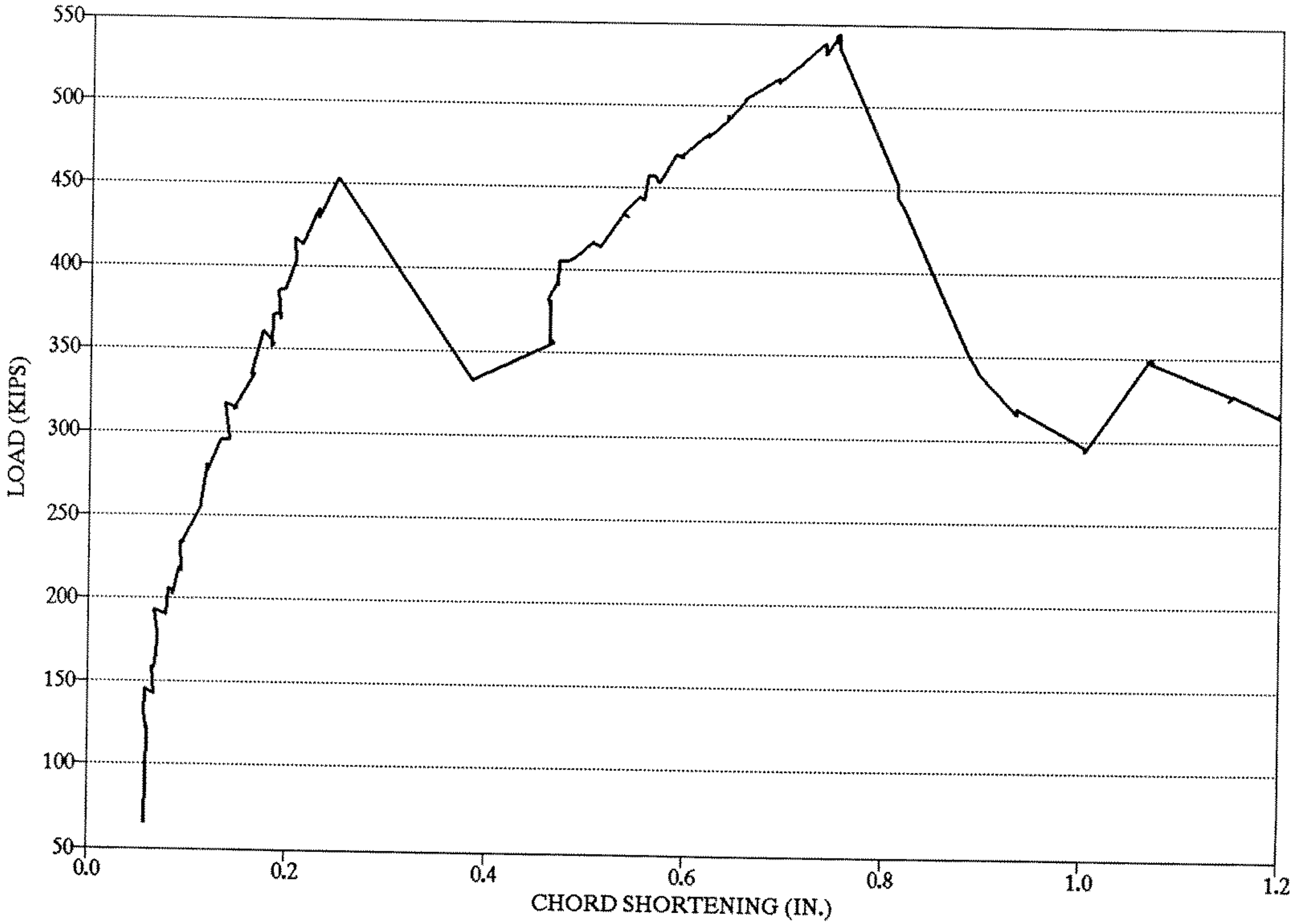


Figure A-64. HORIZONTAL DISPLACEMENTS
SPECIMEN 07

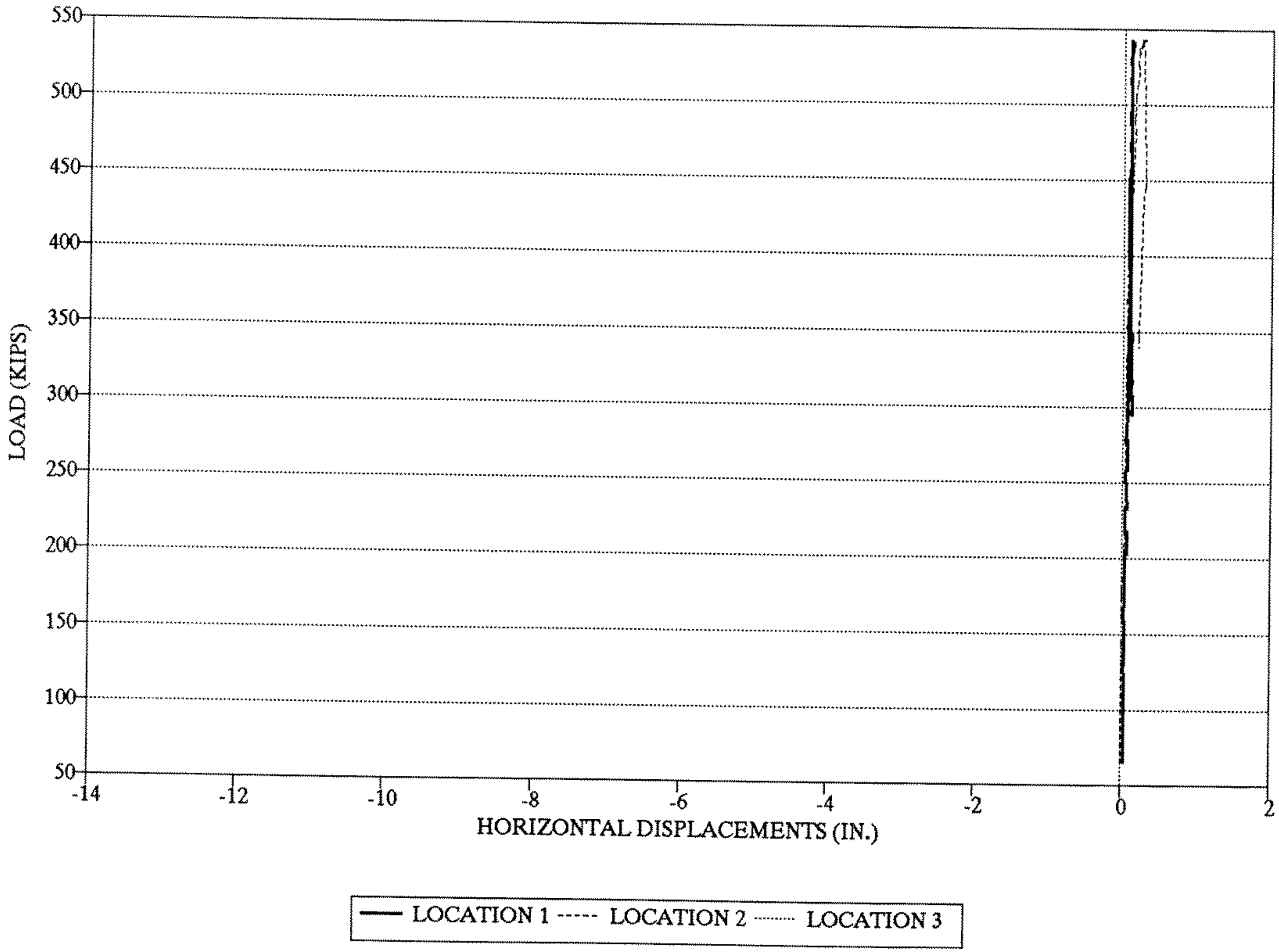


Figure A-65. VERTICAL DISPLACEMENTS
SPECIMEN 07

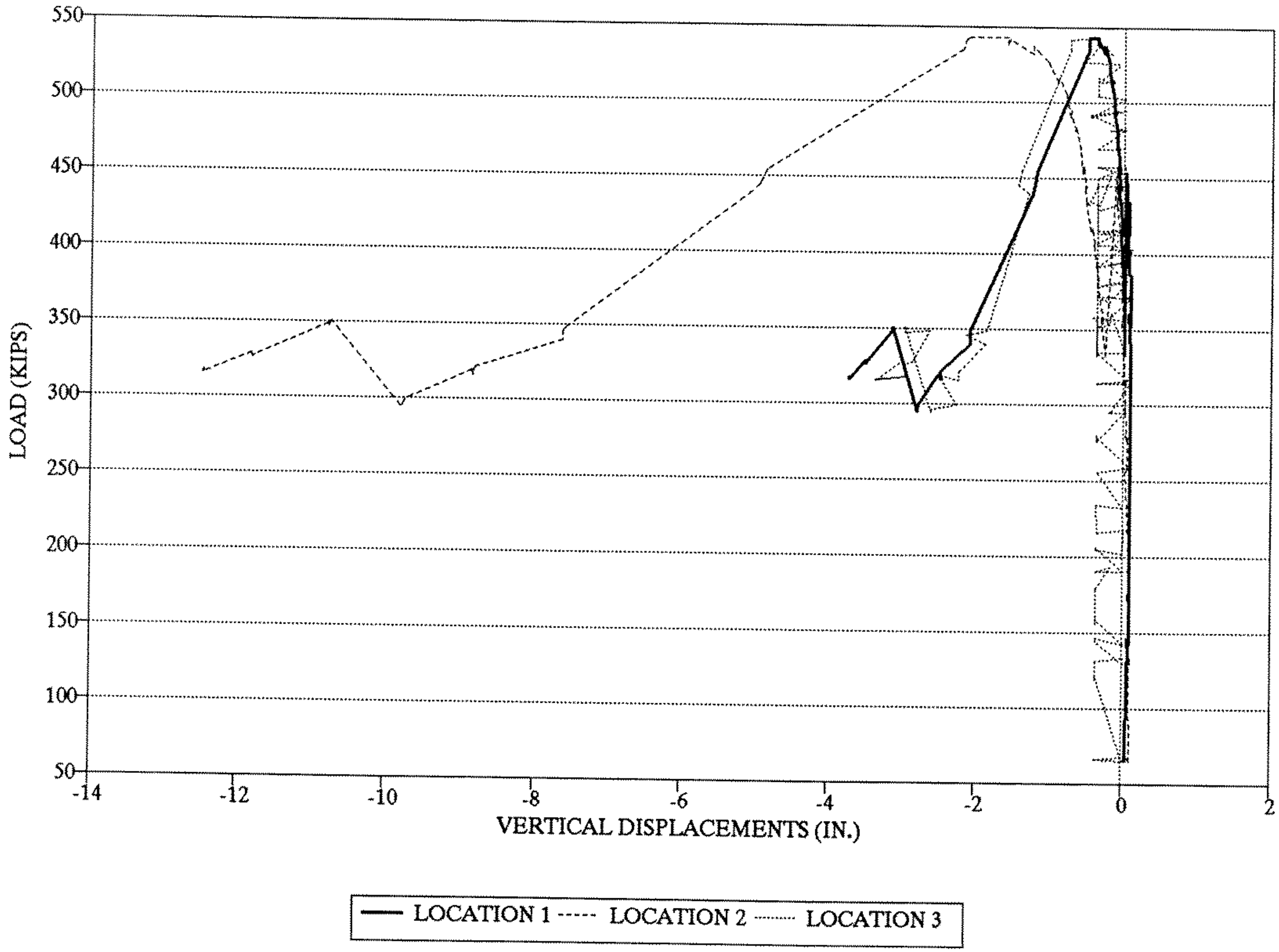


Figure A-66. LOAD AND ECCENTRICITY VS. LOAD STEP

SPECIMEN 07: X ECCENTRICITIES FROM INFLECTION POINTS

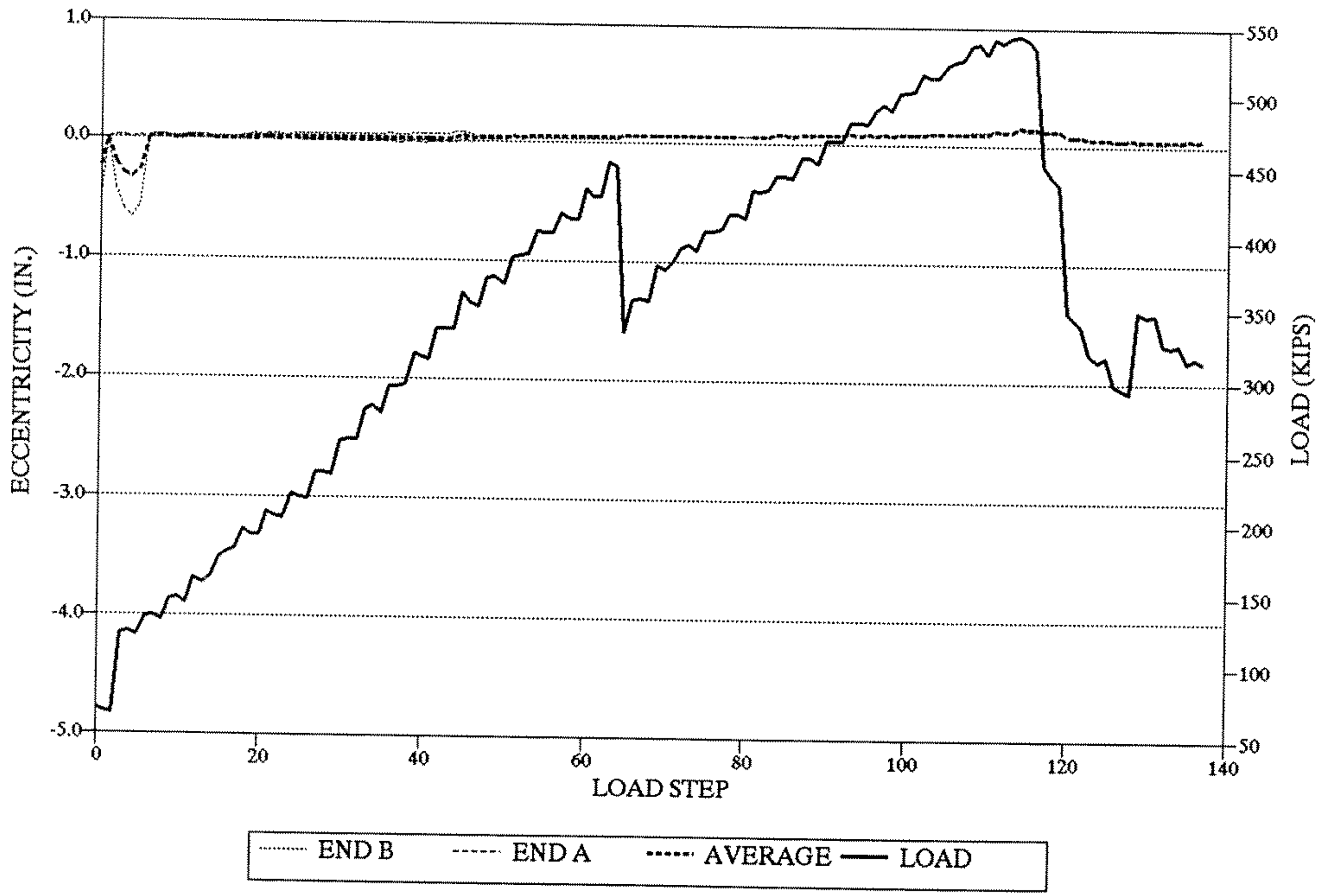


Figure A-67. LOAD AND ECCENTRICITY VS. LOAD STEP

SPECIMEN 07: Y ECCENTRICITIES FROM INFLECTION POINTS

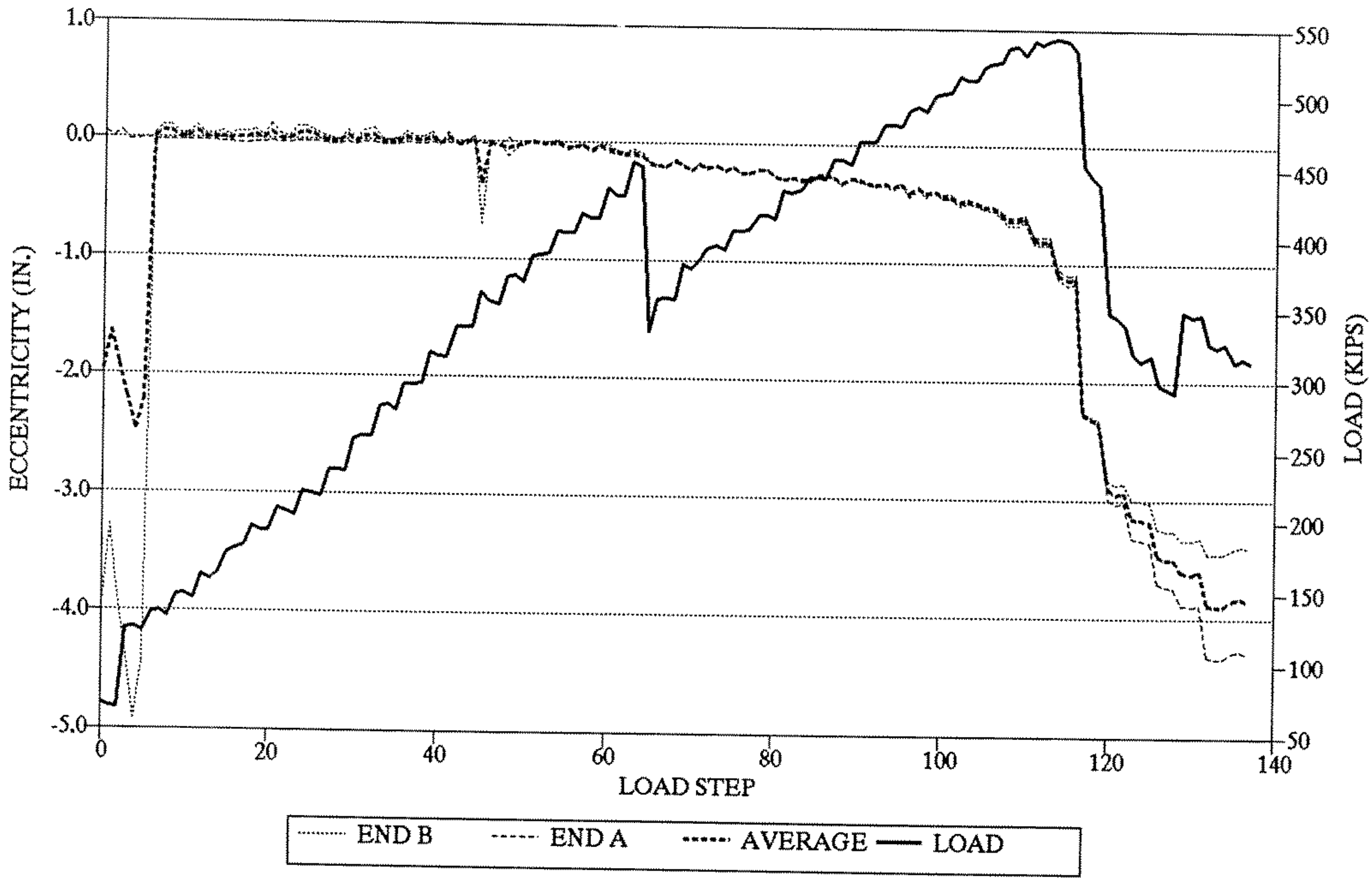


Figure A-68. LOAD AND ECCENTRICITY VS. LOAD STEP

SPECIMEN 07: X ECCENTRICITIES FROM END MOMENTS

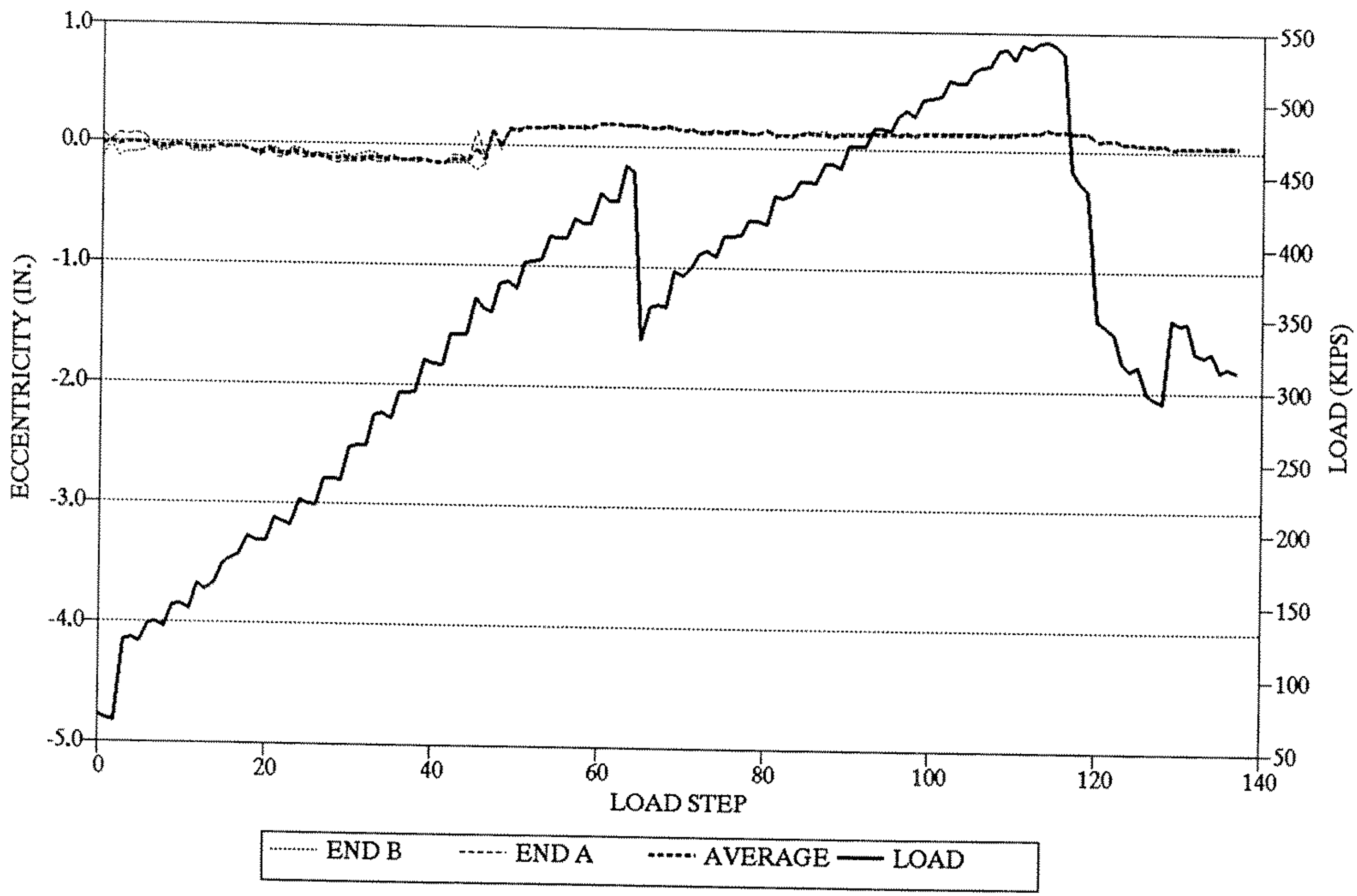


Figure A-69. LOAD AND ECCENTRICITY VS. LOAD STEP

SPECIMEN 07: Y ECCENTRICITIES FROM END MOMENTS

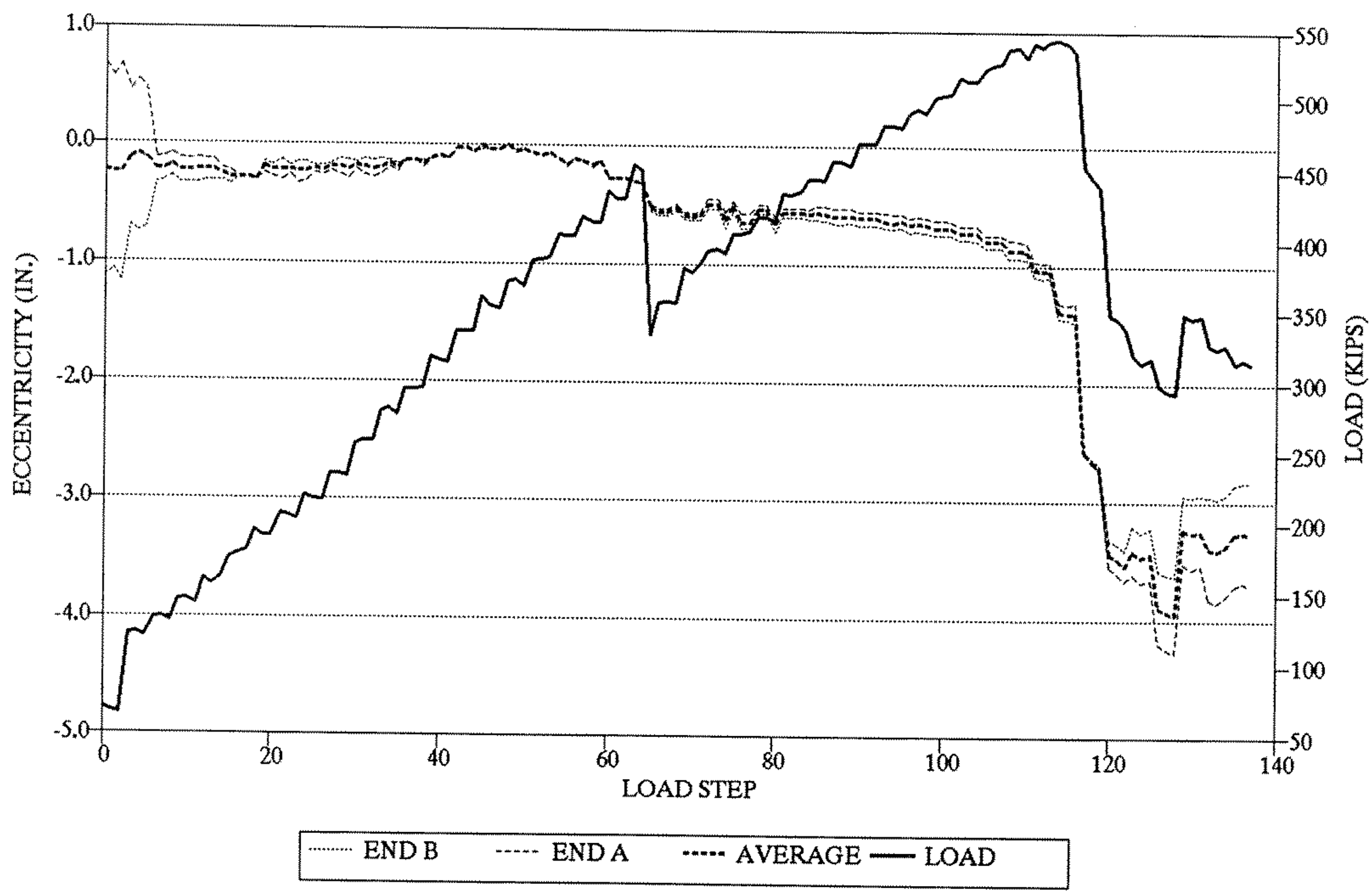


Figure A-70. END ROTATION AND LOAD VS. LOAD STEP
SPECIMEN 07

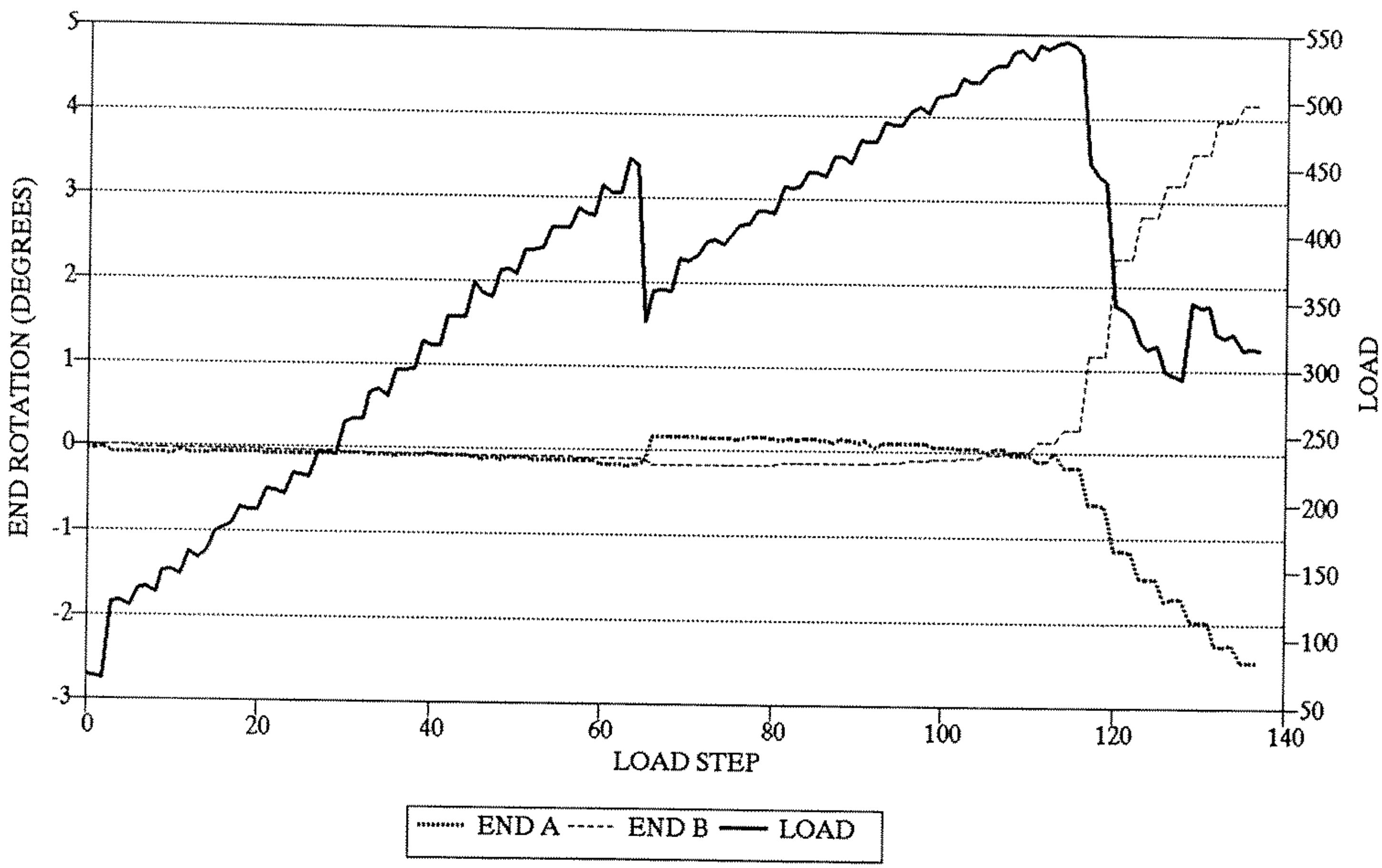


Figure A-71. EFFECTIVE LENGTH VS. LOAD STEP
SPECIMEN 08

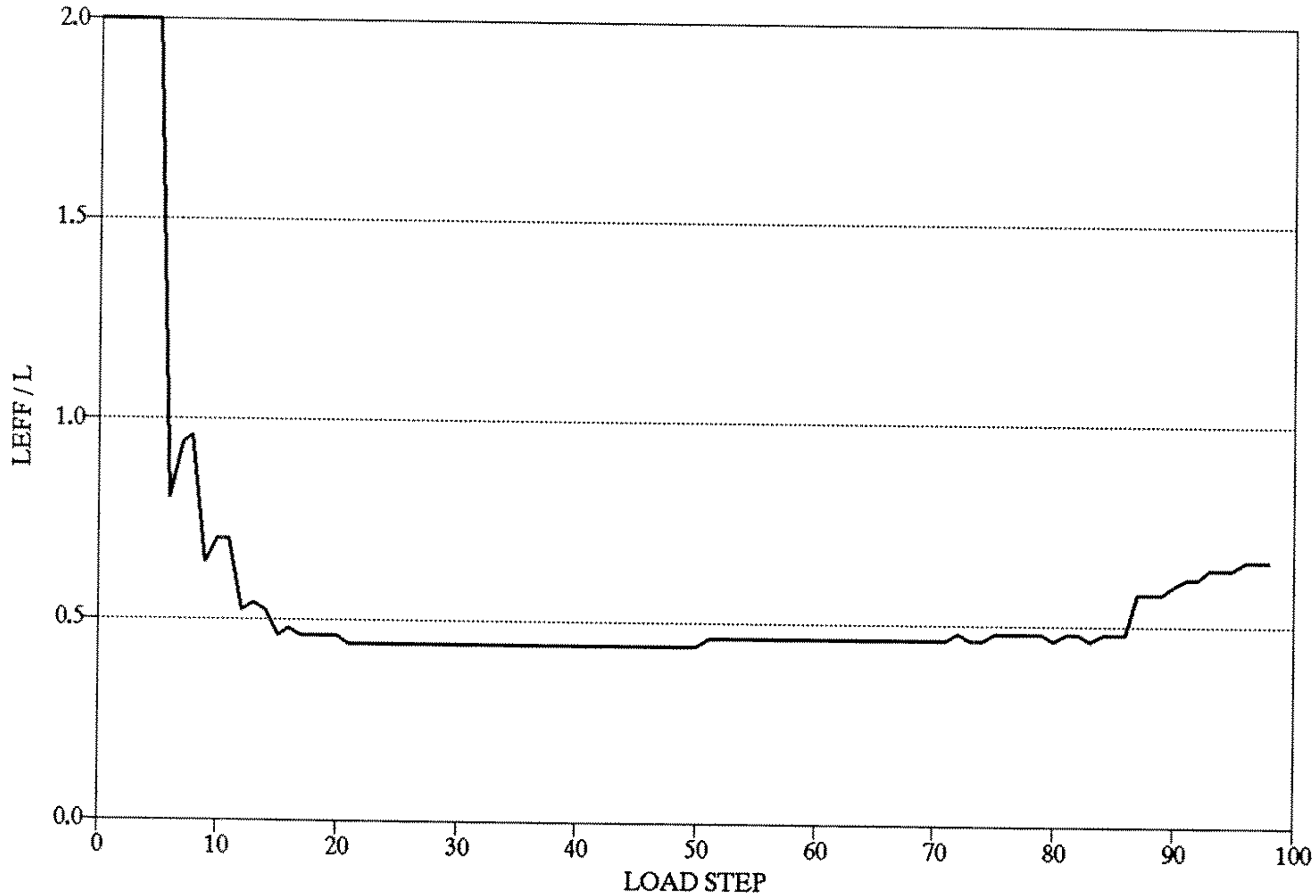


Figure A-72. LOAD AND DEFLECTION VS. LOAD STEP
SPECIMEN 08

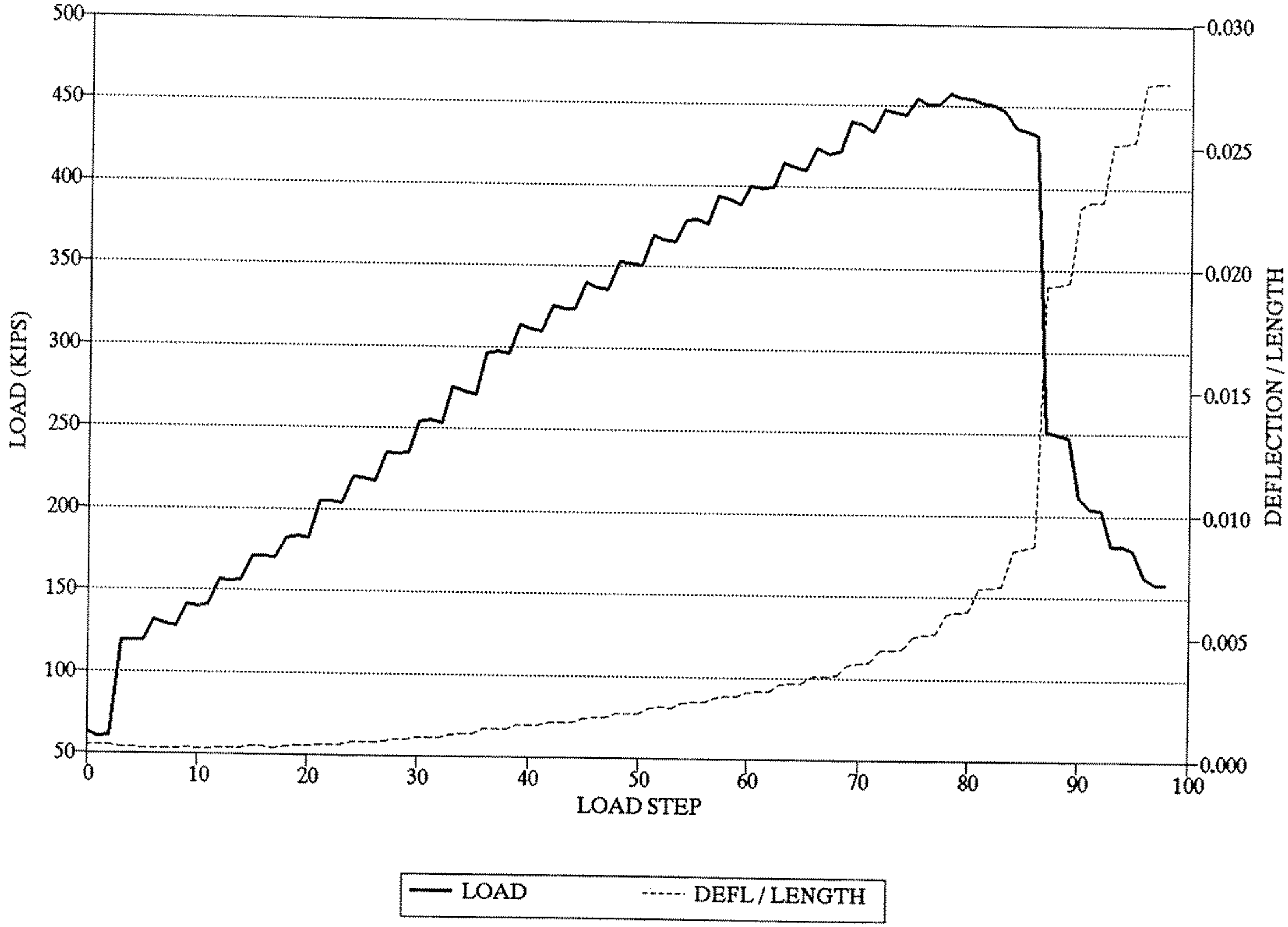


Figure A-73. LOAD VS. CHORD SHORTENING
SPECIMEN 08

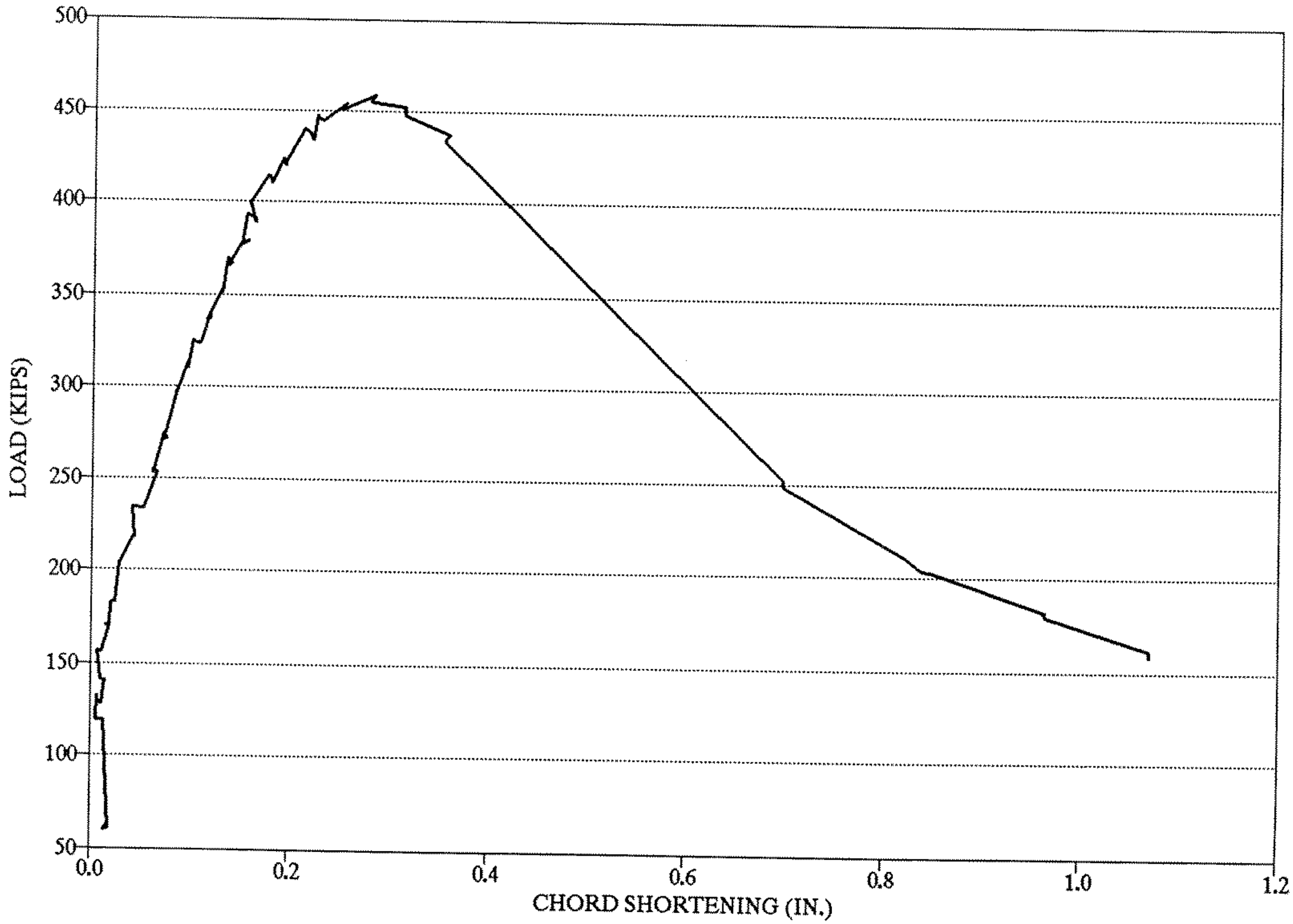


Figure A-74. HORIZONTAL DISPLACEMENTS
SPECIMEN 08

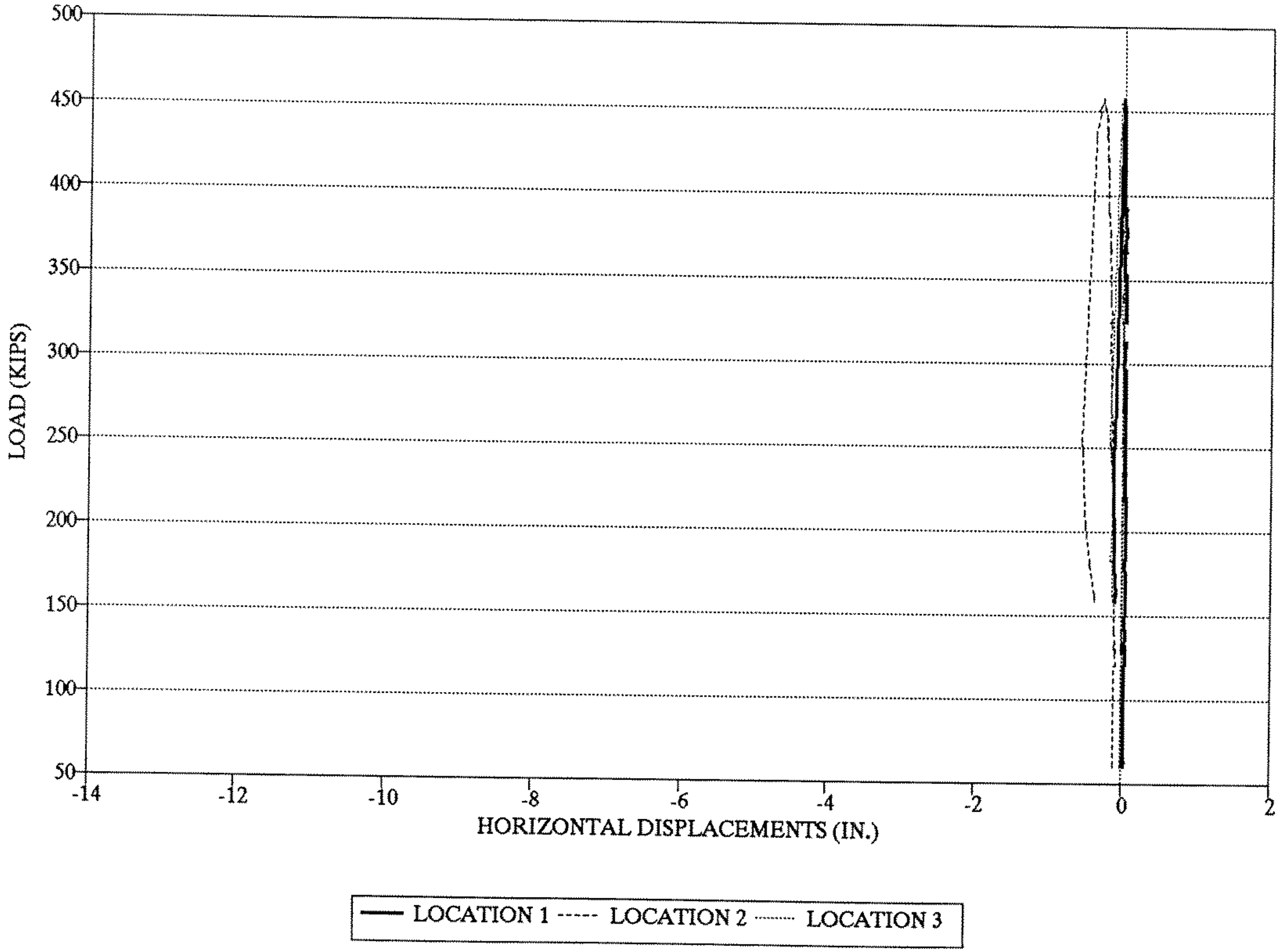


Figure A-75. VERTICAL DISPLACEMENTS
SPECIMEN 08

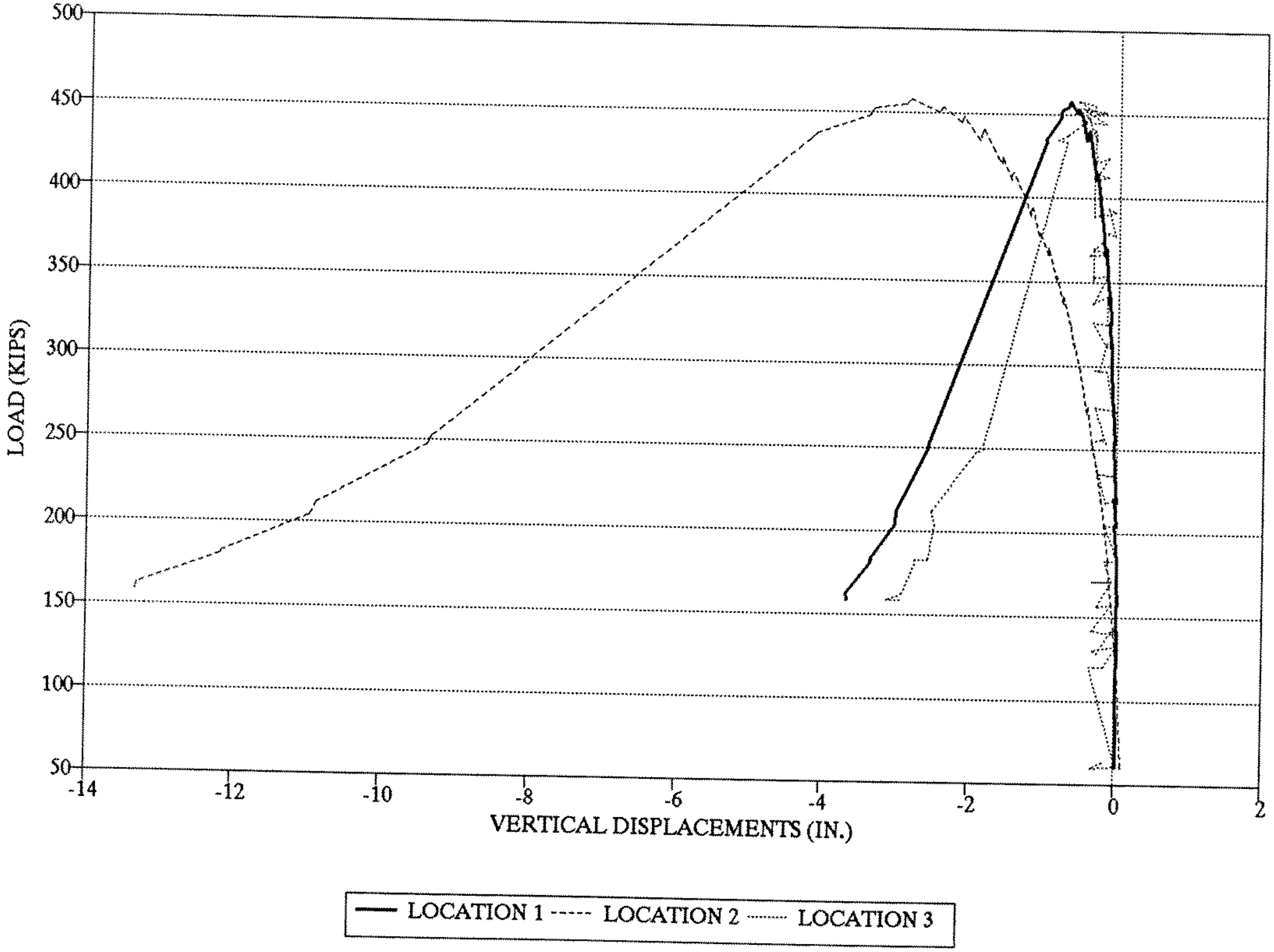


Figure A-76. LOAD AND ECCENTRICITY VS. LOAD STEP

SPECIMEN 08: X ECCENTRICITIES FROM INFLECTION POINTS

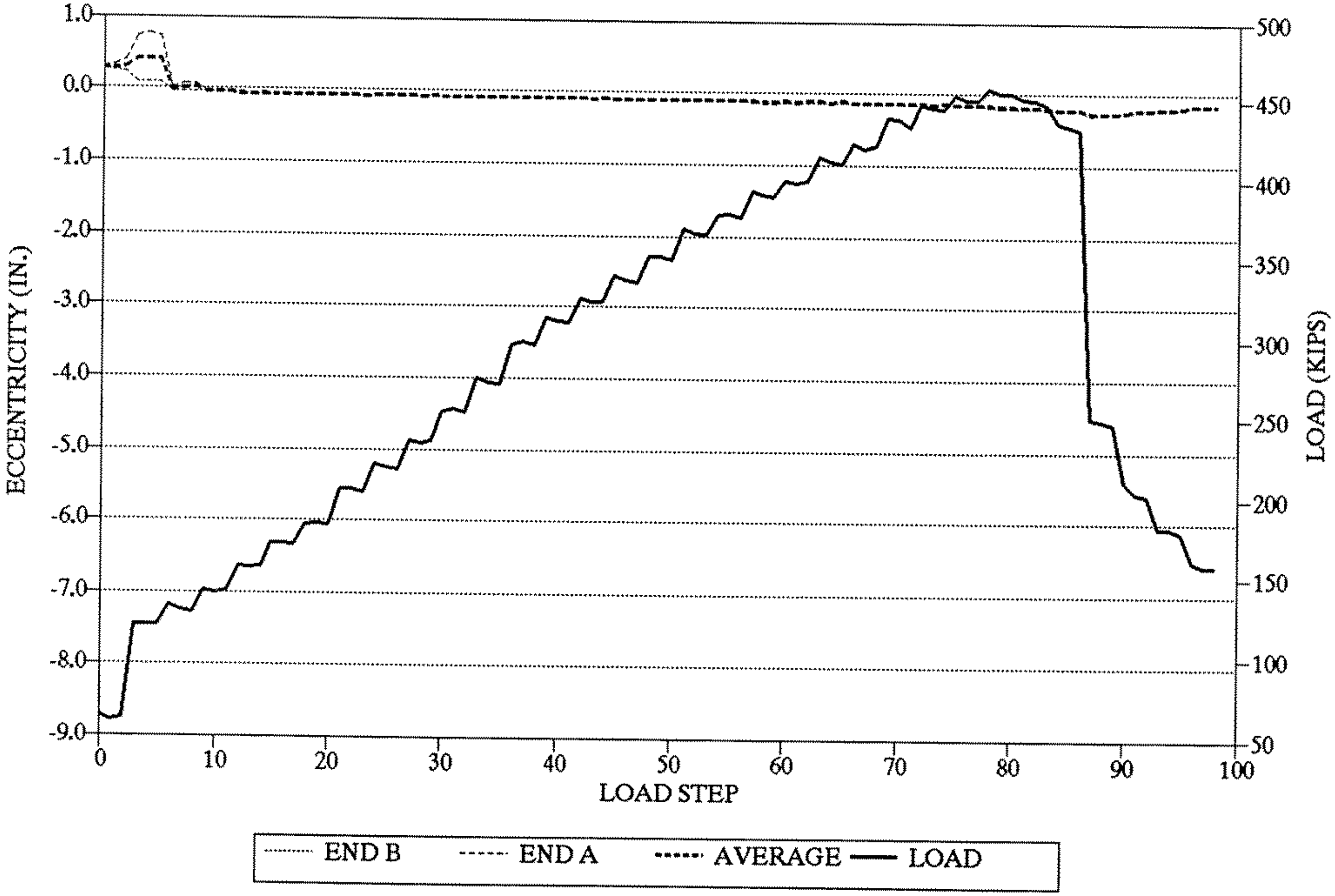


Figure A-77. LOAD AND ECCENTRICITY VS. LOAD STEP

SPECIMEN 08: Y ECCENTRICITIES FROM INFLECTION POINTS

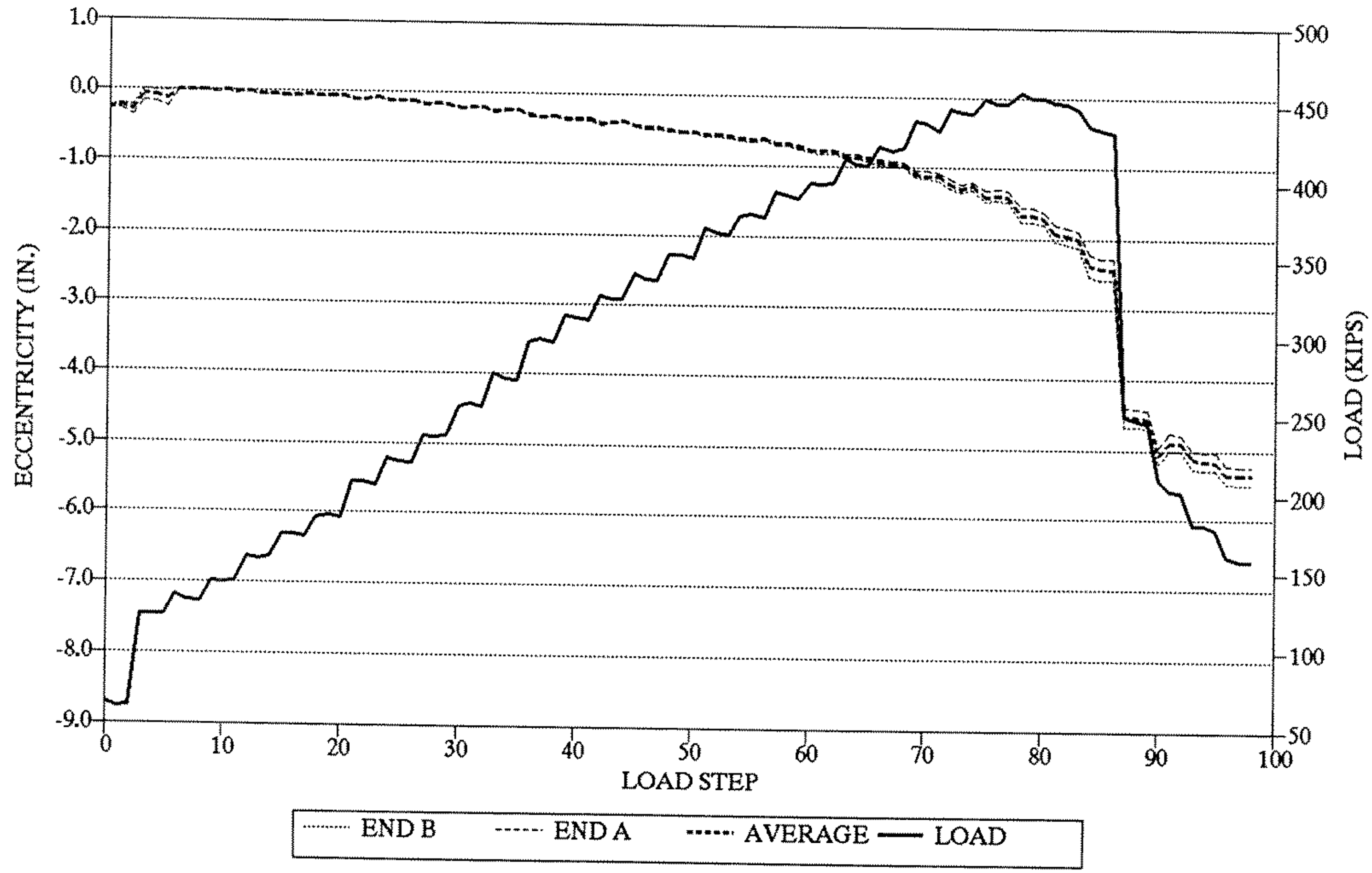


Figure A-78. LOAD AND ECCENTRICITY VS. LOAD STEP

SPECIMEN 08: X ECCENTRICITIES FROM END MOMENTS

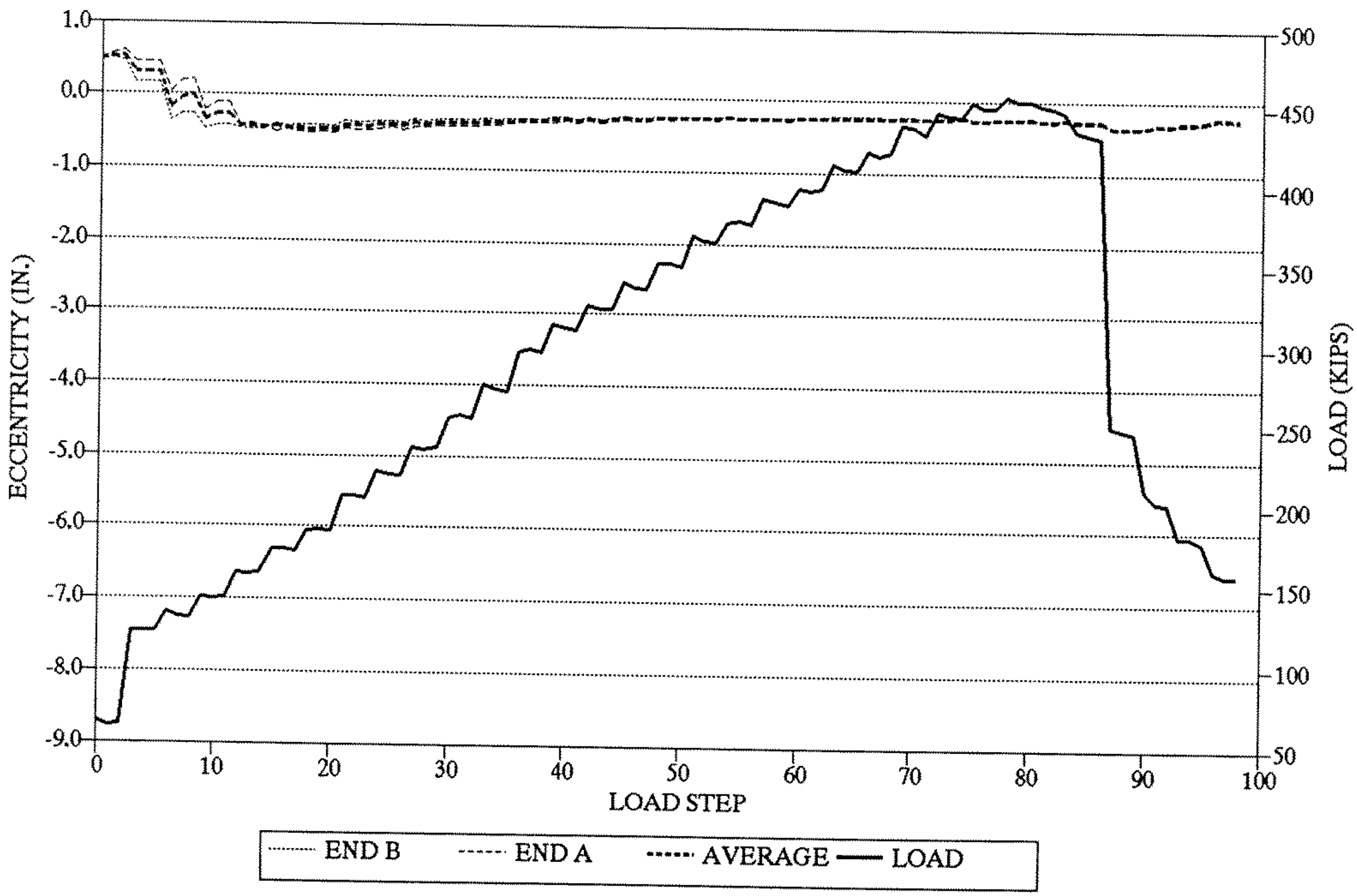


Figure A-79. LOAD AND ECCENTRICITY VS. LOAD STEP

SPECIMEN 08: Y ECCENTRICITIES FROM END MOMENTS

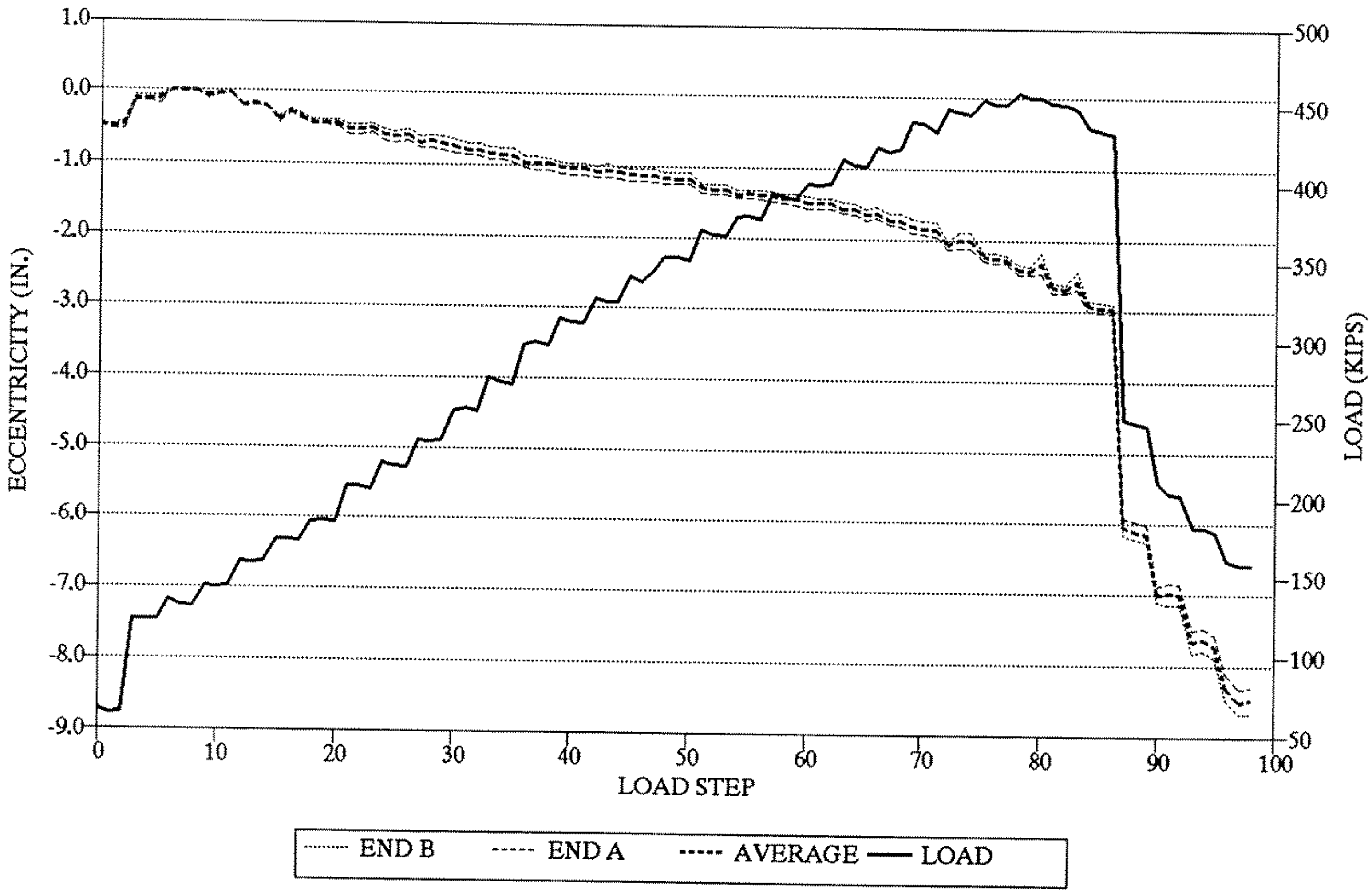


Figure A-80. END ROTATION AND LOAD VS. LOAD STEP
SPECIMEN 08

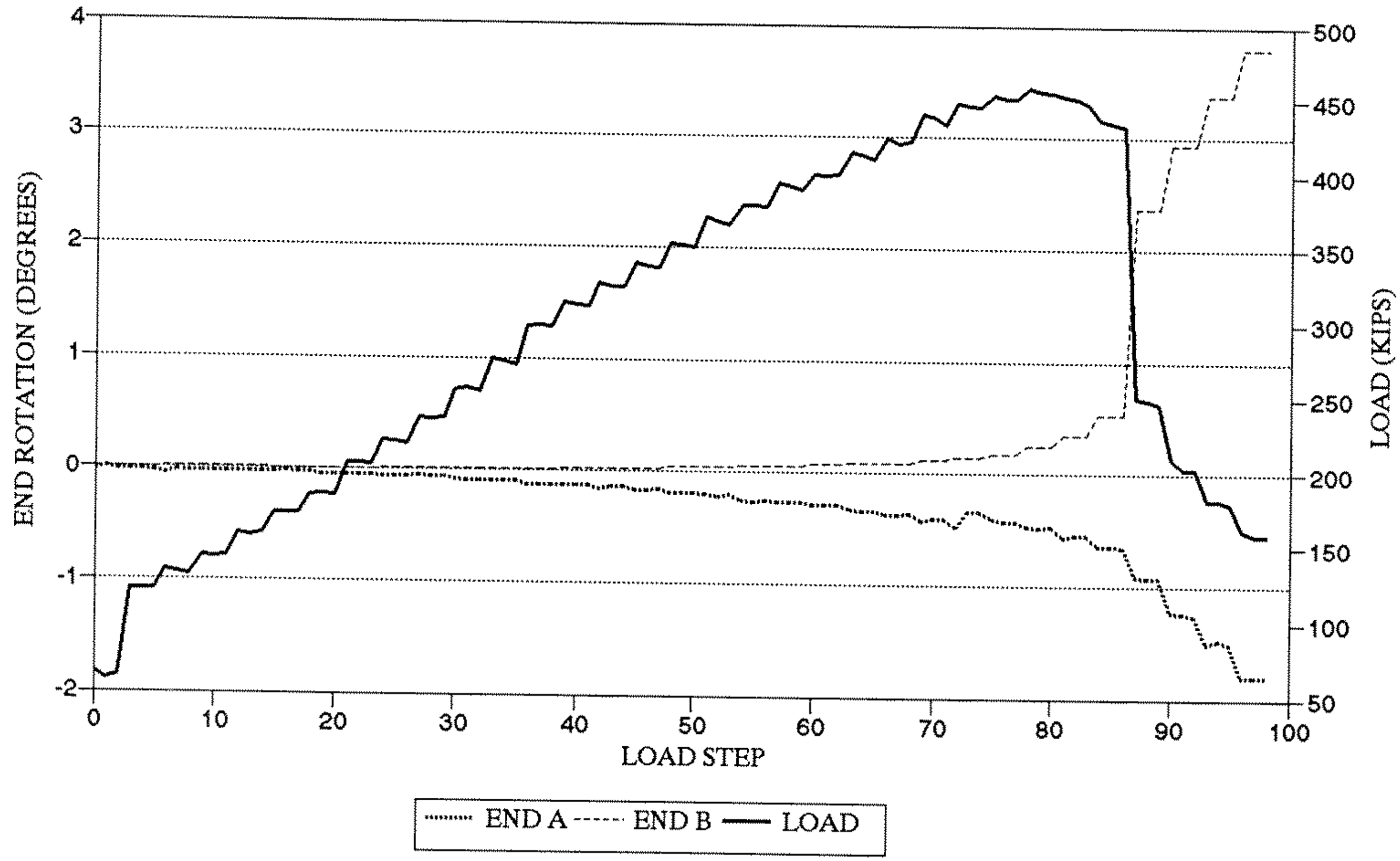


Figure A-81. EFFECTIVE LENGTH VS. LOAD STEP
SPECIMEN 09

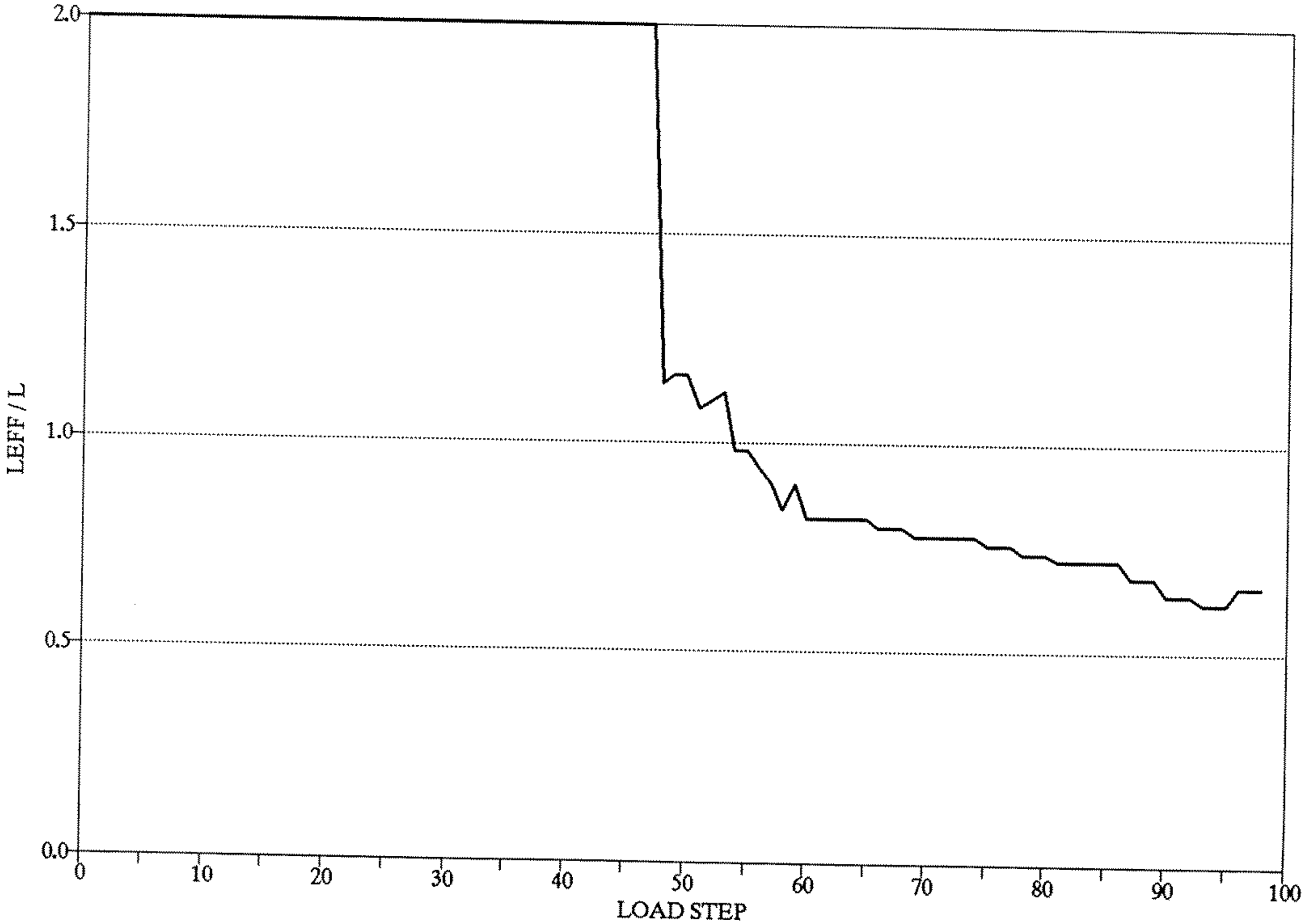


Figure A-82. LOAD AND DEFLECTION VS. LOAD STEP
SPECIMEN 09

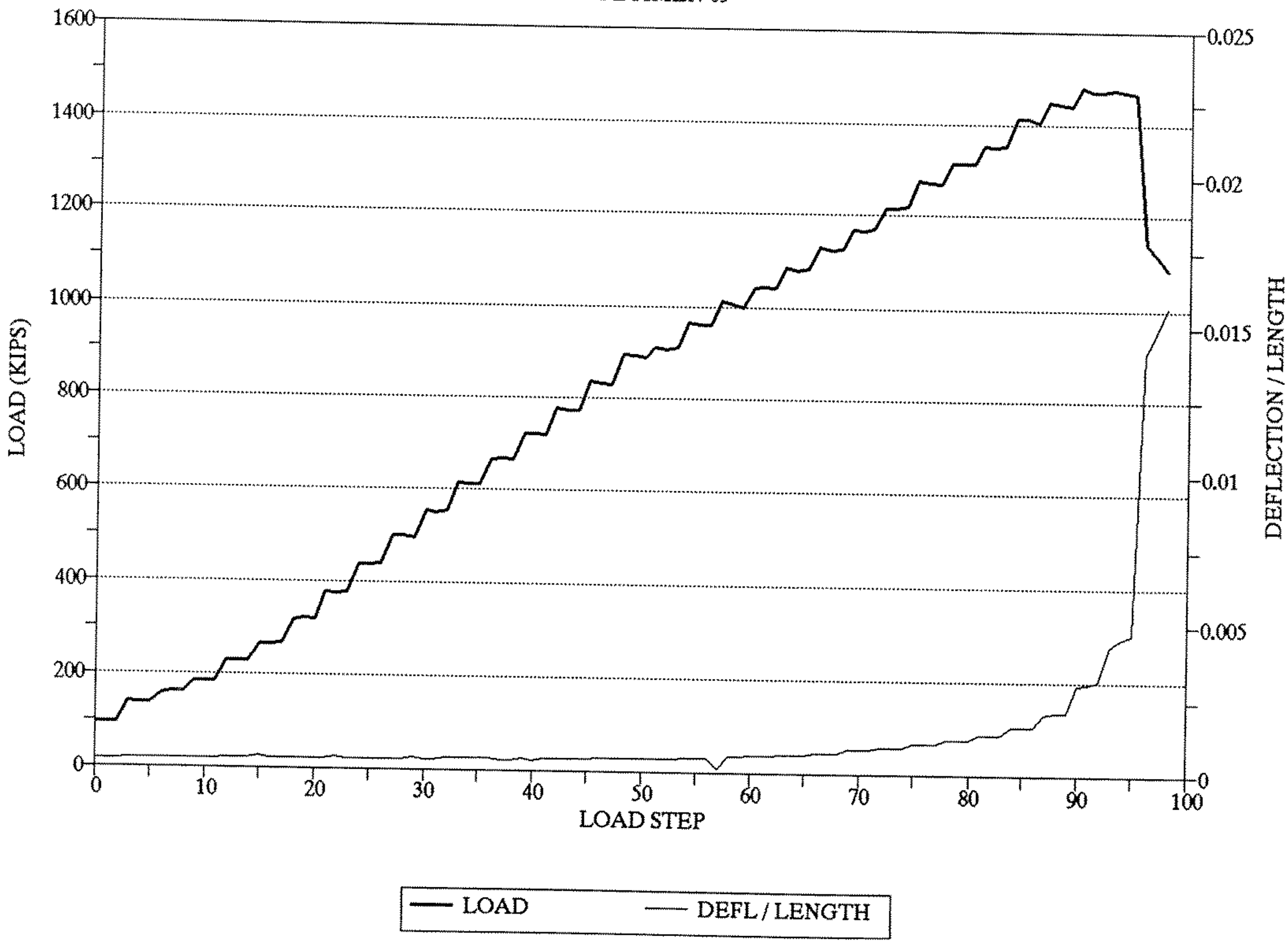


Figure A-83. LOAD VS. CHORD SHORTENING
SPECIMEN 09

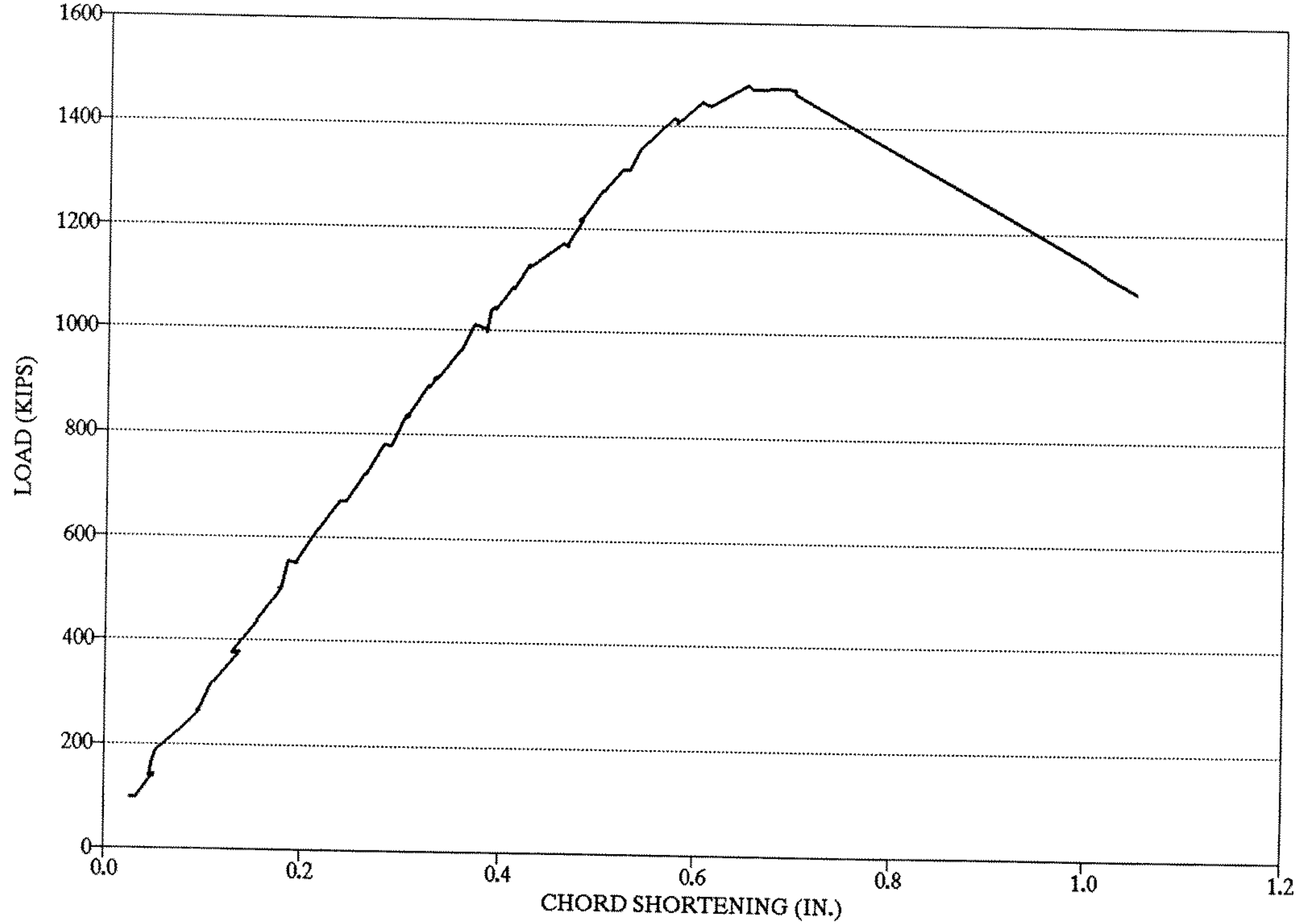


Figure A-84. HORIZONTAL DISPLACEMENTS
SPECIMEN 09

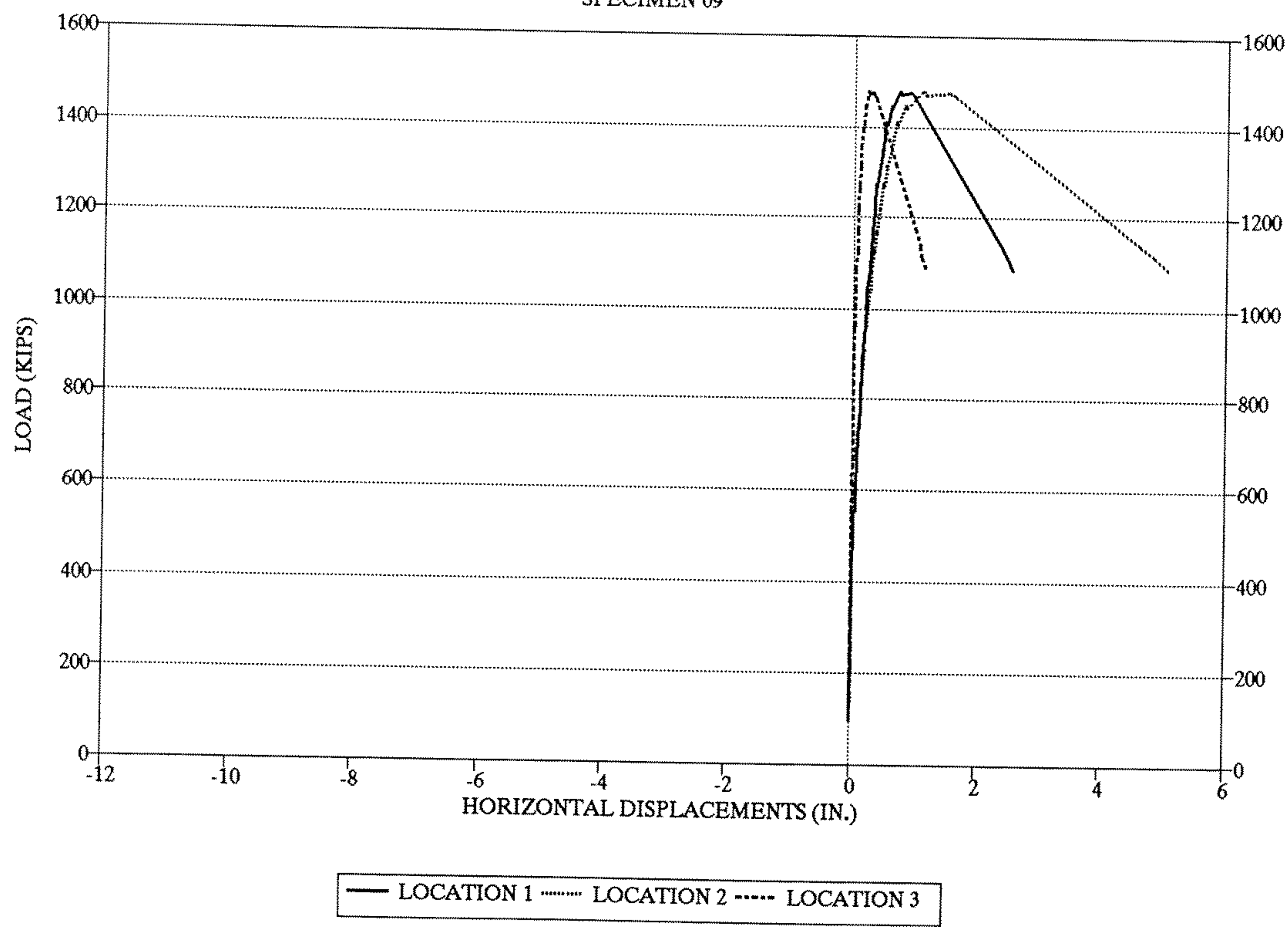


Figure A-85. VERTICAL DISPLACEMENTS
SPECIMEN 09

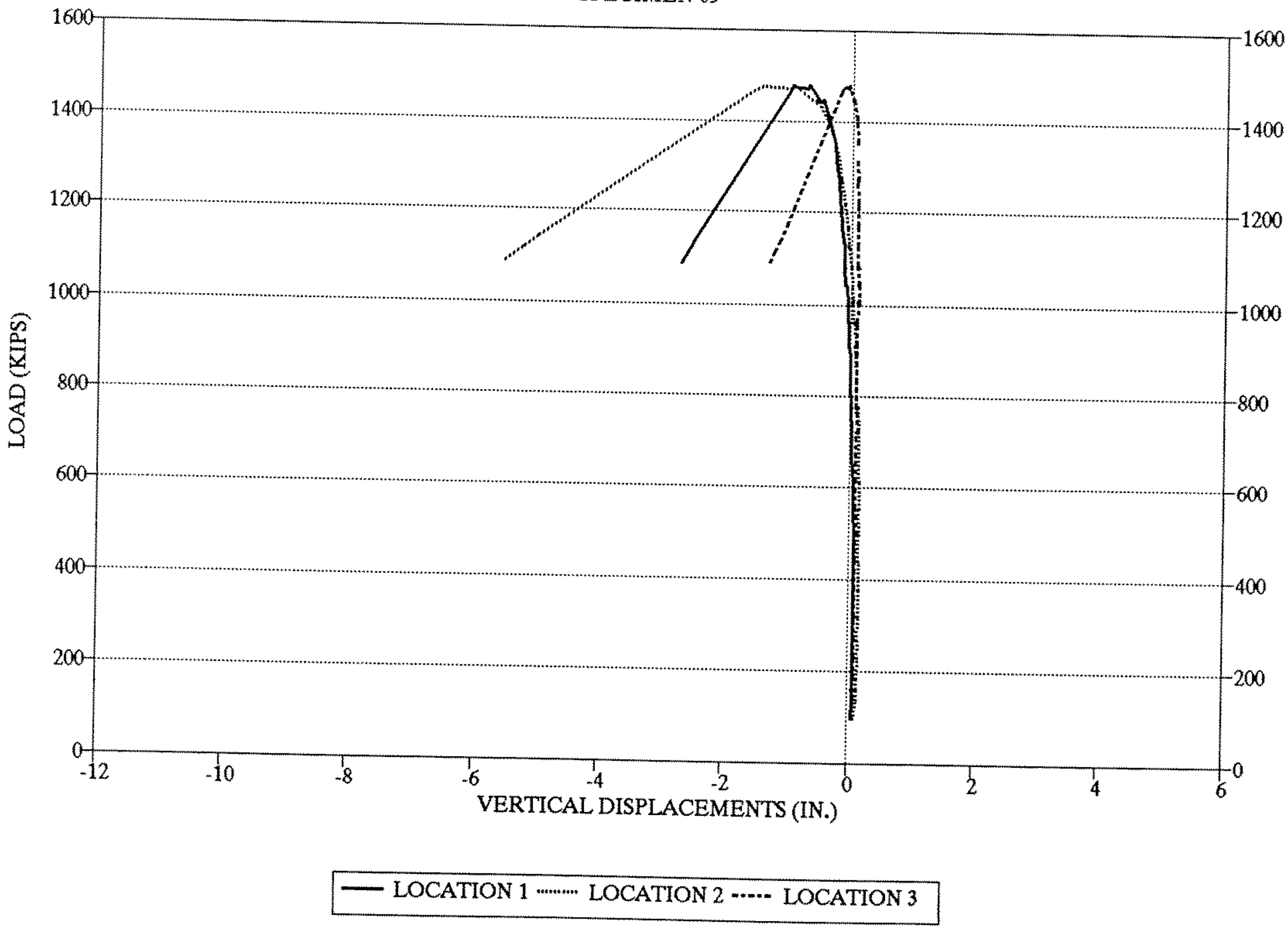


Figure A-86. LOAD AND ECCENTRICITY VS. LOAD STEP

SPECIMEN 09: X ECCENTRICITIES FROM INFLECTION POINTS

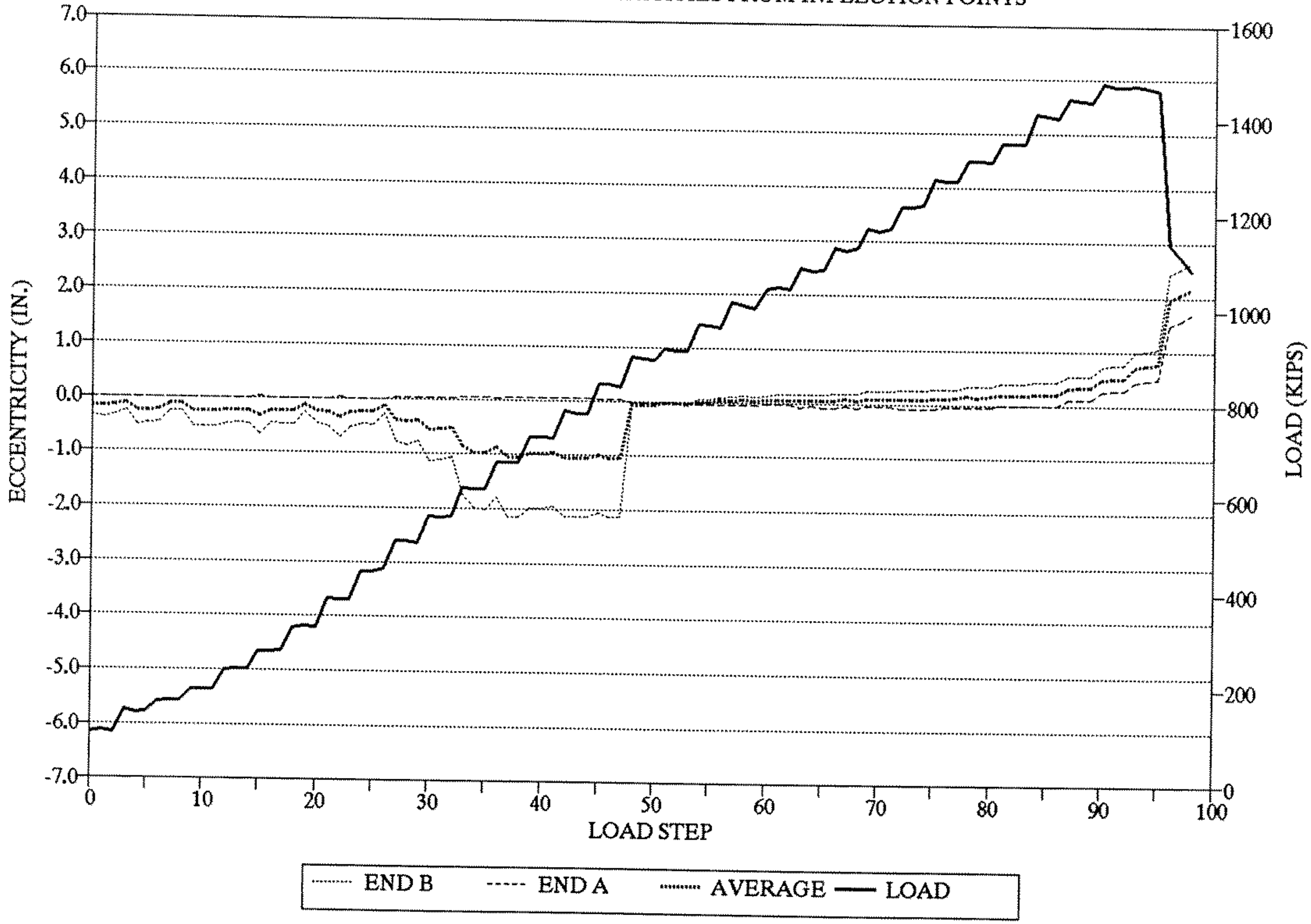


Figure A-87. LOAD AND ECCENTRICITY VS. LOAD STEP
SPECIMEN 09: Y ECCENTRICITIES FROM INFLECTION POINTS

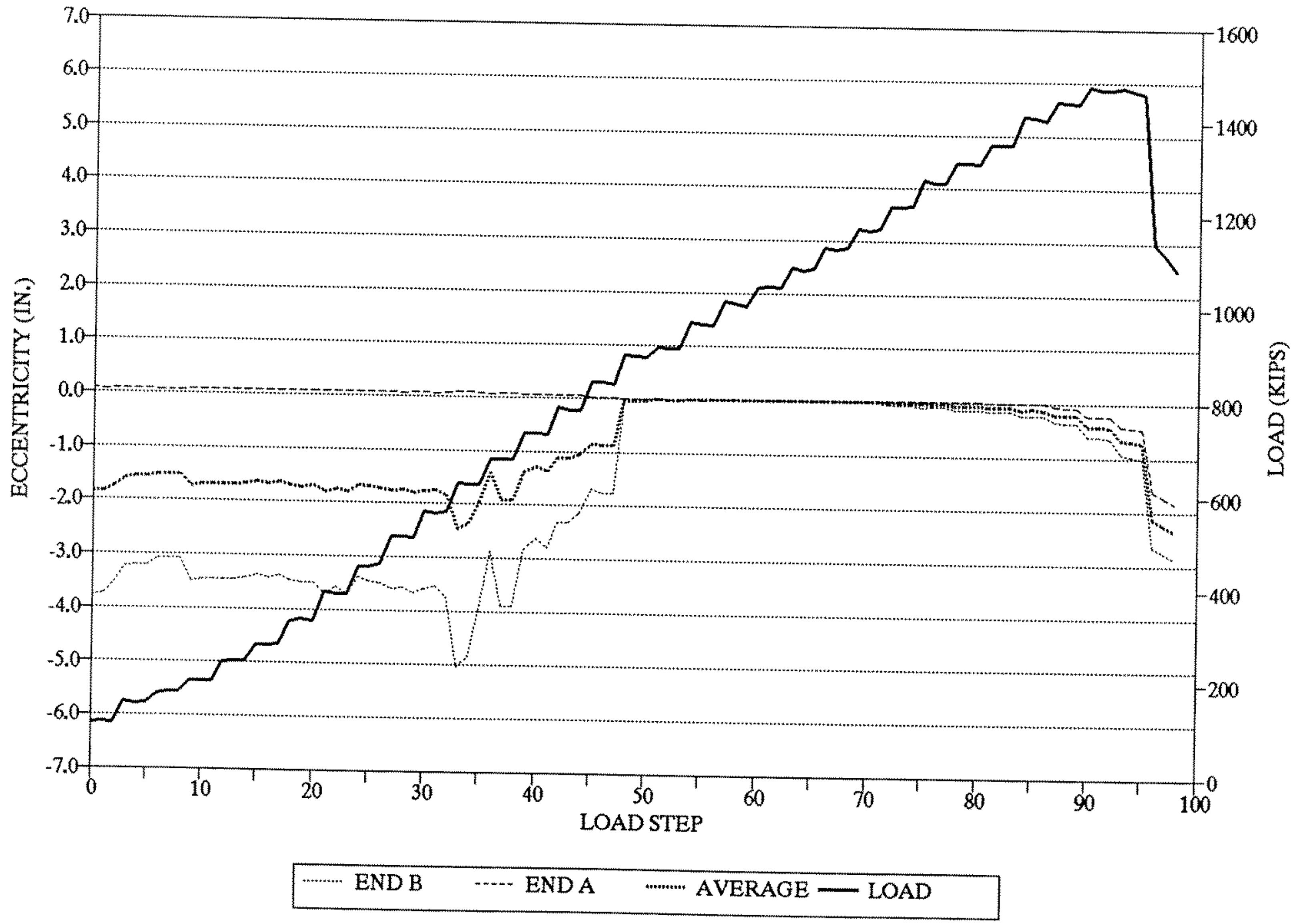


Figure A-88. LOAD AND ECCENTRICITY VS. LOAD STEP

SPECIMEN 09: X ECCENTRICITIES FROM END MOMENTS

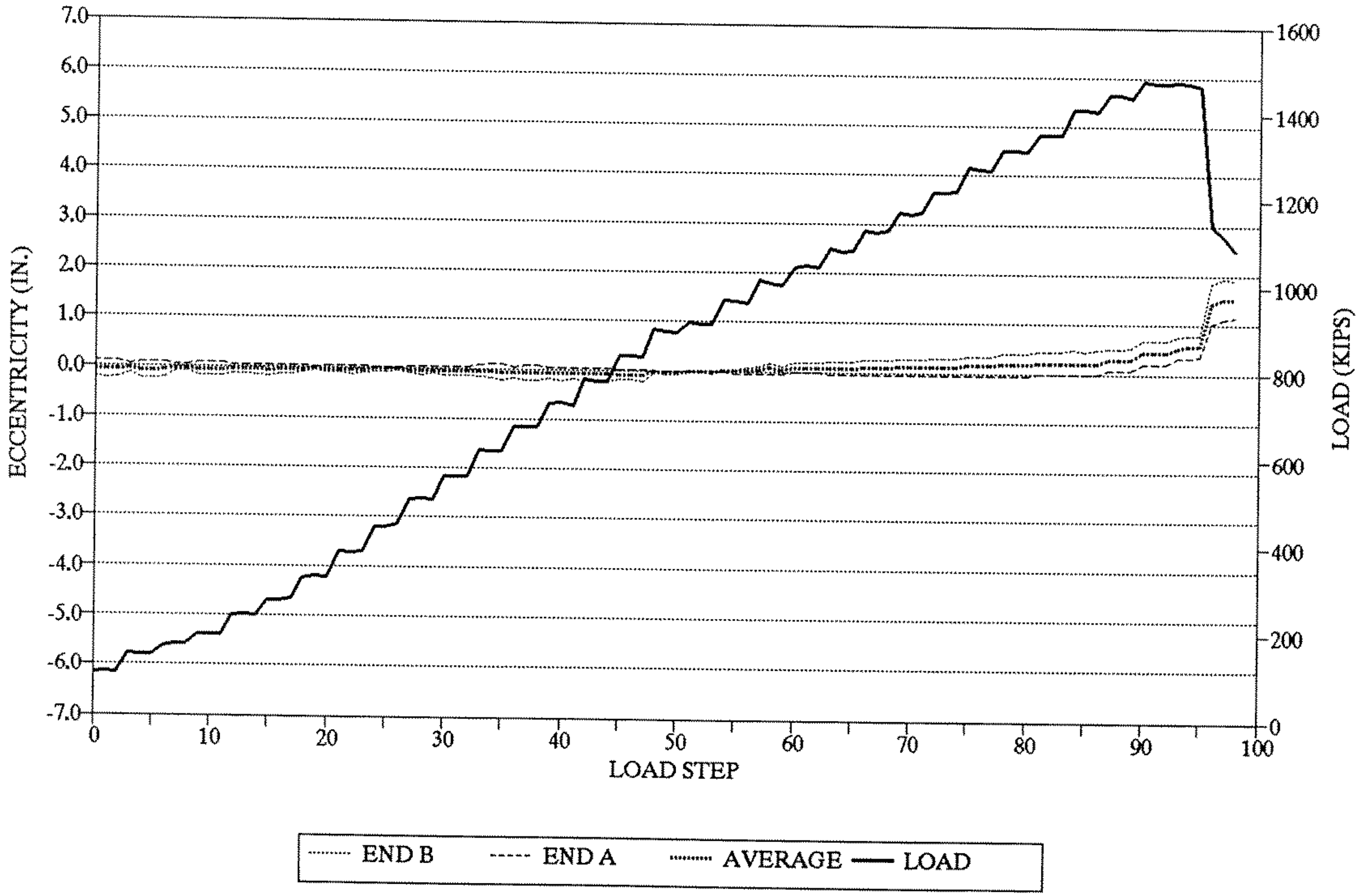


Figure A-89. LOAD AND ECCENTRICITY VS. LOAD STEP

SPECIMEN 09: Y ECCENTRICITIES FROM END MOMENTS

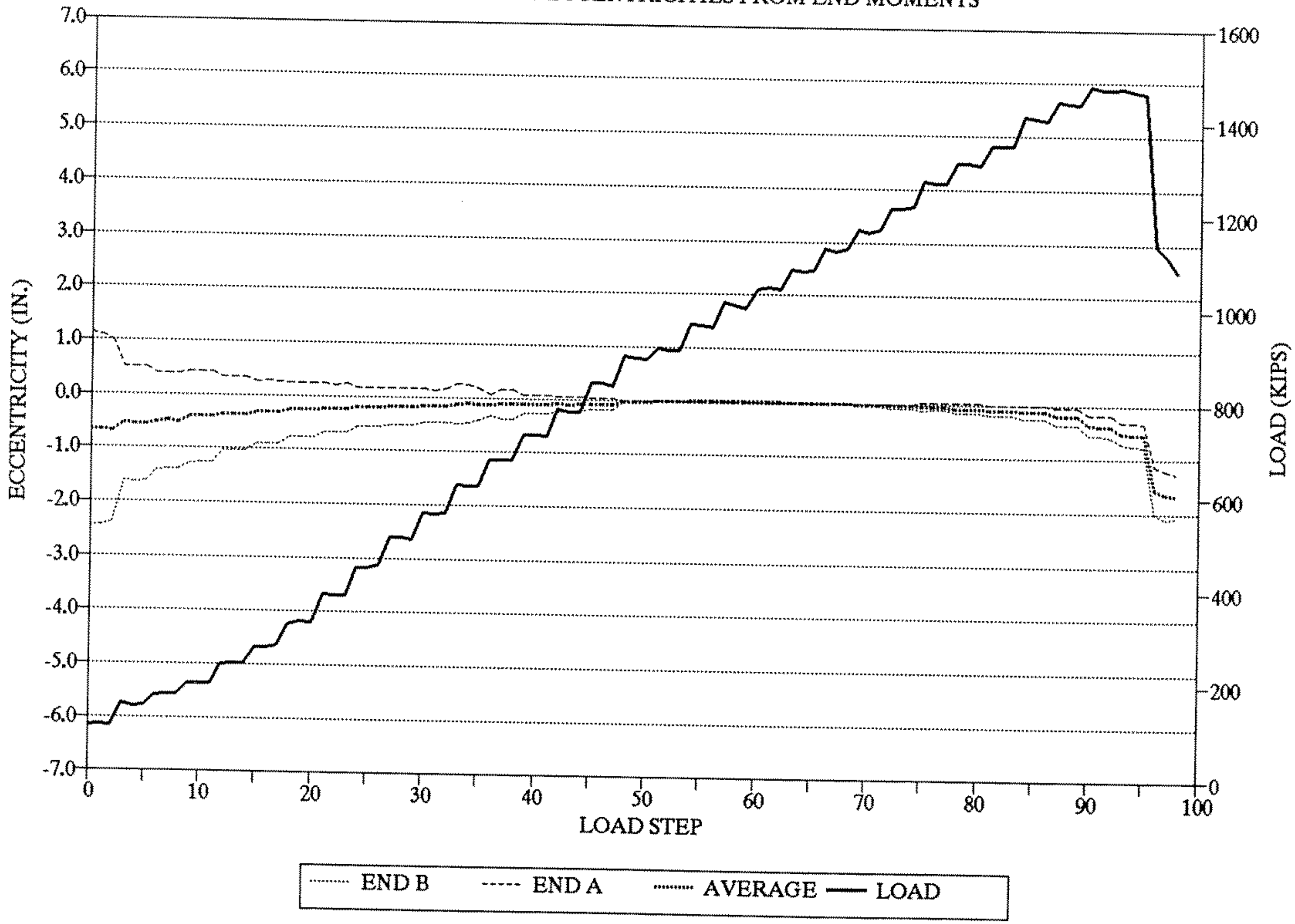


Figure A-90. END ROTATION AND LOAD VS. LOAD STEP
SPECIMEN 09

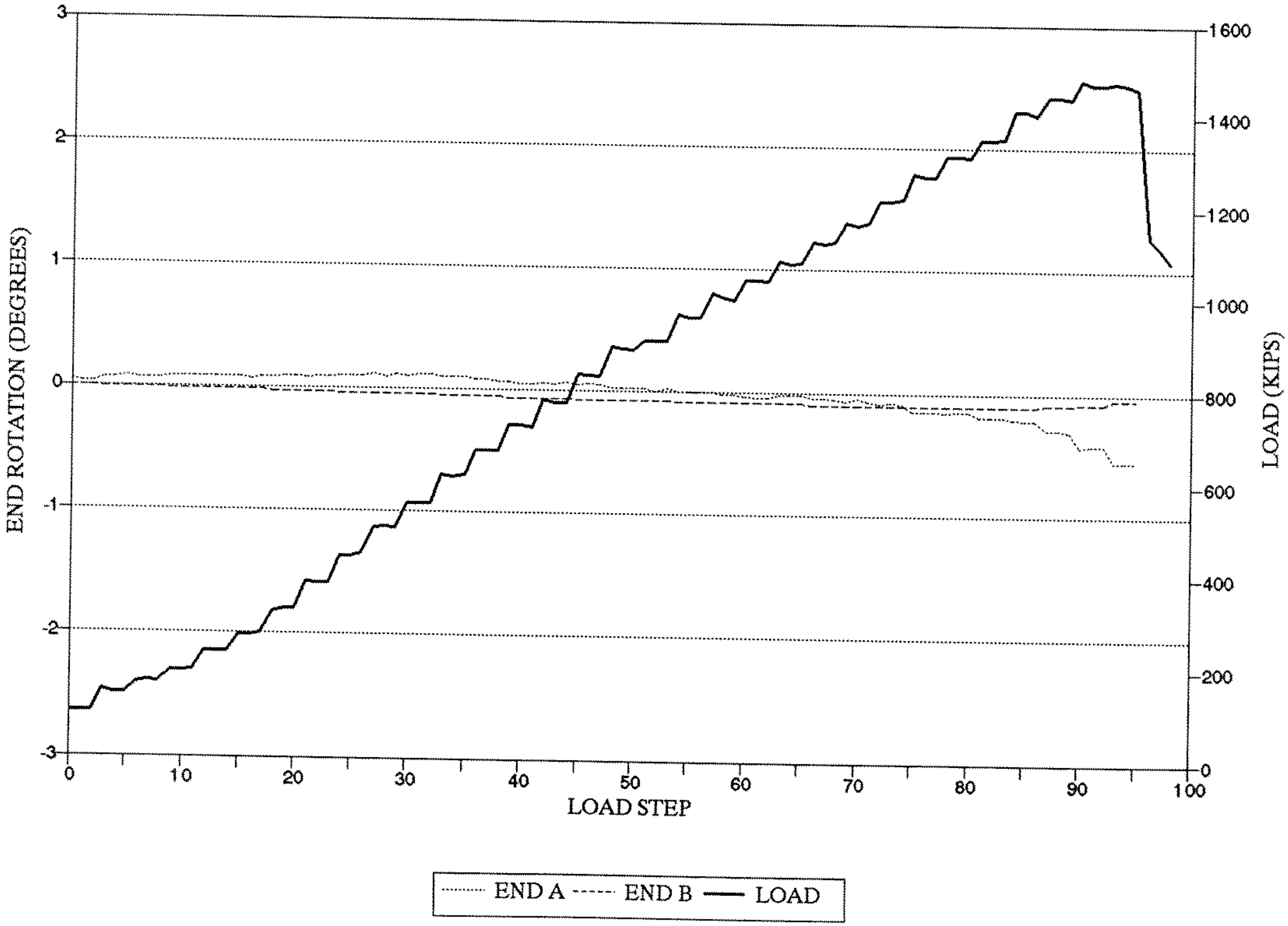


Figure A-91. EFFECTIVE LENGTH VS. LOAD STEP
SPECIMEN 10

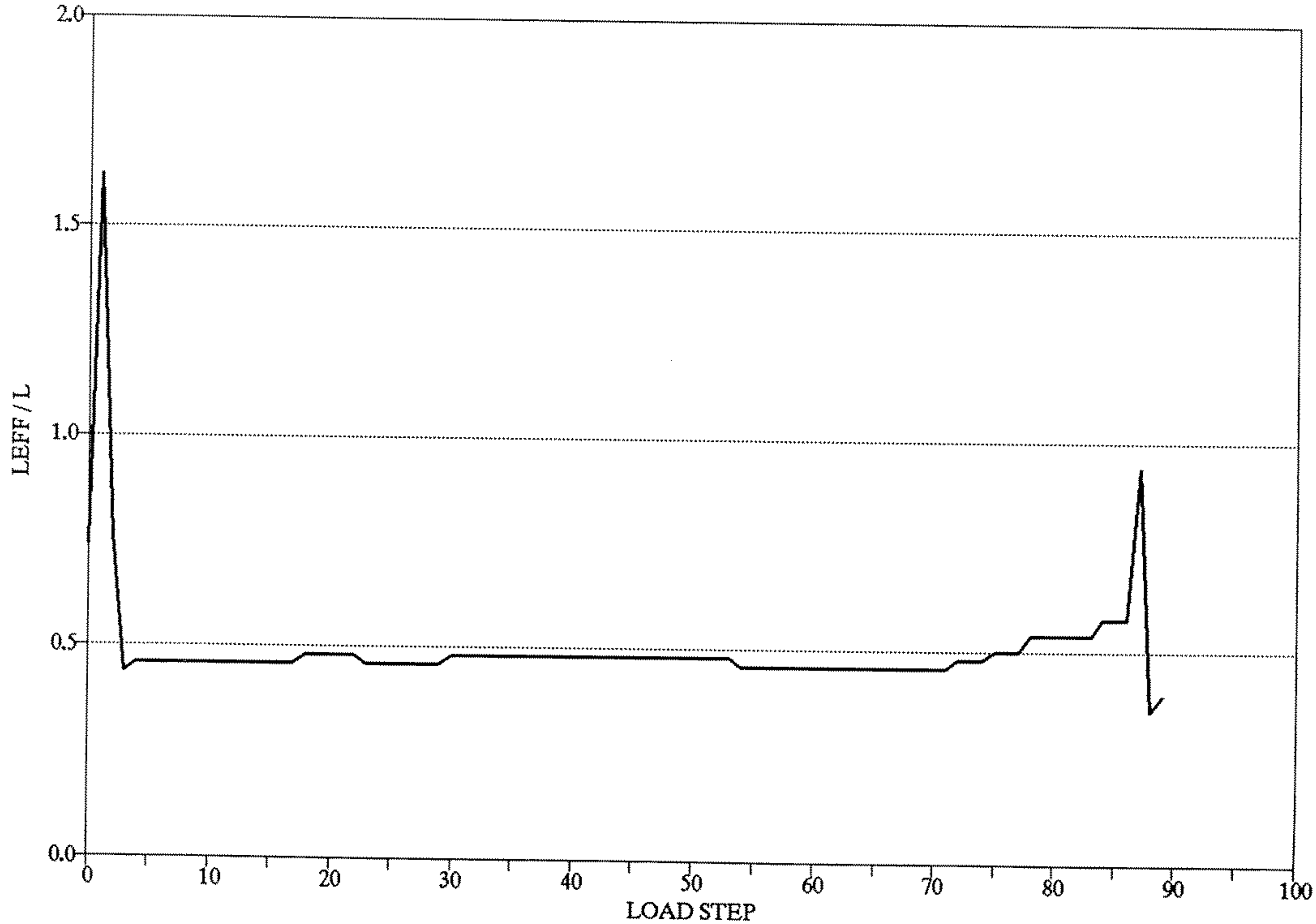


Figure A-92. LOAD AND DEFLECTION VS. LOAD STEP
SPECIMEN 10

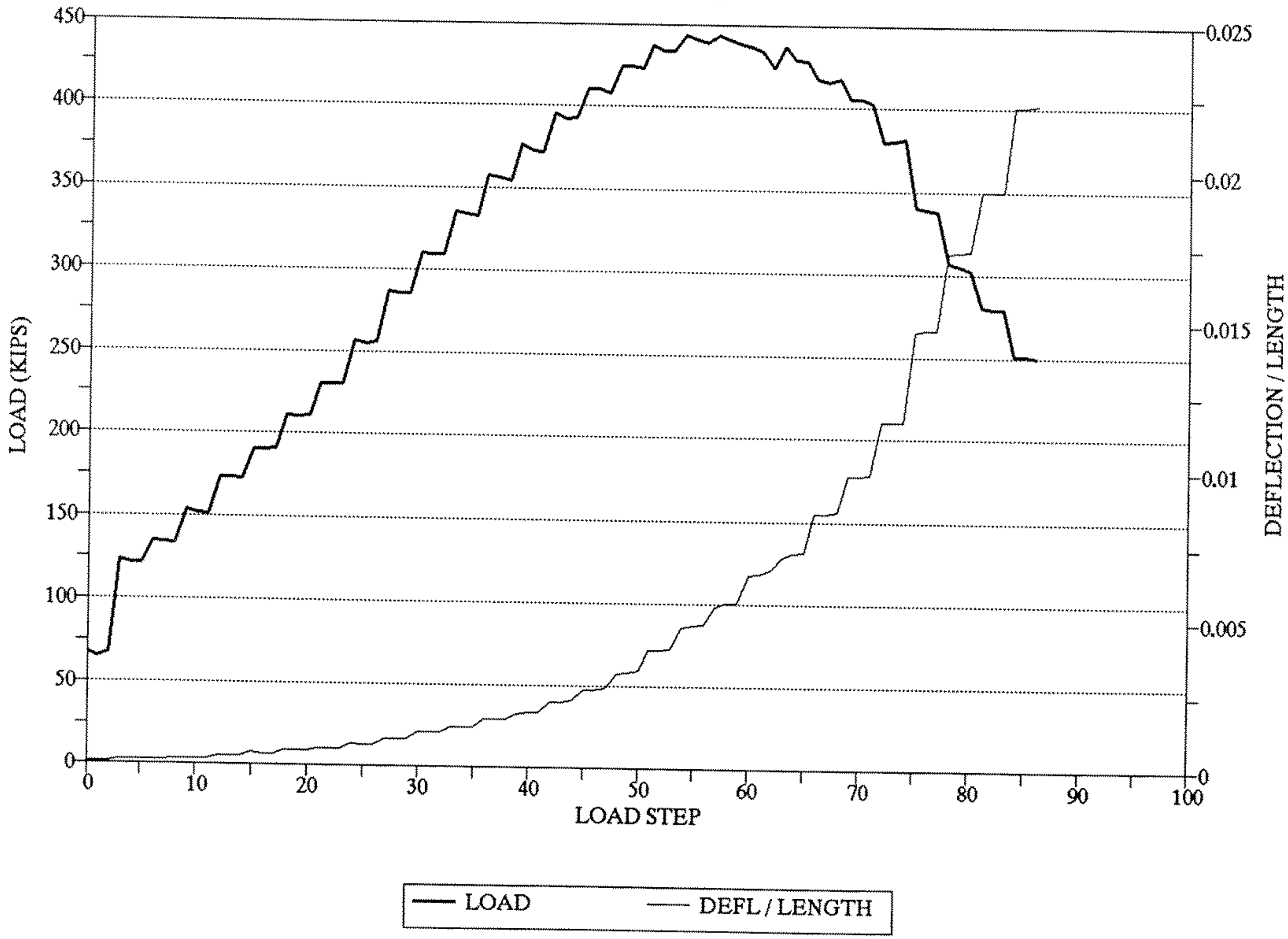


Figure A-93. LOAD VS. CHORD SHORTENING
SPECIMEN 10

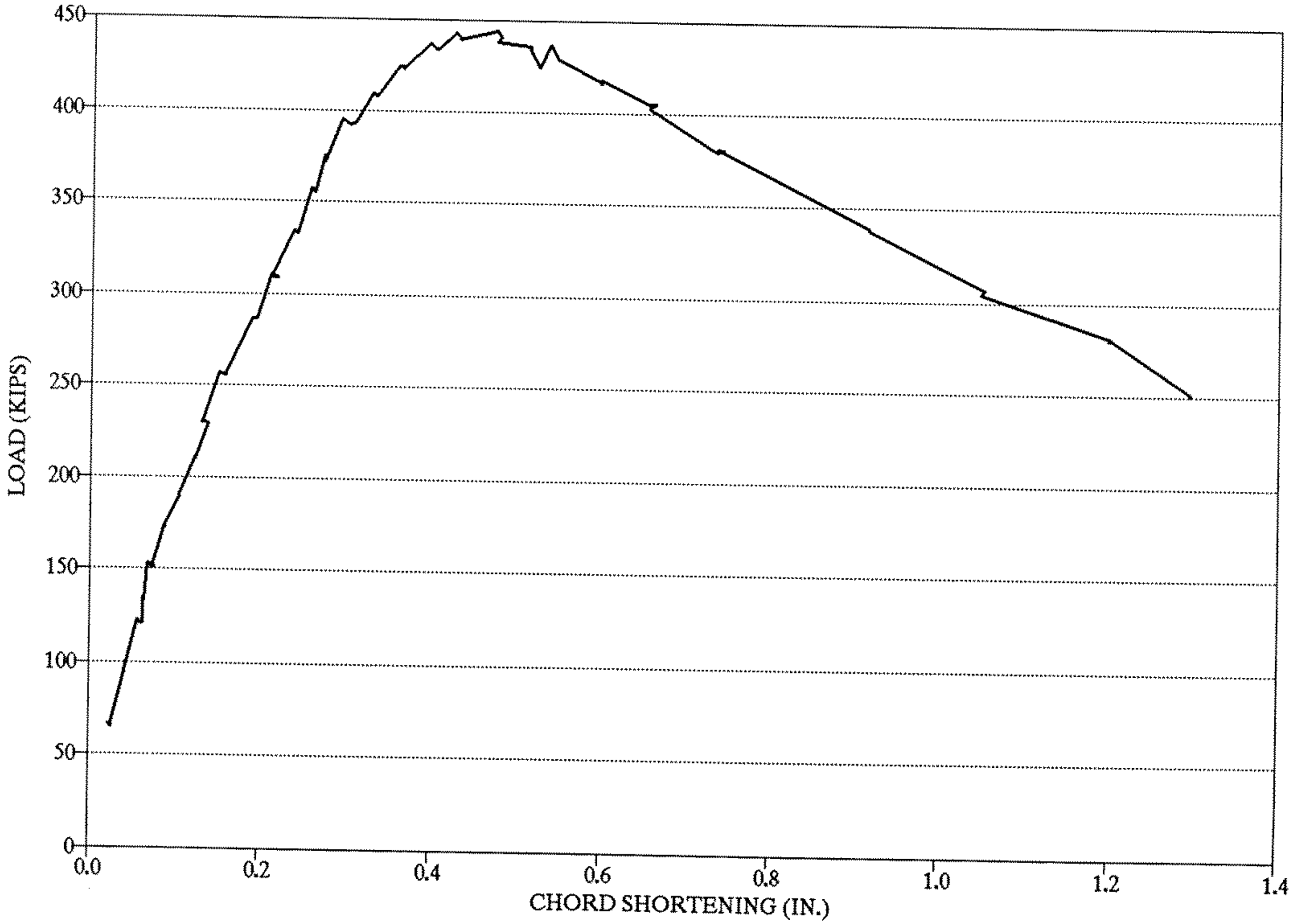


Figure A-94. HORIZONTAL DISPLACEMENTS
SPECIMEN 10

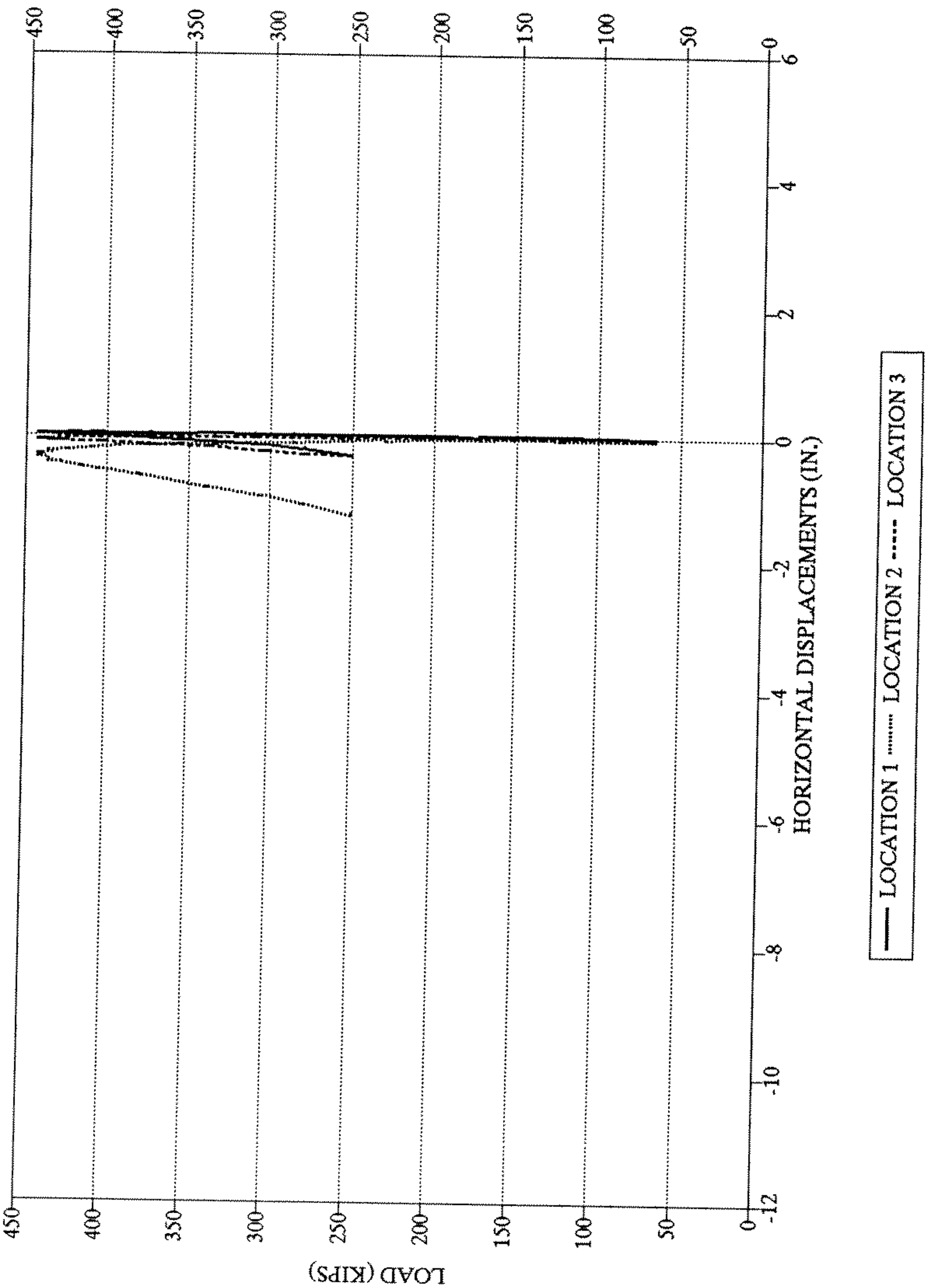


Figure A-95. VERTICAL DISPLACEMENTS
SPECIMEN 10

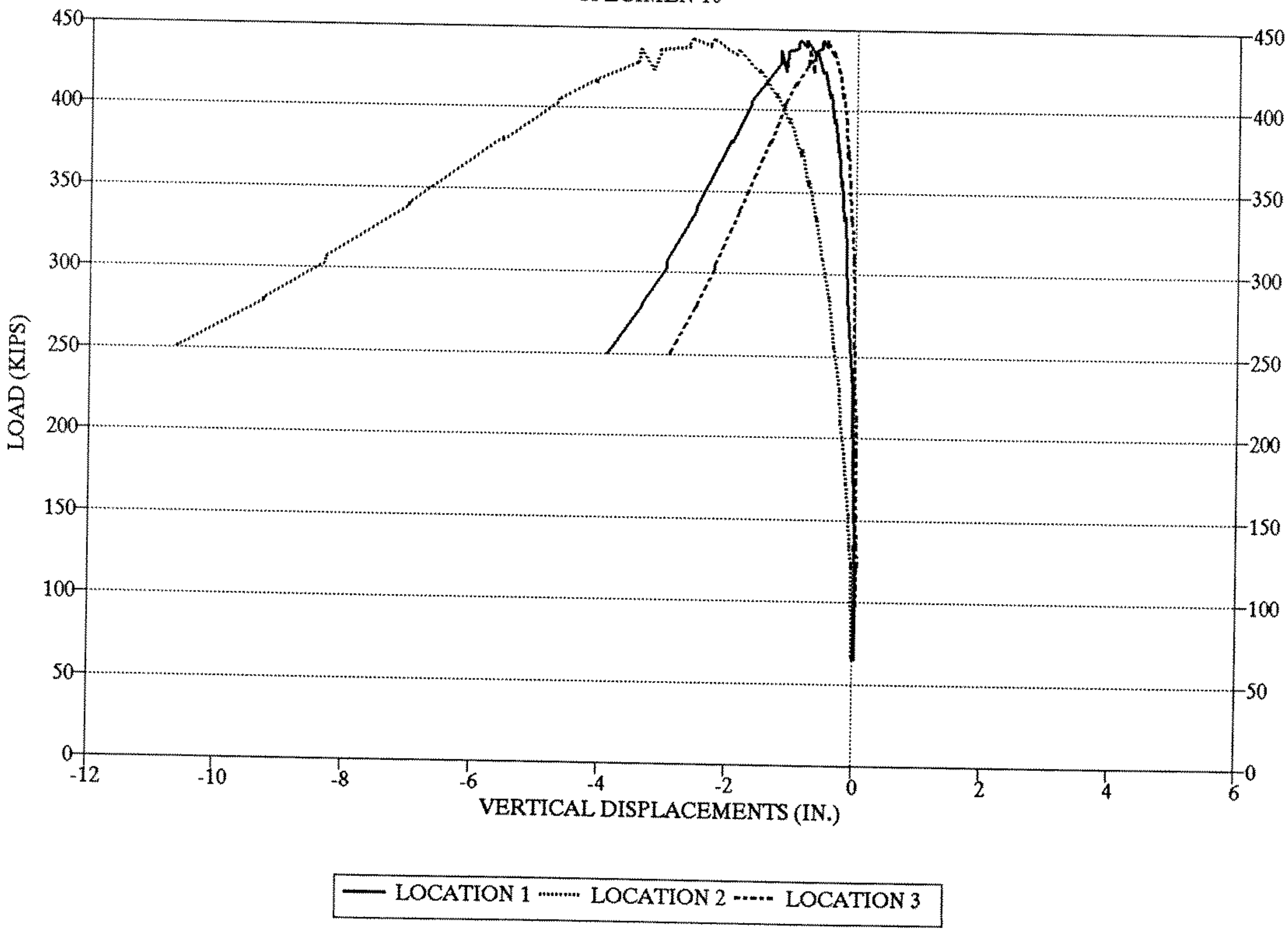


Figure A-96. LOAD AND ECCENTRICITY VS. LOAD STEP

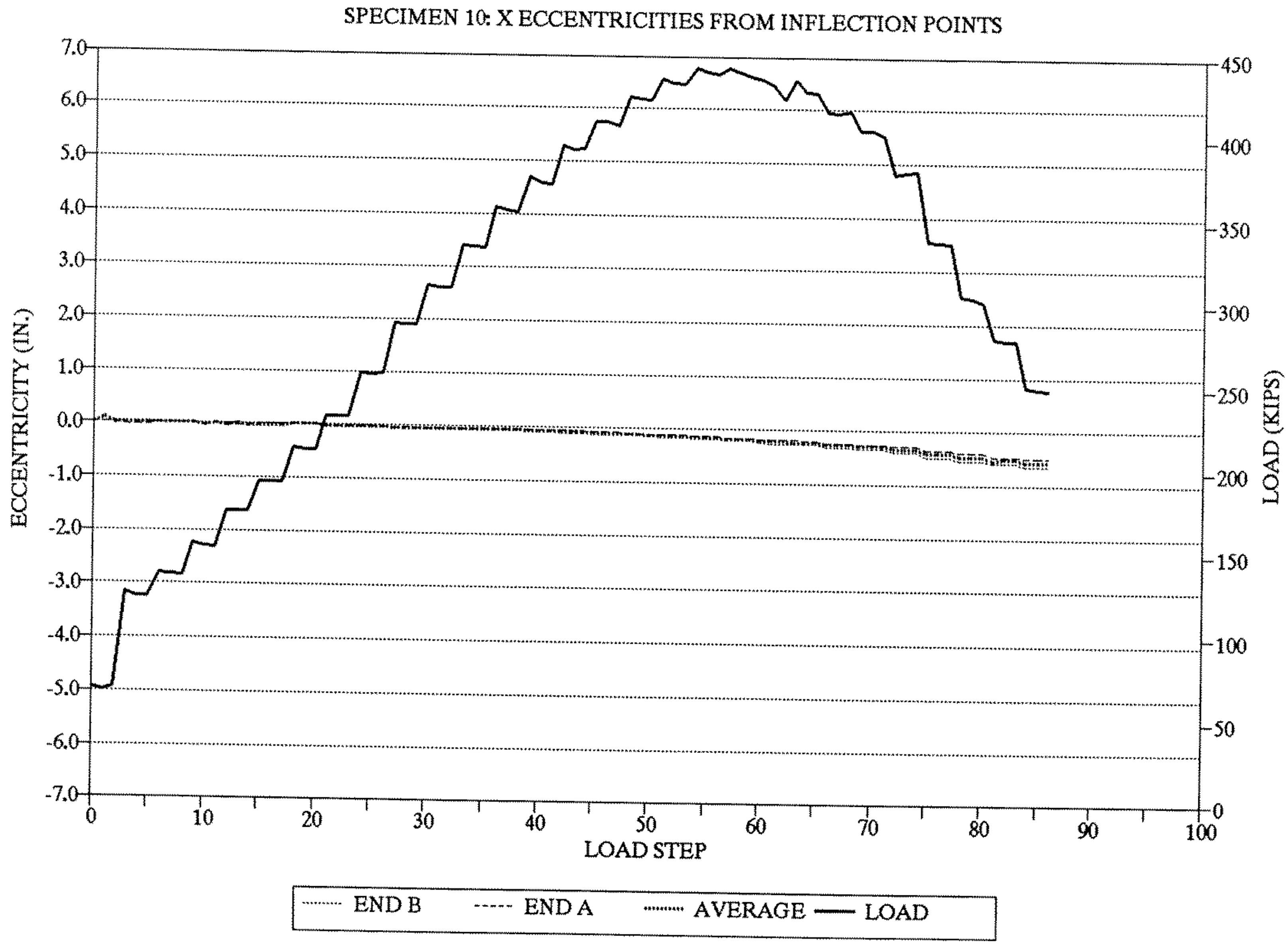


Figure A-97. LOAD AND ECCENTRICITY VS. LOAD STEP

SPECIMEN 10: Y ECCENTRICITIES FROM INFLECTION POINTS

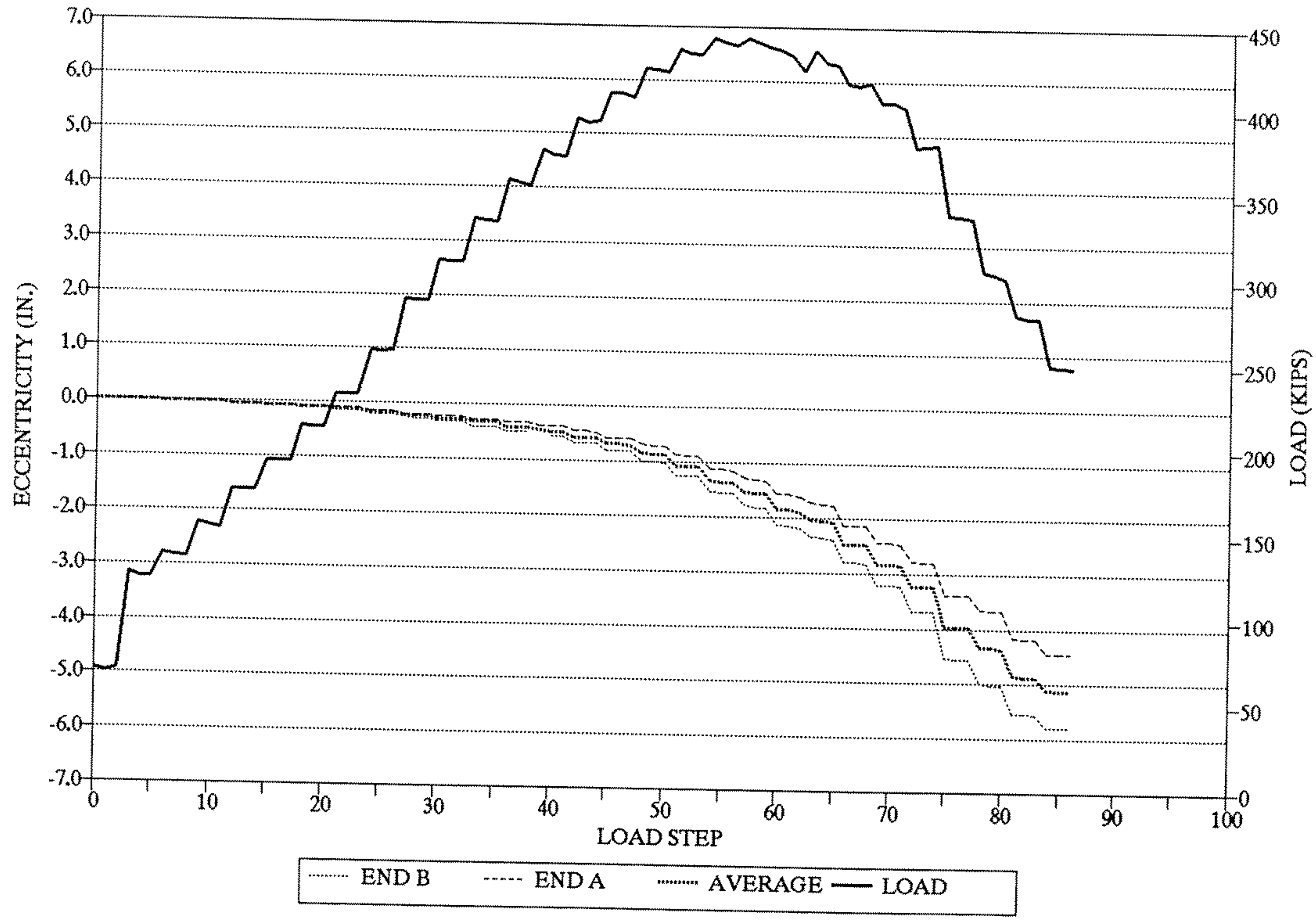


Figure A-98. LOAD AND ECCENTRICITY VS. LOAD STEP

SPECIMEN 10: X ECCENTRICITIES FROM END MOMENTS

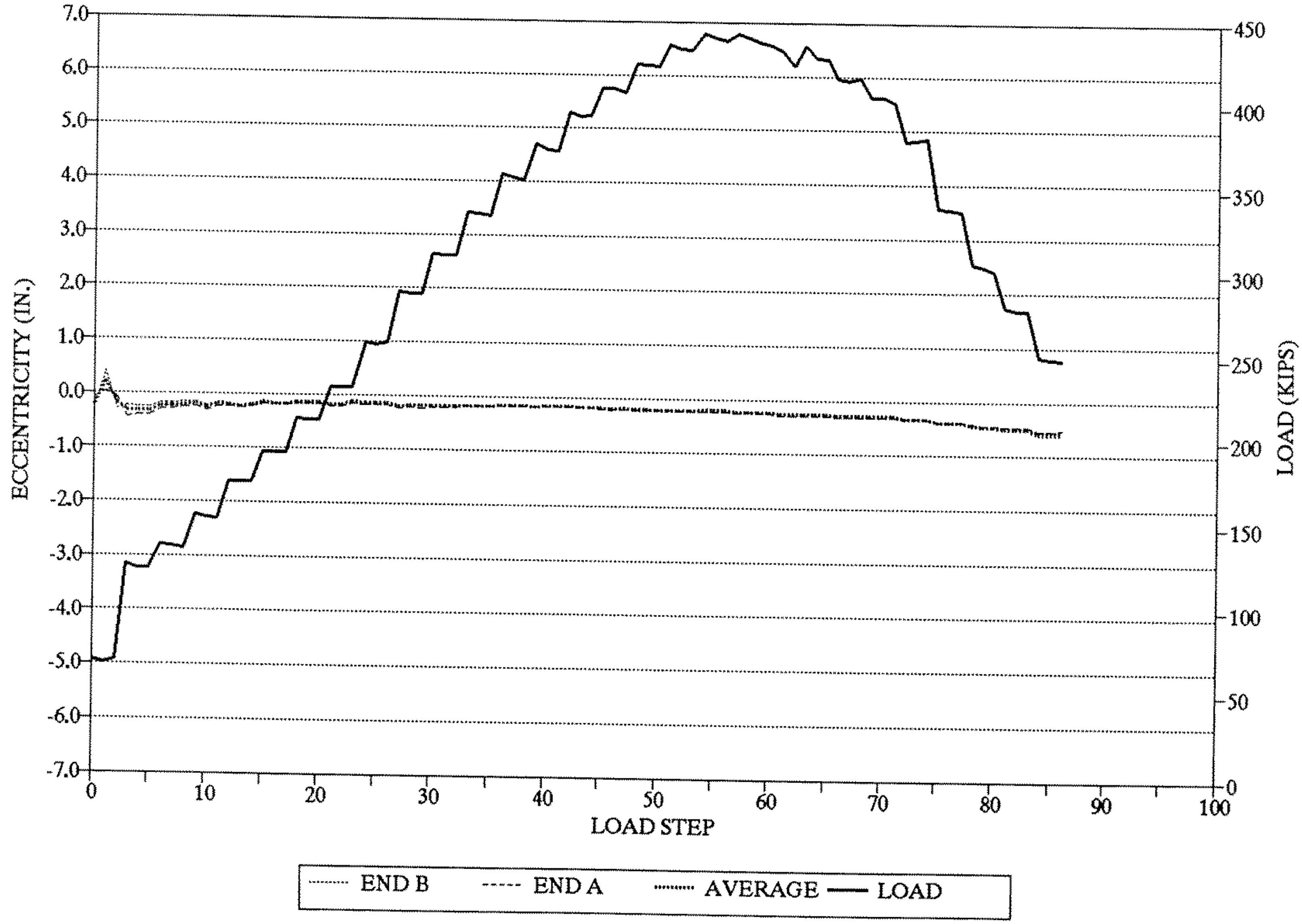


Figure A-99. LOAD AND ECCENTRICITY VS. LOAD STEP
SPECIMEN 10:Y-AXIS BY END MOMENTS

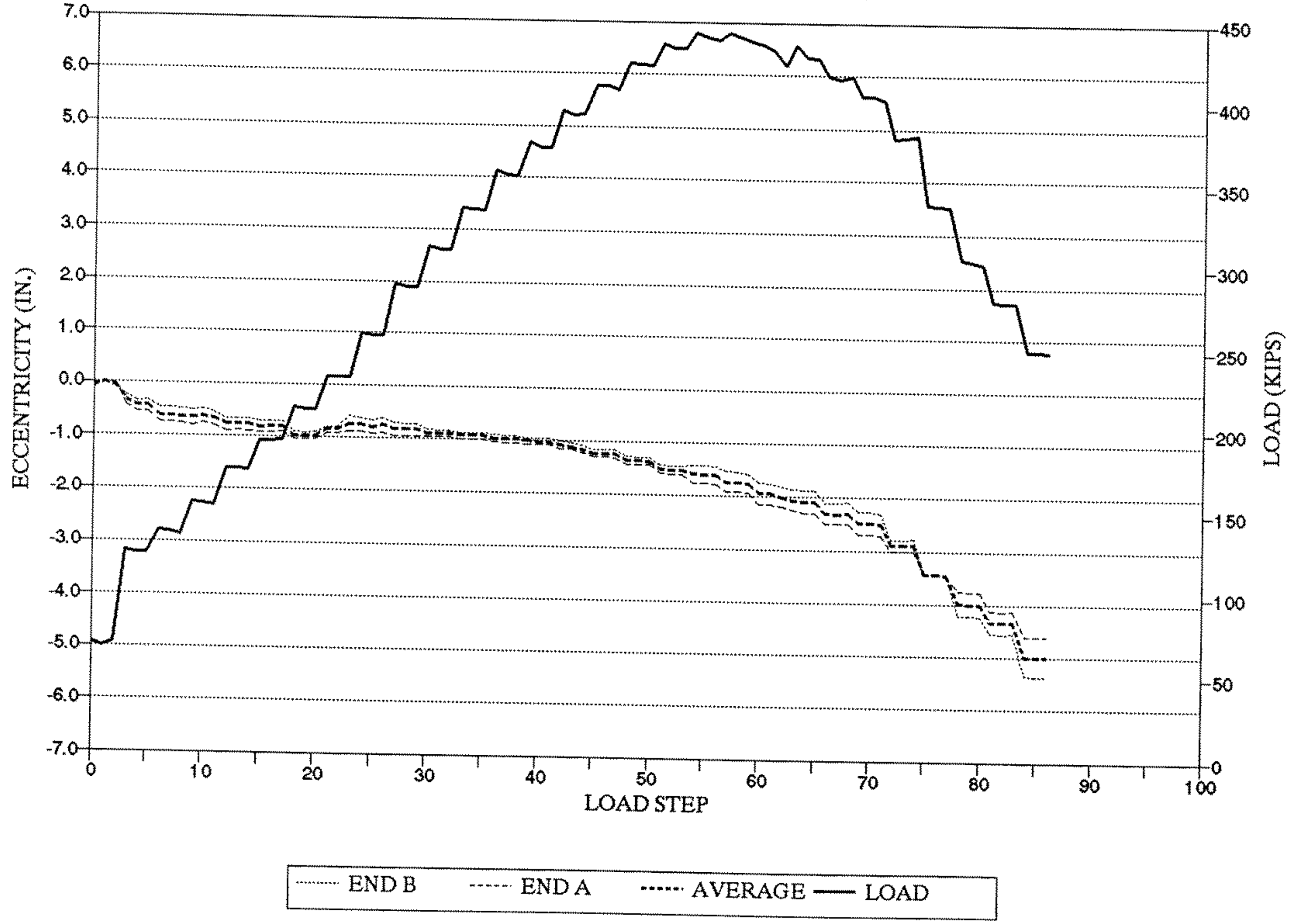


Figure A-100. END ROTATION AND LOAD VS. LOAD STEP
SPECIMEN 10

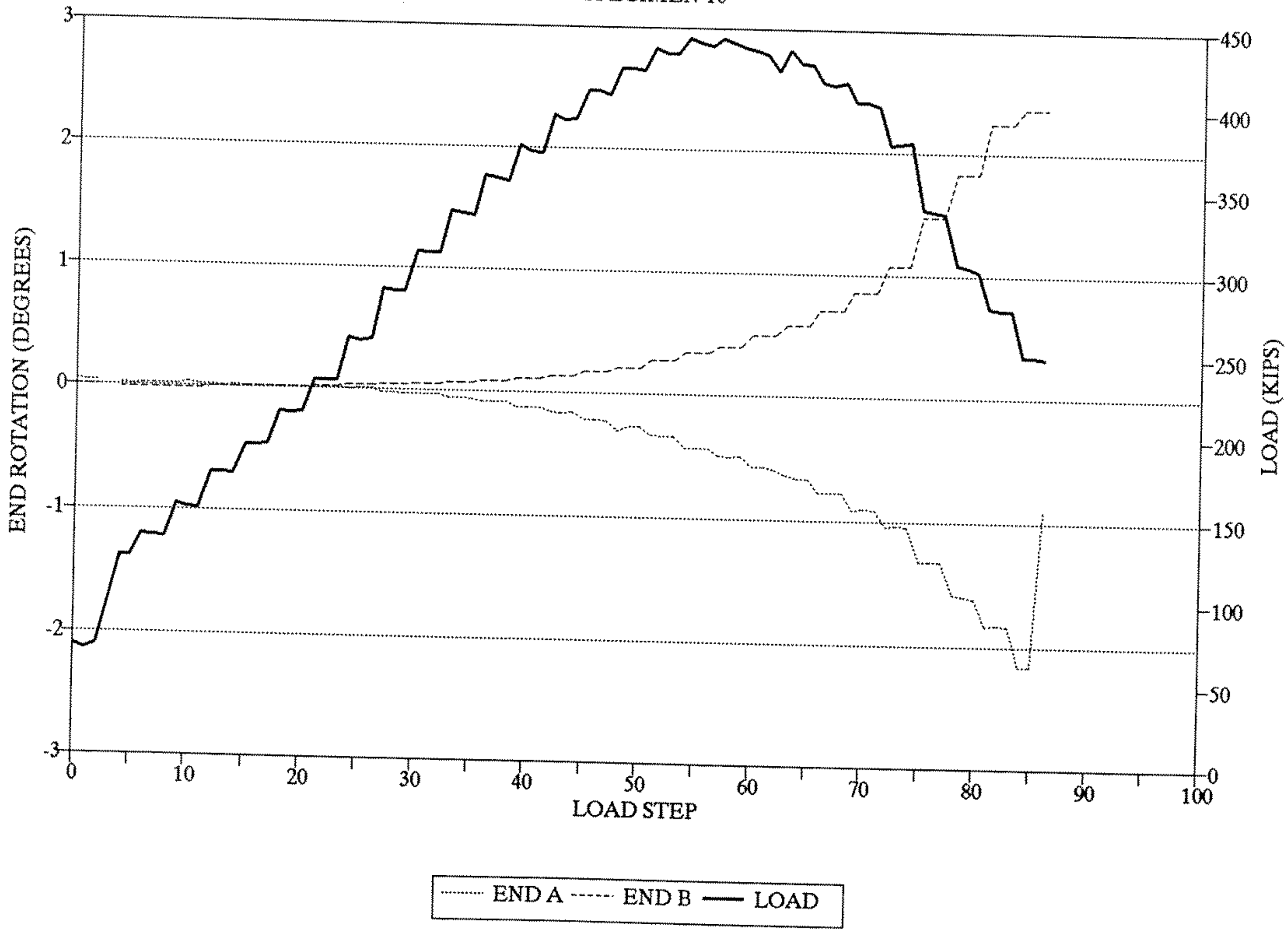


Figure A-101. EFFECTIVE LENGTH VS. LOAD STEP
SPECIMEN 11

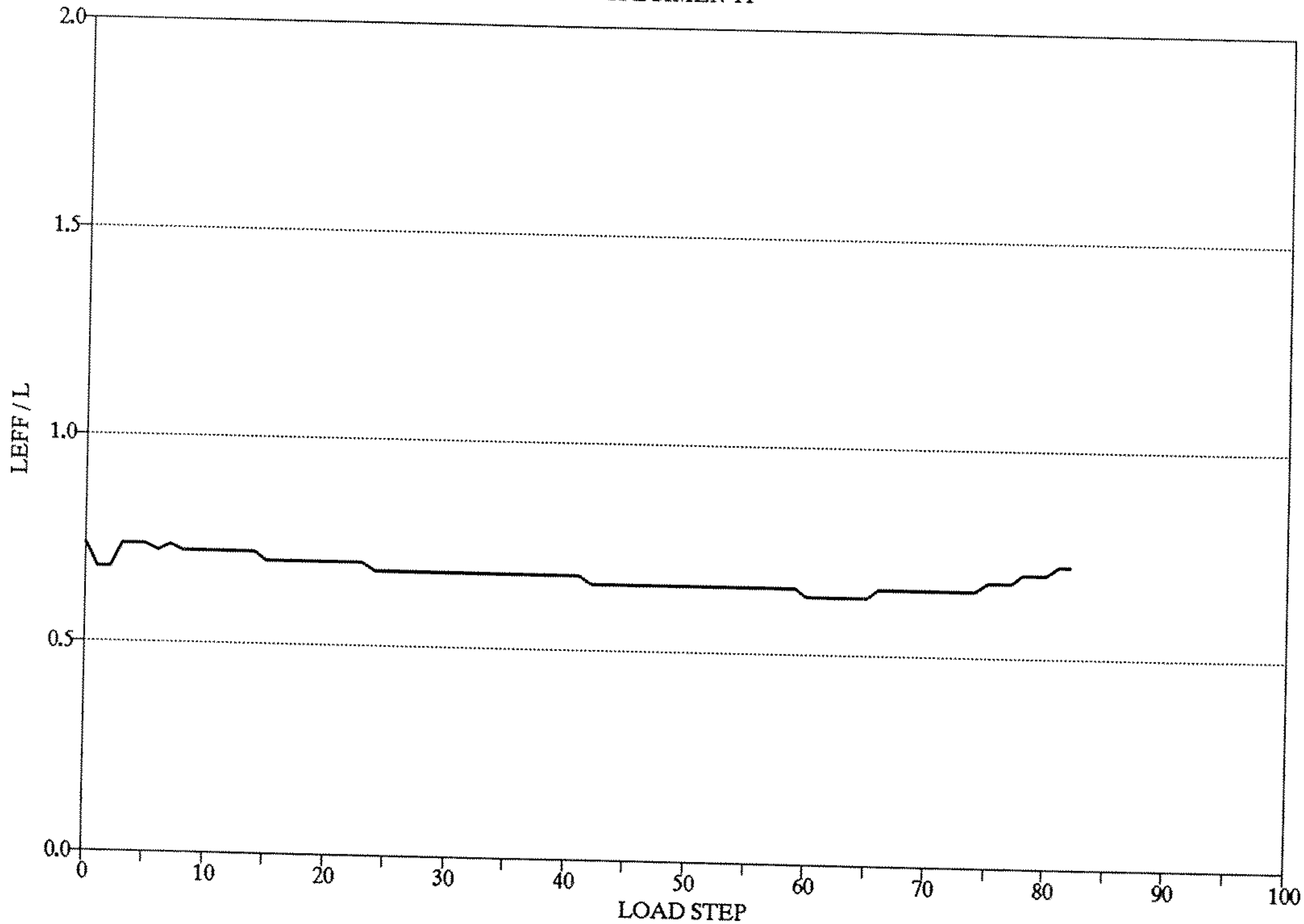


Figure A-102. LOAD AND DEFLECTION VS. LOAD STEP
SPECIMEN 11

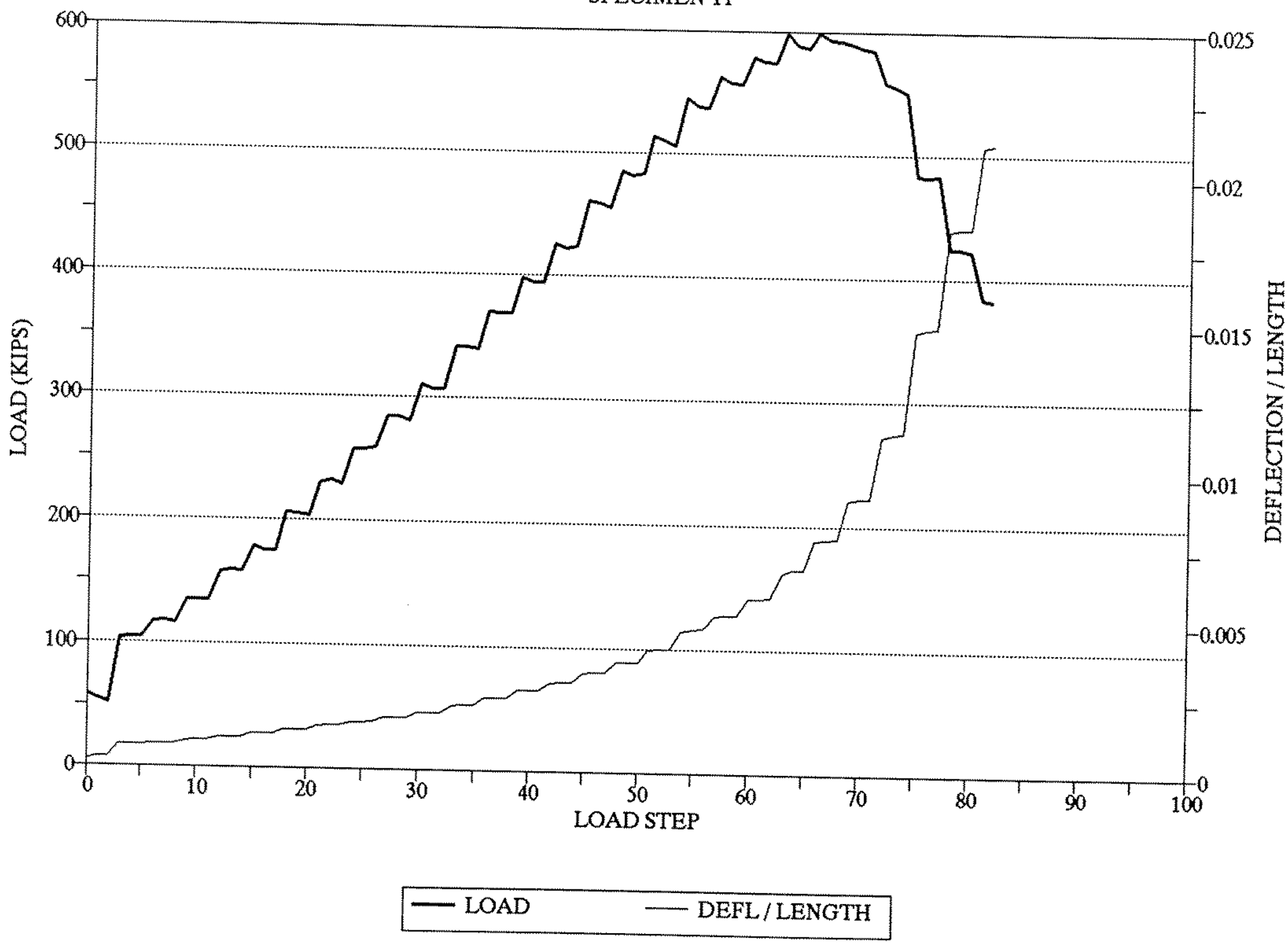


Figure A-103. LOAD VS. CHORD SHORTENING
SPECIMEN 11

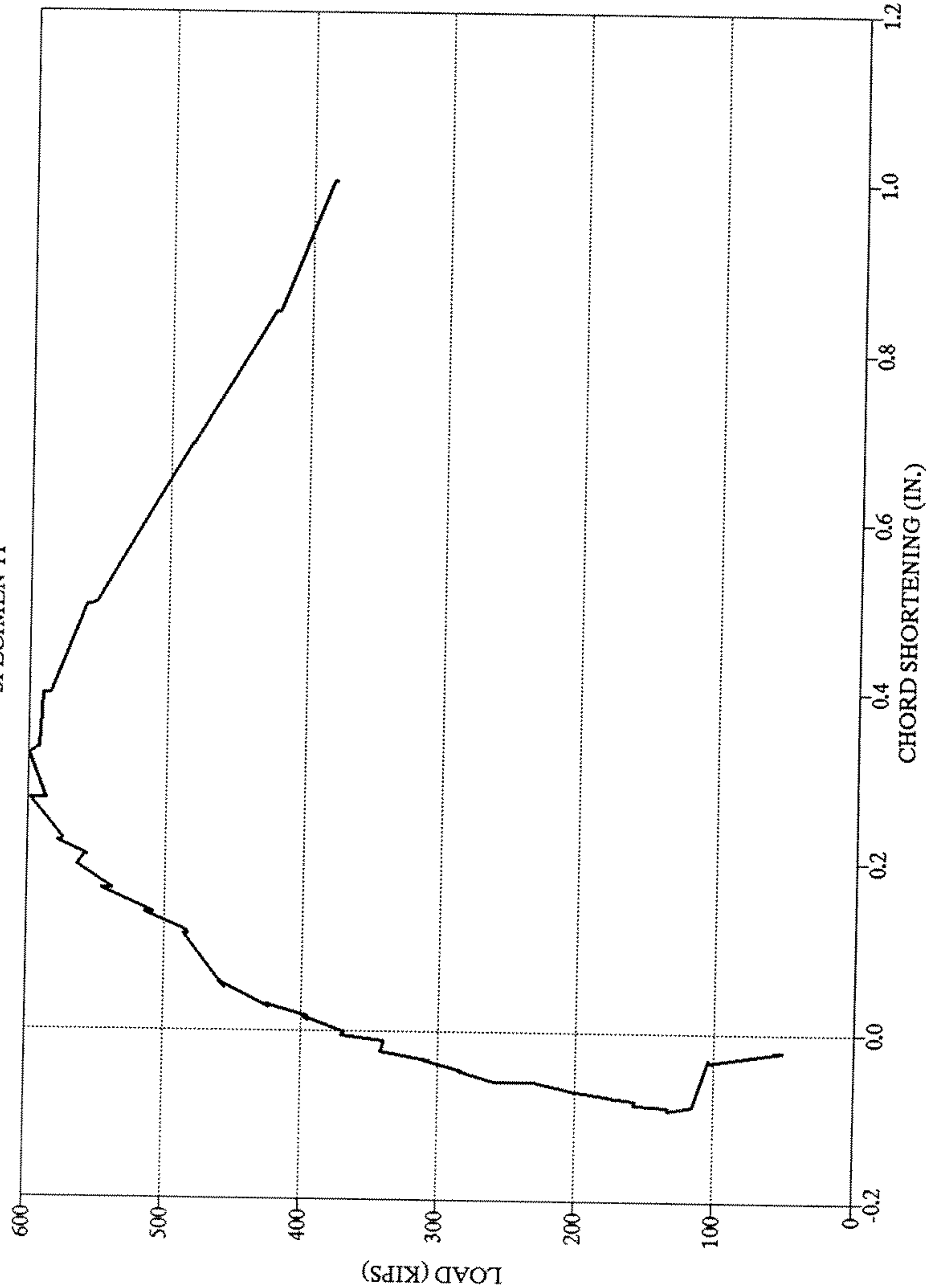


Figure A-104. HORIZONTAL DISPLACEMENTS
SPECIMEN 11

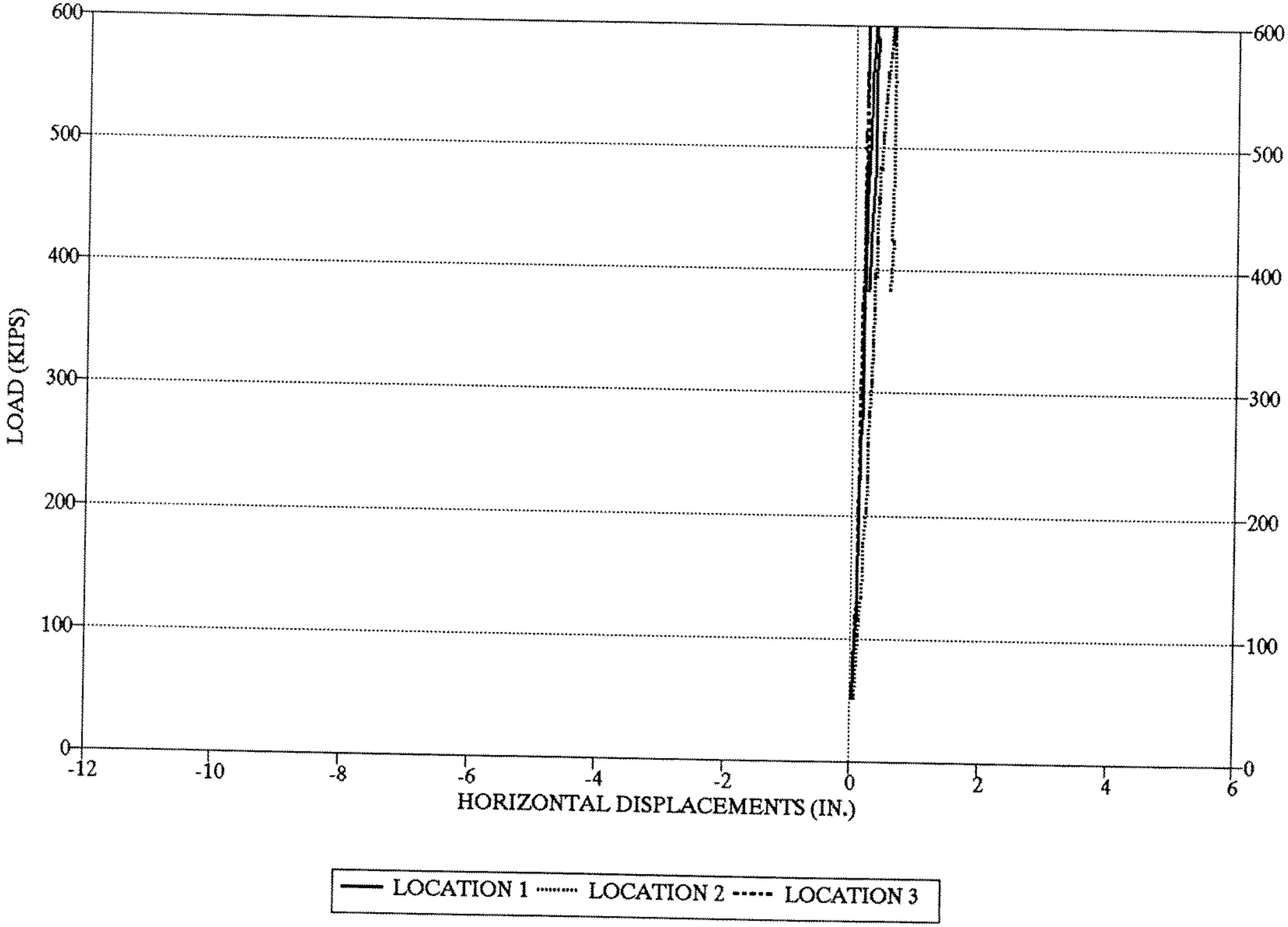


Figure A-105. VERTICAL DISPLACEMENTS
SPECIMEN 11

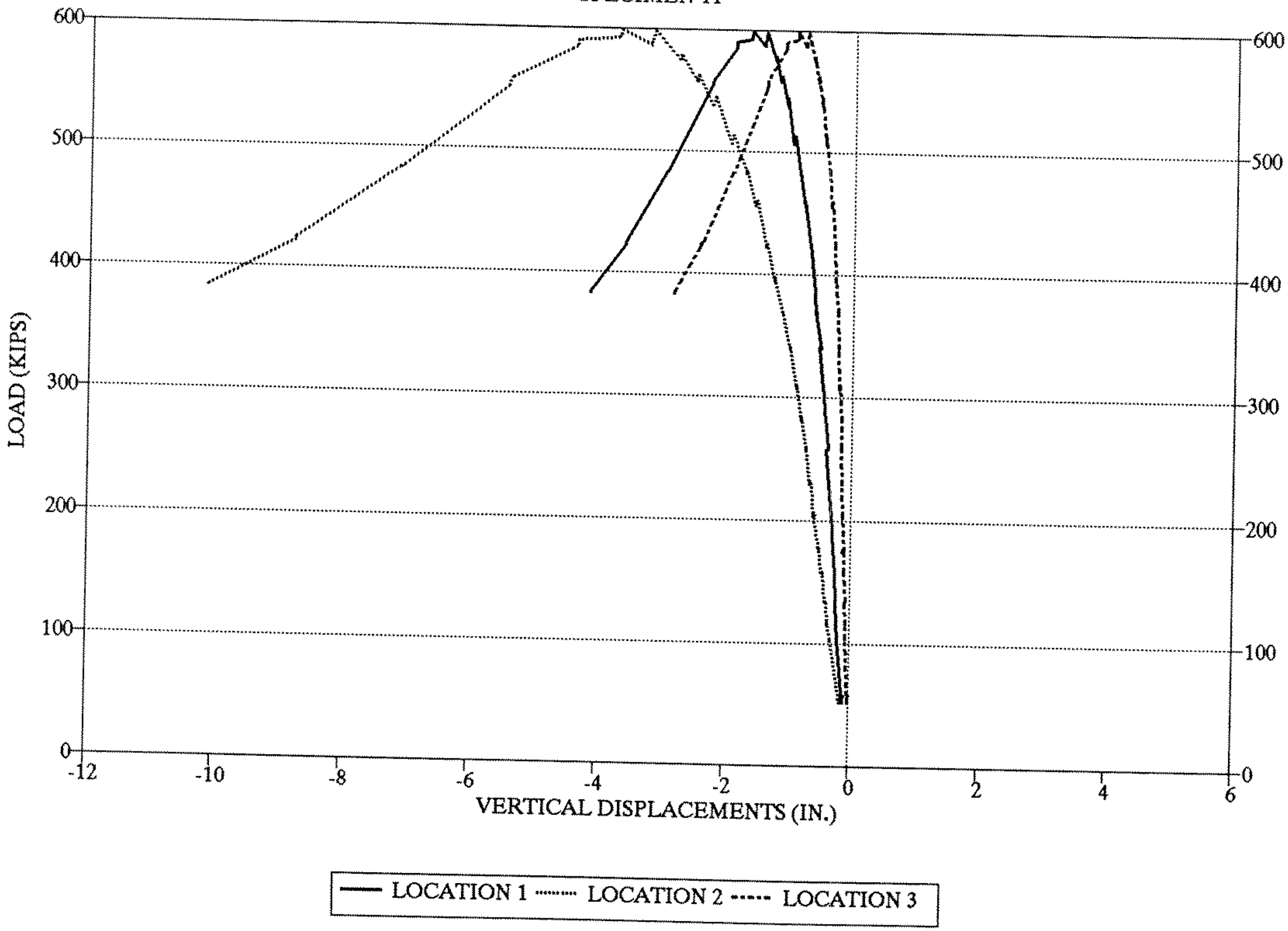


Figure A-106. LOAD AND ECCENTRICITY VS. LOAD STEP

SPECIMEN 11: X ECCENTRICITIES FROM END MOMENTS

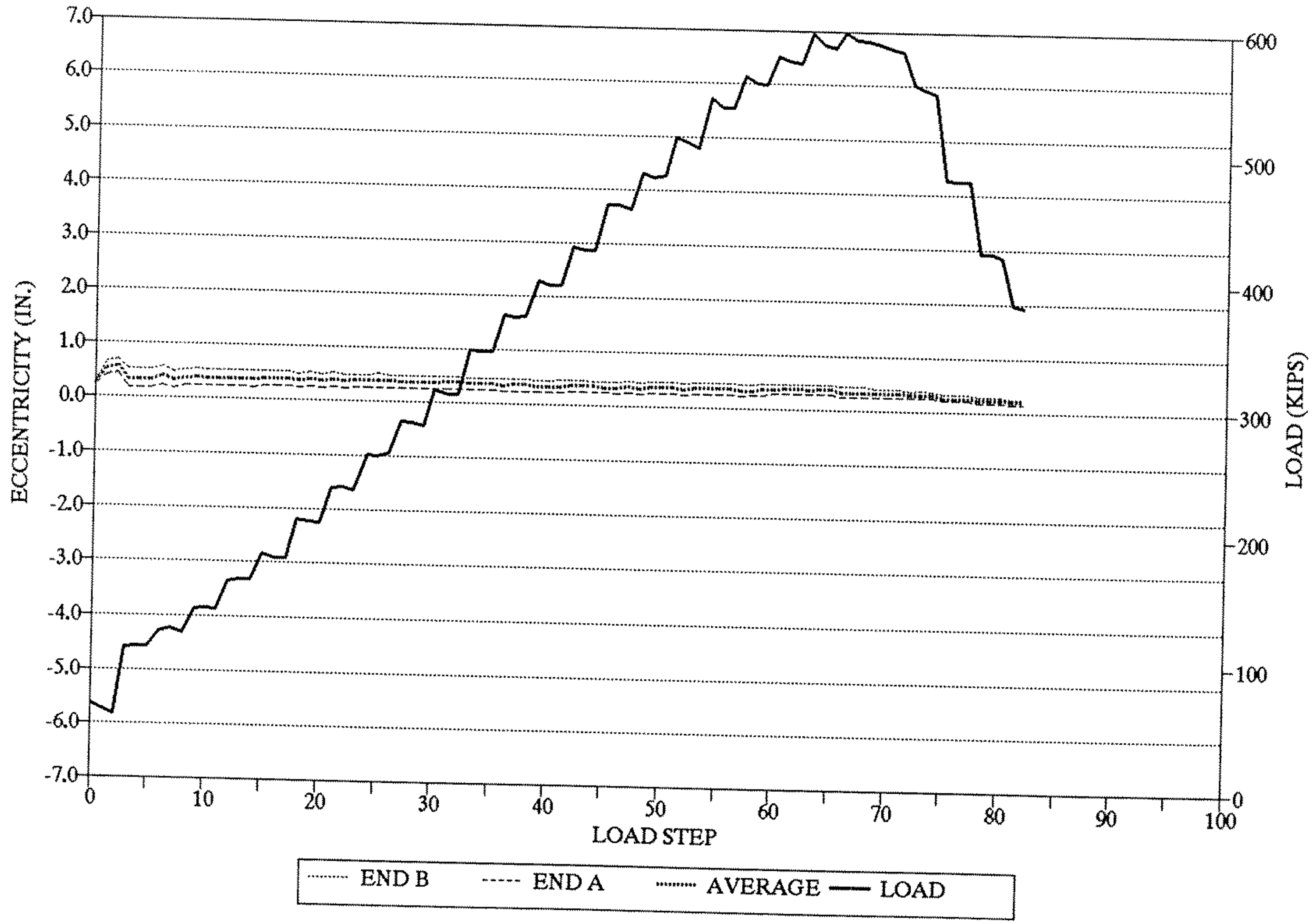


Figure A-107. LOAD AND ECCENTRICITY VS. LOAD STEP

SPECIMEN 11: Y ECCENTRICITIES FROM END MOMENTS

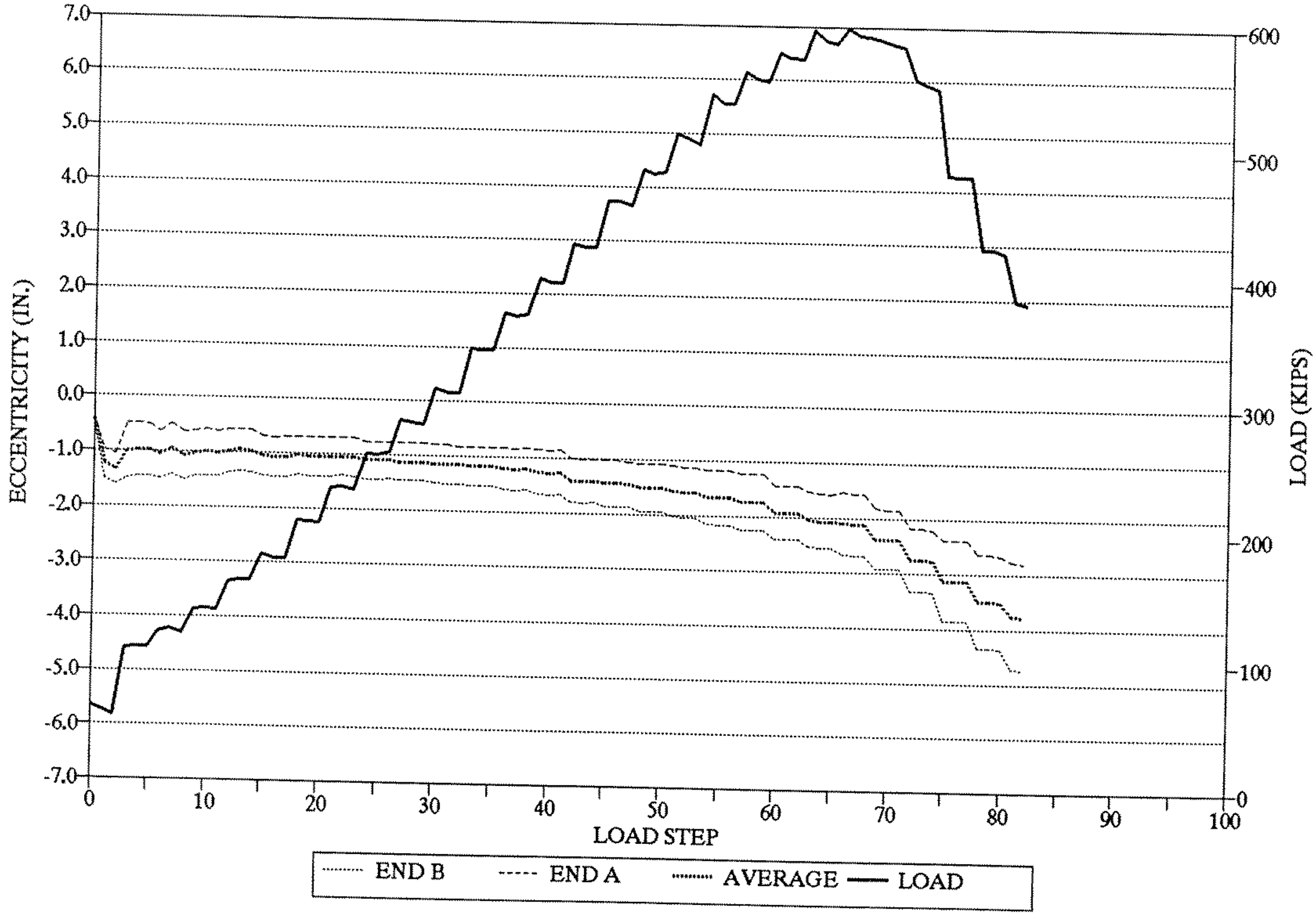


Figure A-108. LOAD AND ECCENTRICITY VS. LOAD STEP

SPECIMEN 11: X ECCENTRICITIES FROM INFLECTION POINTS

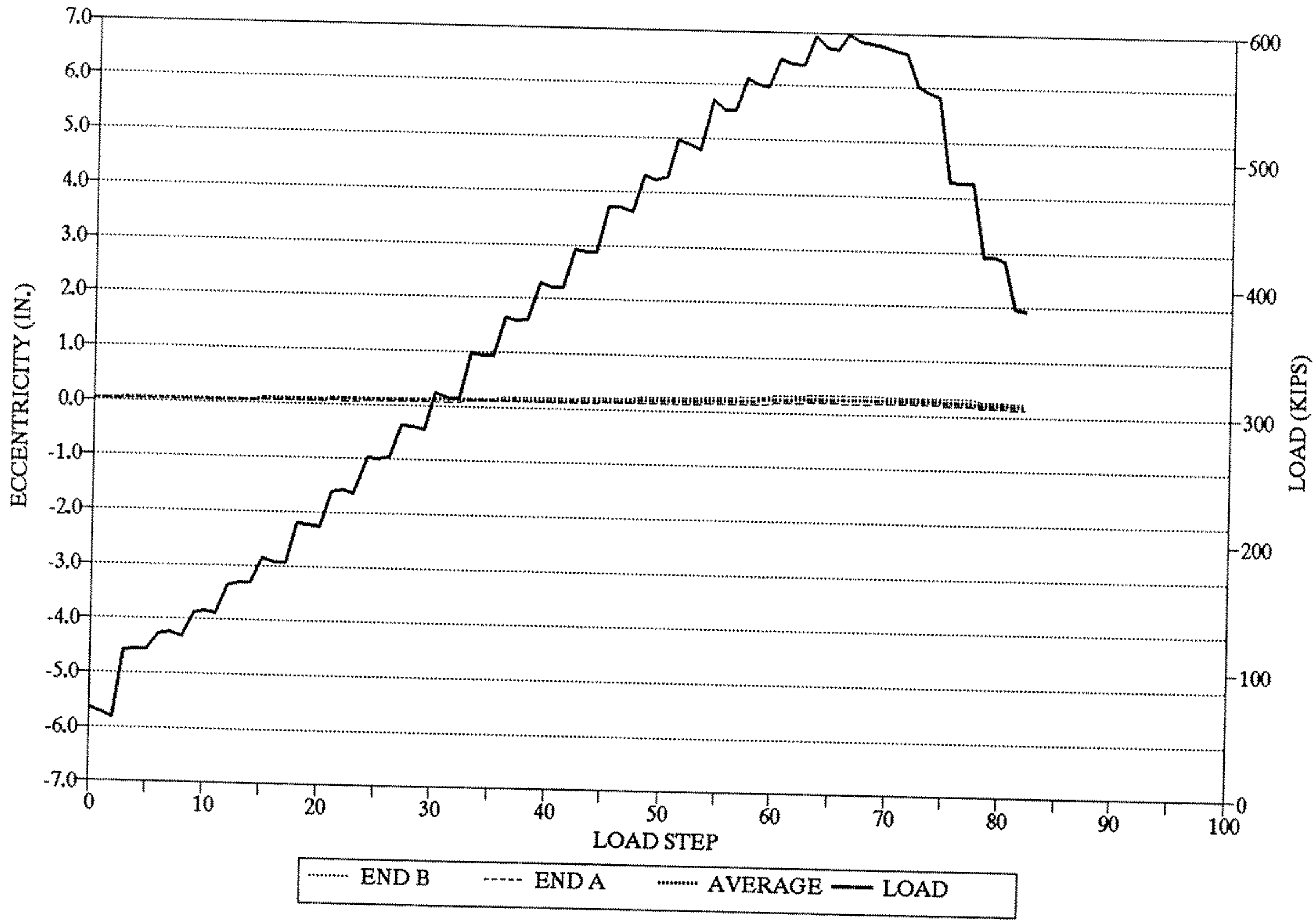


Figure A-109. LOAD AND ECCENTRICITY VS. LOAD STEP

SPECIMEN 11: Y ECCENTRICITIES FROM INFLECTION POINTS

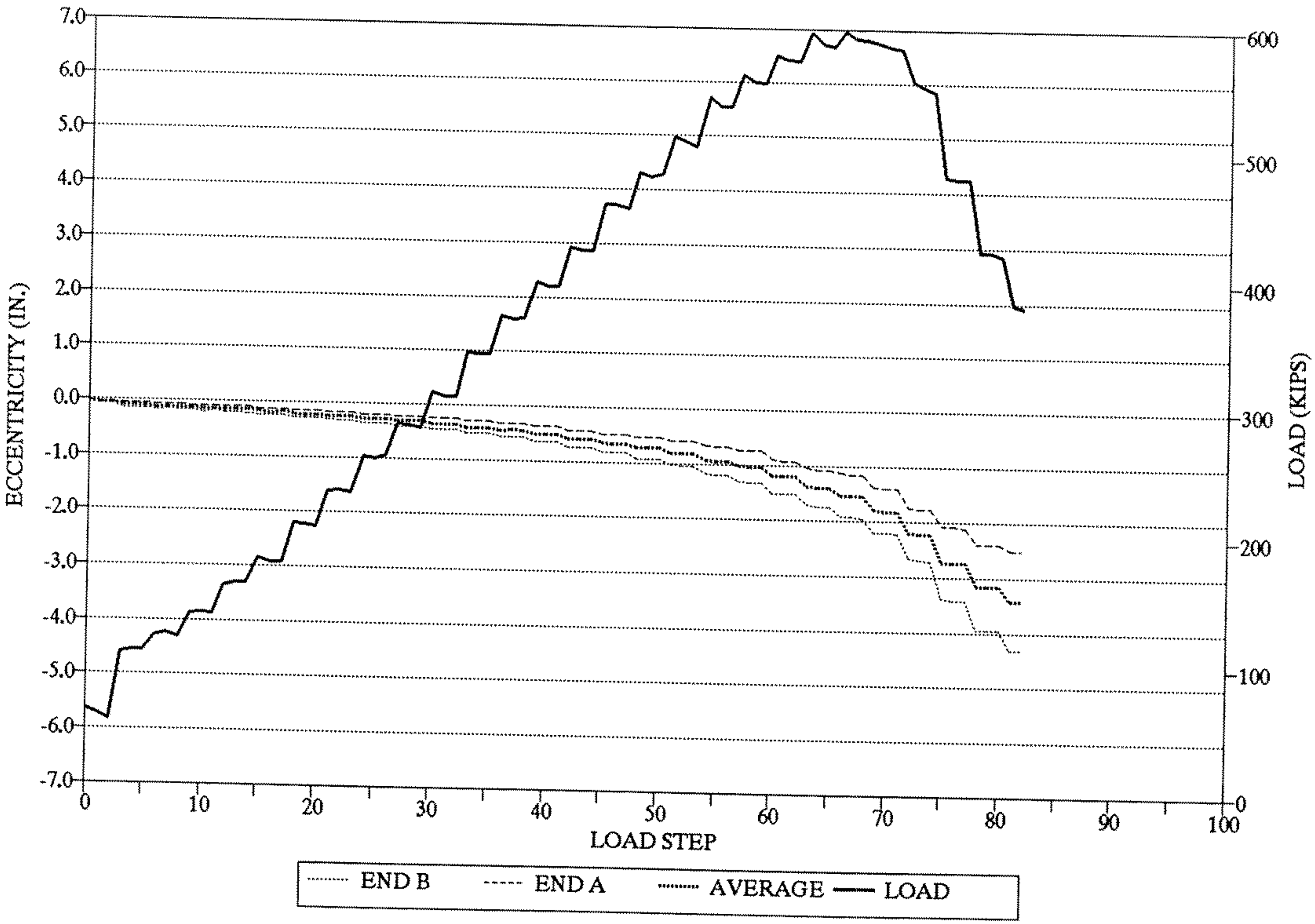


Figure A-110. END ROTATION AND LOAD VS. LOAD STEP
SPECIMEN 11

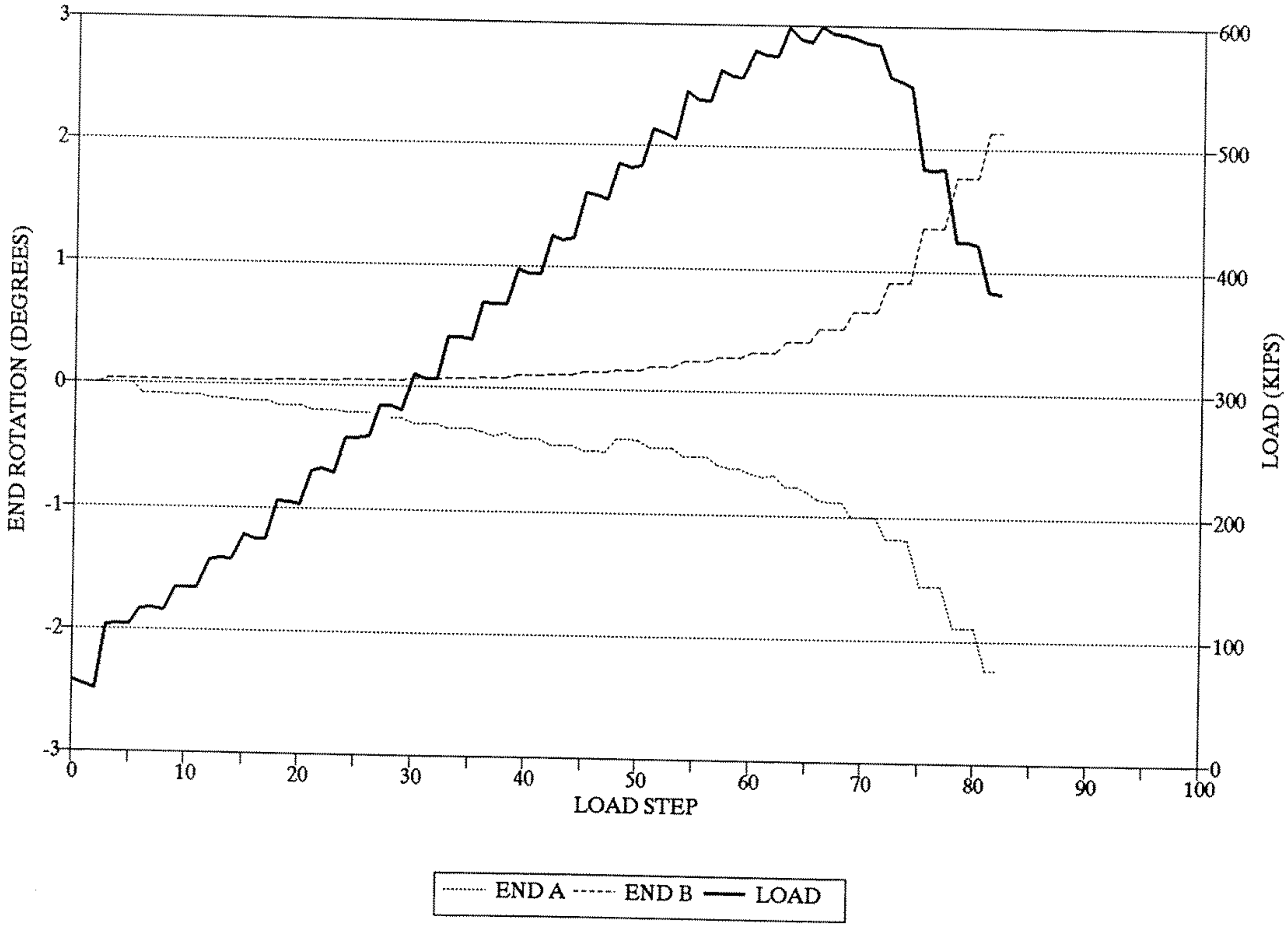


Figure A-111. EFFECTIVE LENGTH VS. LOAD STEP
SPECIMEN 12

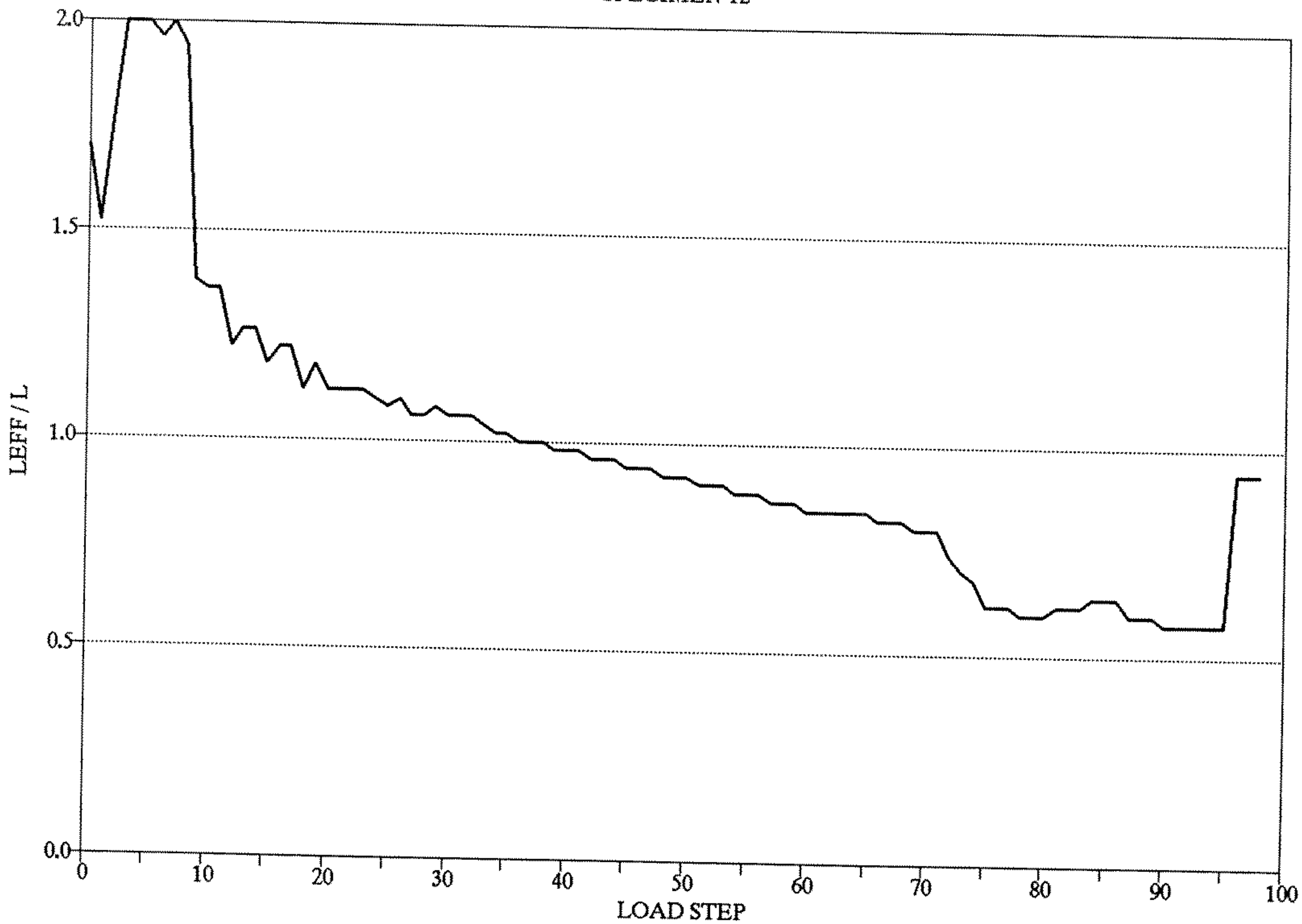


Figure A-112. LOAD AND DEFLECTION VS. LOAD STEP
SPECIMEN 12

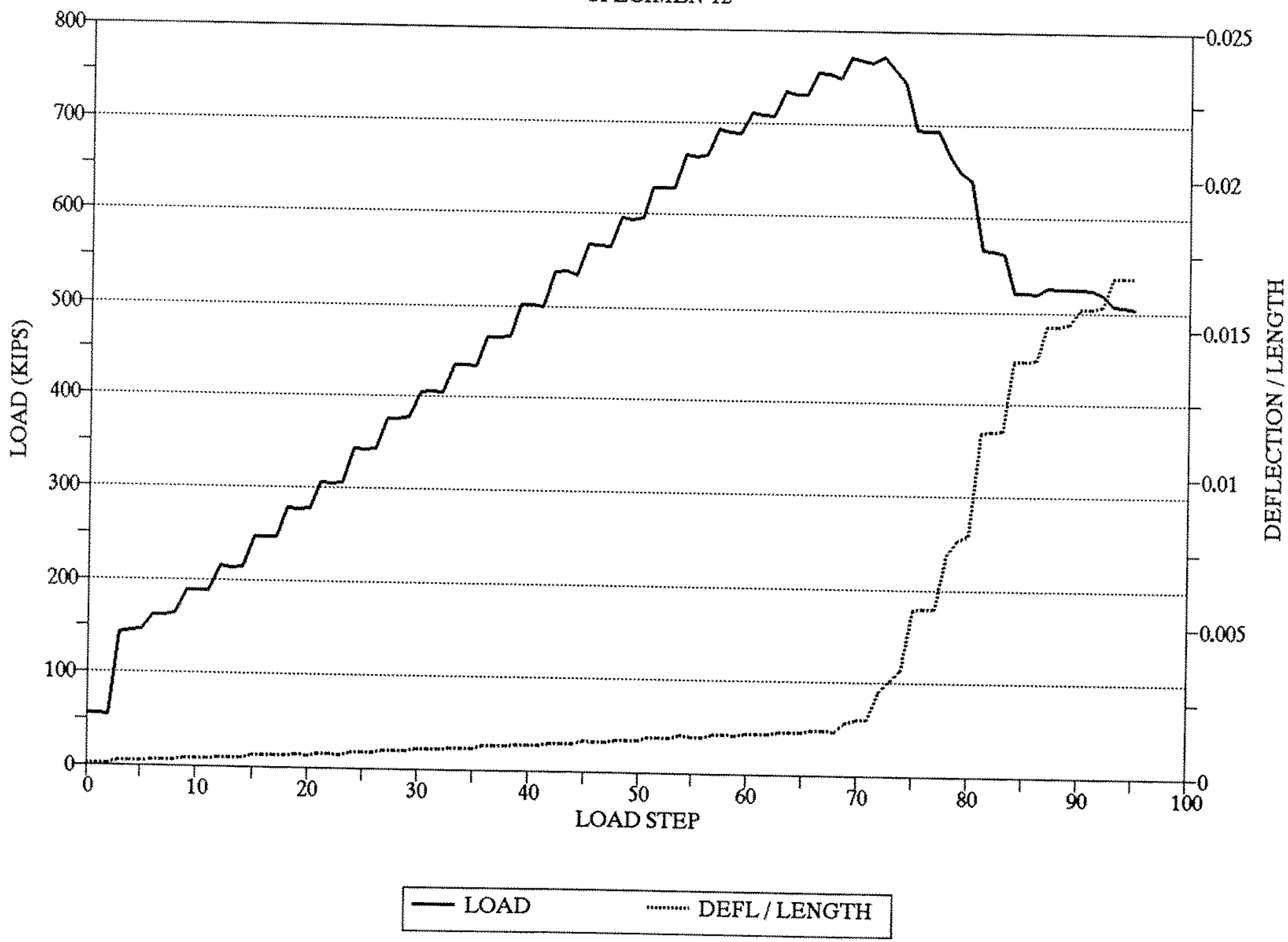


Figure A-113. LOAD VS. CHORD SHORTENING
SPECIMEN 12

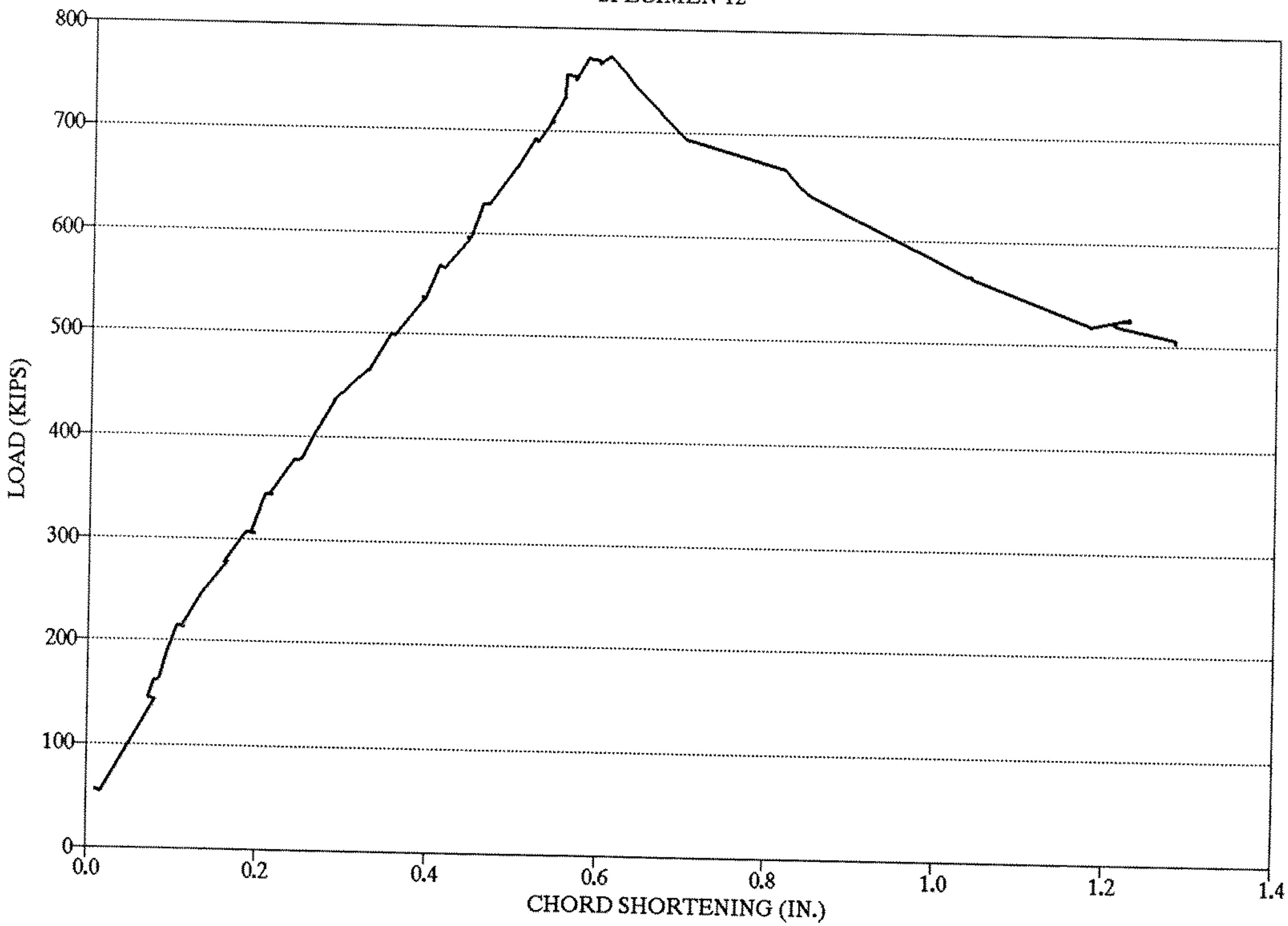


Figure A-114. HORIZONTAL DISPLACEMENTS
SPECIMEN 12

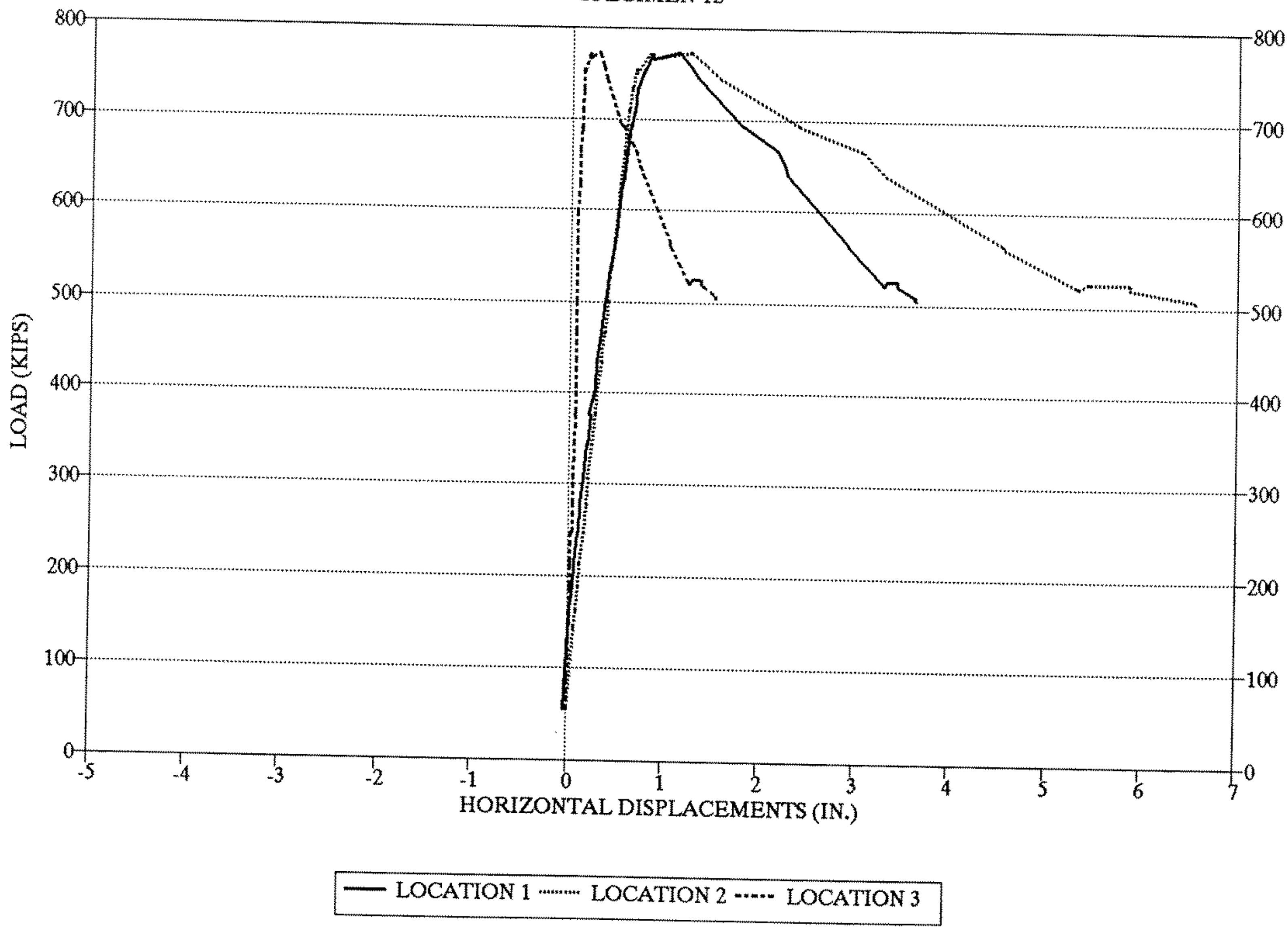


Figure A-115. VERTICAL DISPLACEMENTS
SPECIMEN 12

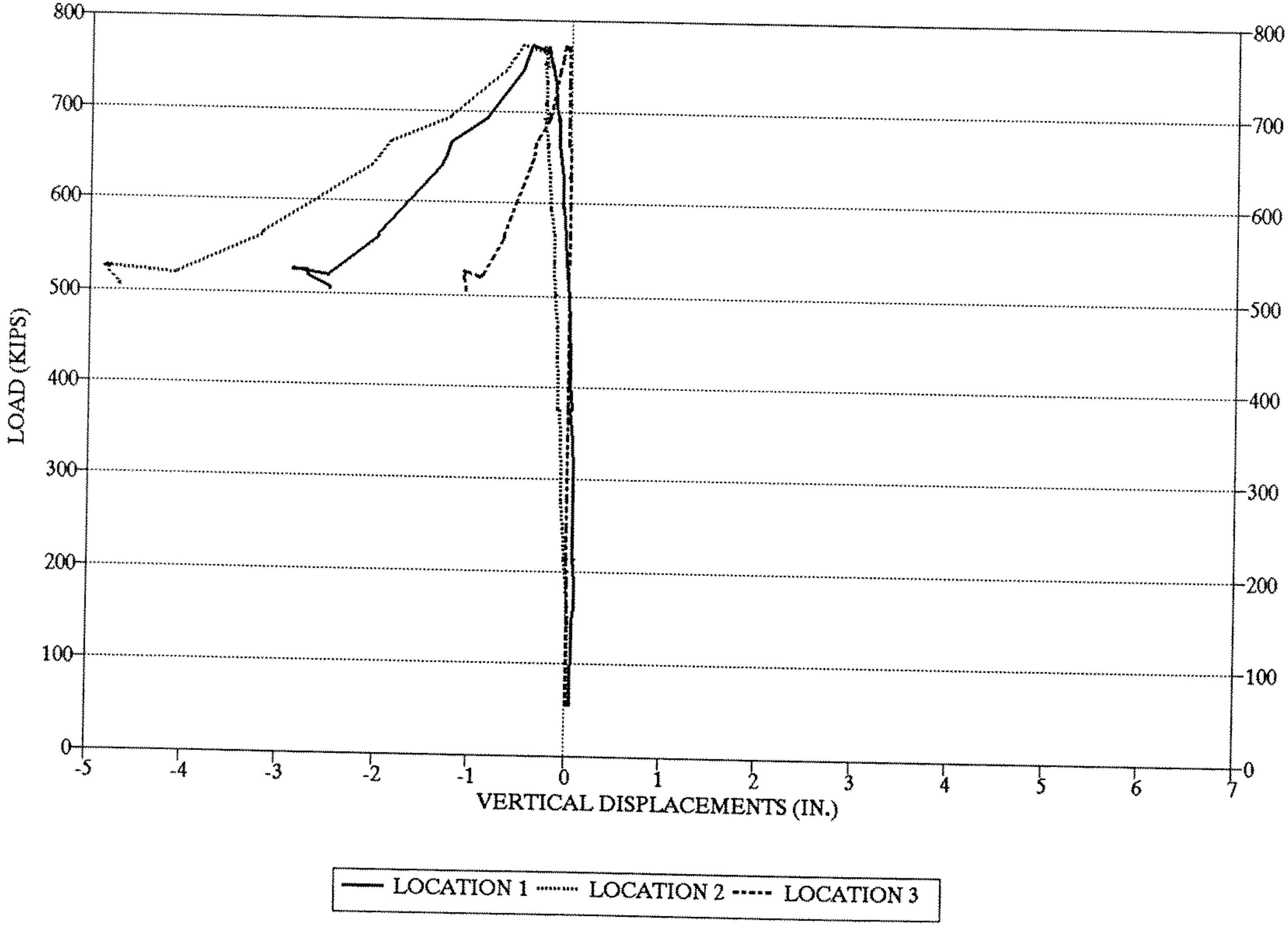


Figure A-116. LOAD AND ECCENTRICITY VS. LOAD STEP

SPECIMEN 12: X ECCENTRICITIES FROM INFLECTION POINTS

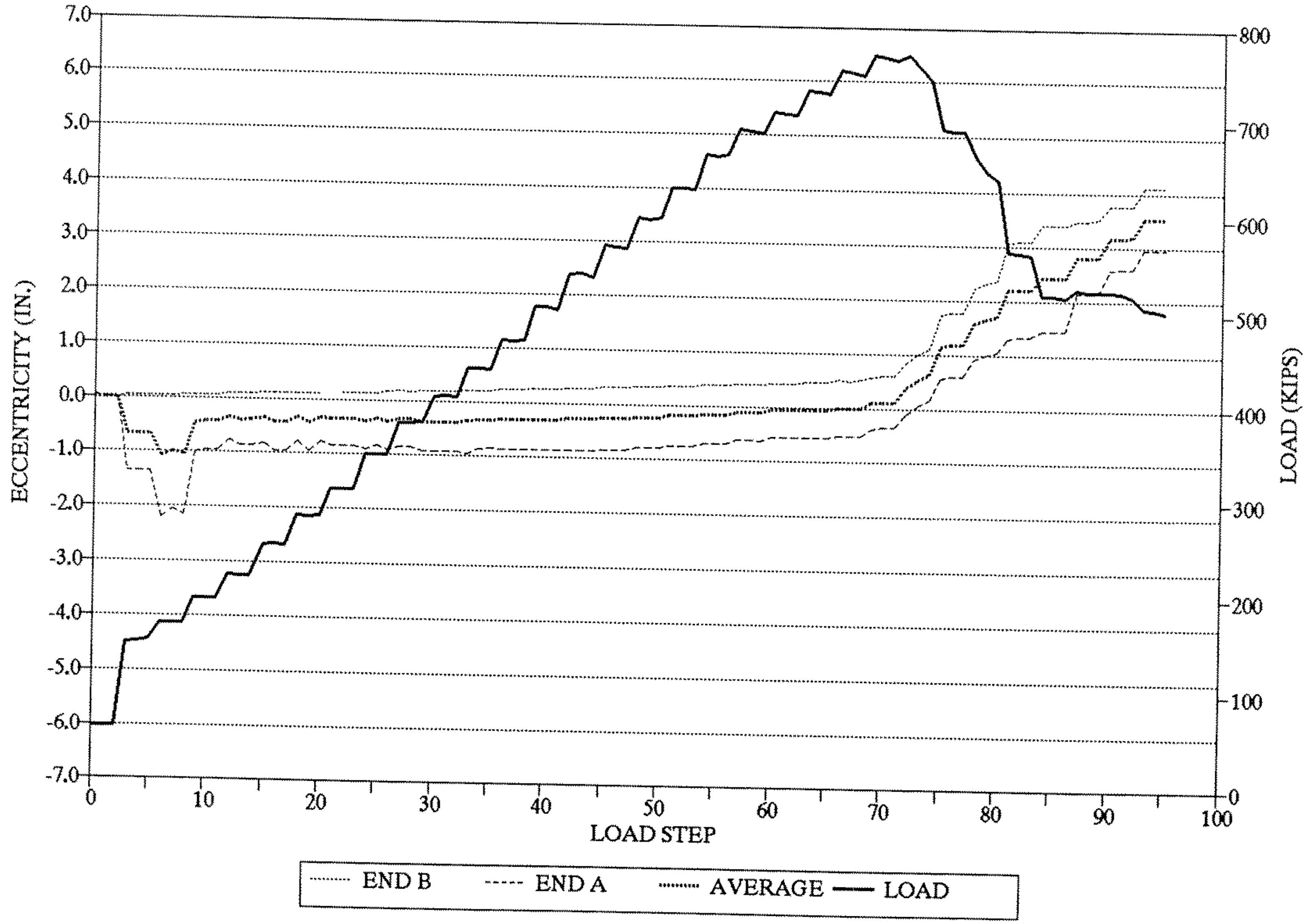


Figure A-117. LOAD AND ECCENTRICITY VS. LOAD STEP

SPECIMEN 12: Y ECCENTRICITIES FROM INFLECTION POINTS

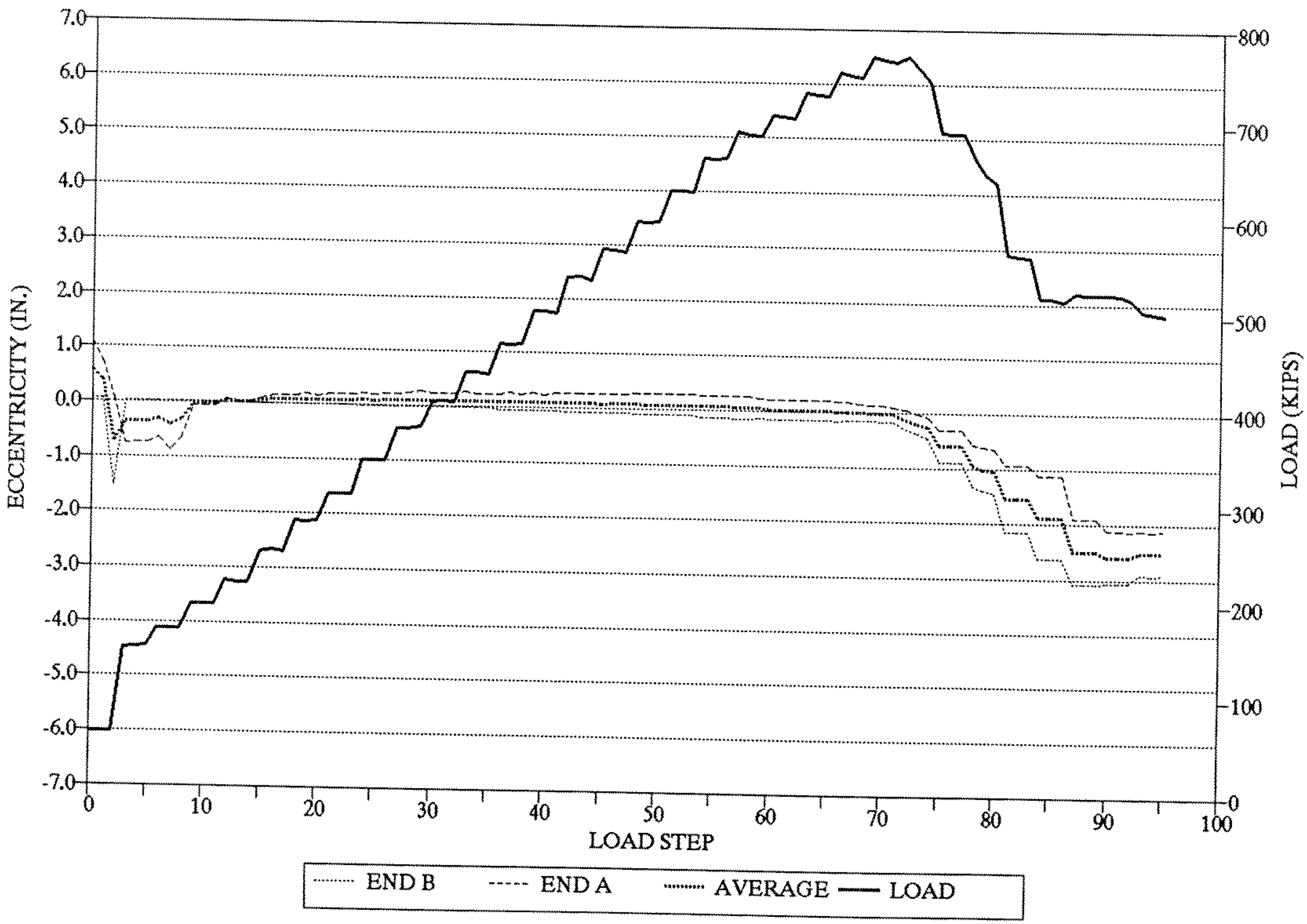


Figure A-118. LOAD AND ECCENTRICITY VS. LOAD STEP

SPECIMEN 12: X ECCENTRICITIES FROM END MOMENTS

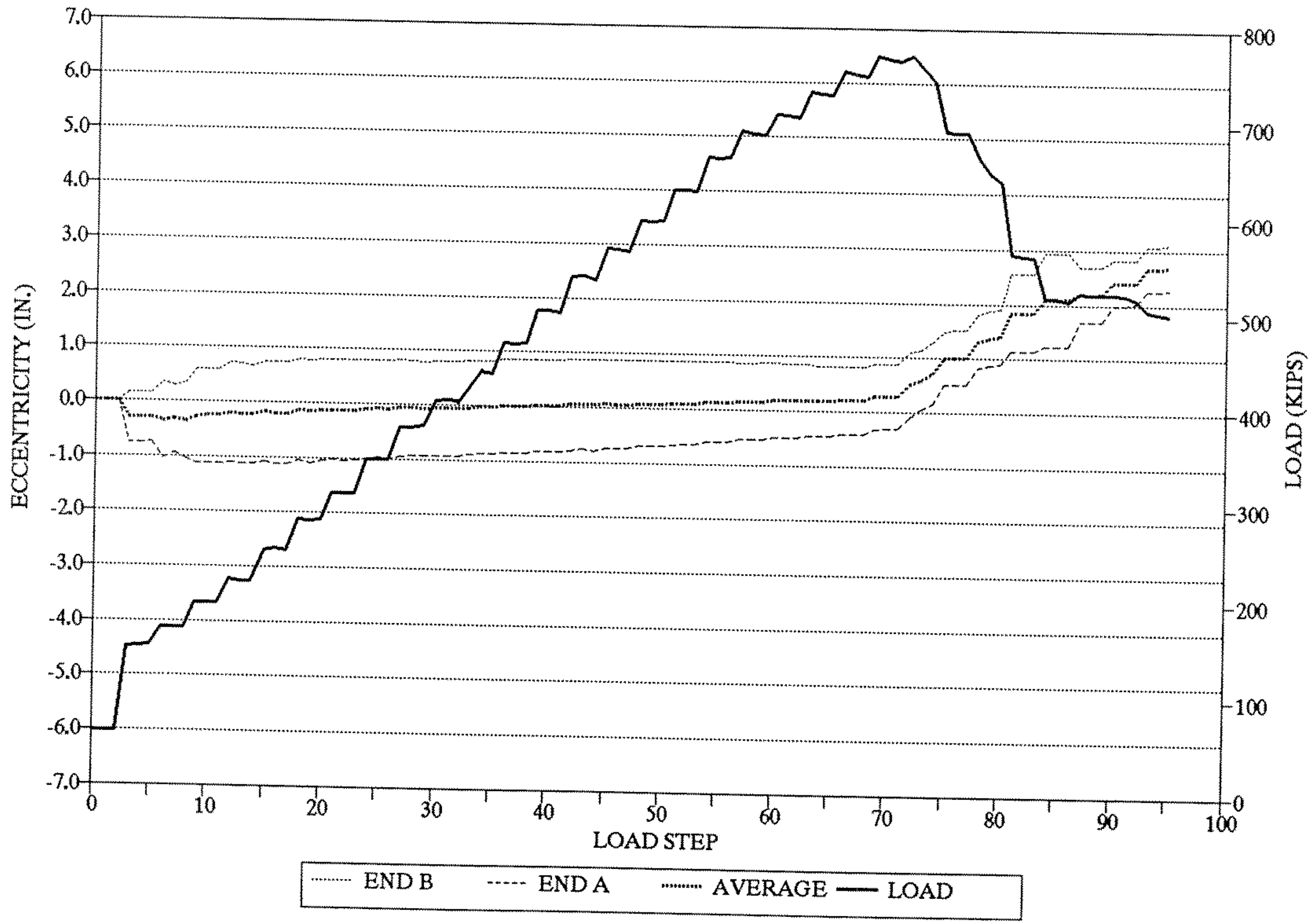


Figure A-119. LOAD AND ECCENTRICITY VS. LOAD STEP

SPECIMEN 12: Y ECCENTRICITIES FROM END MOMENTS

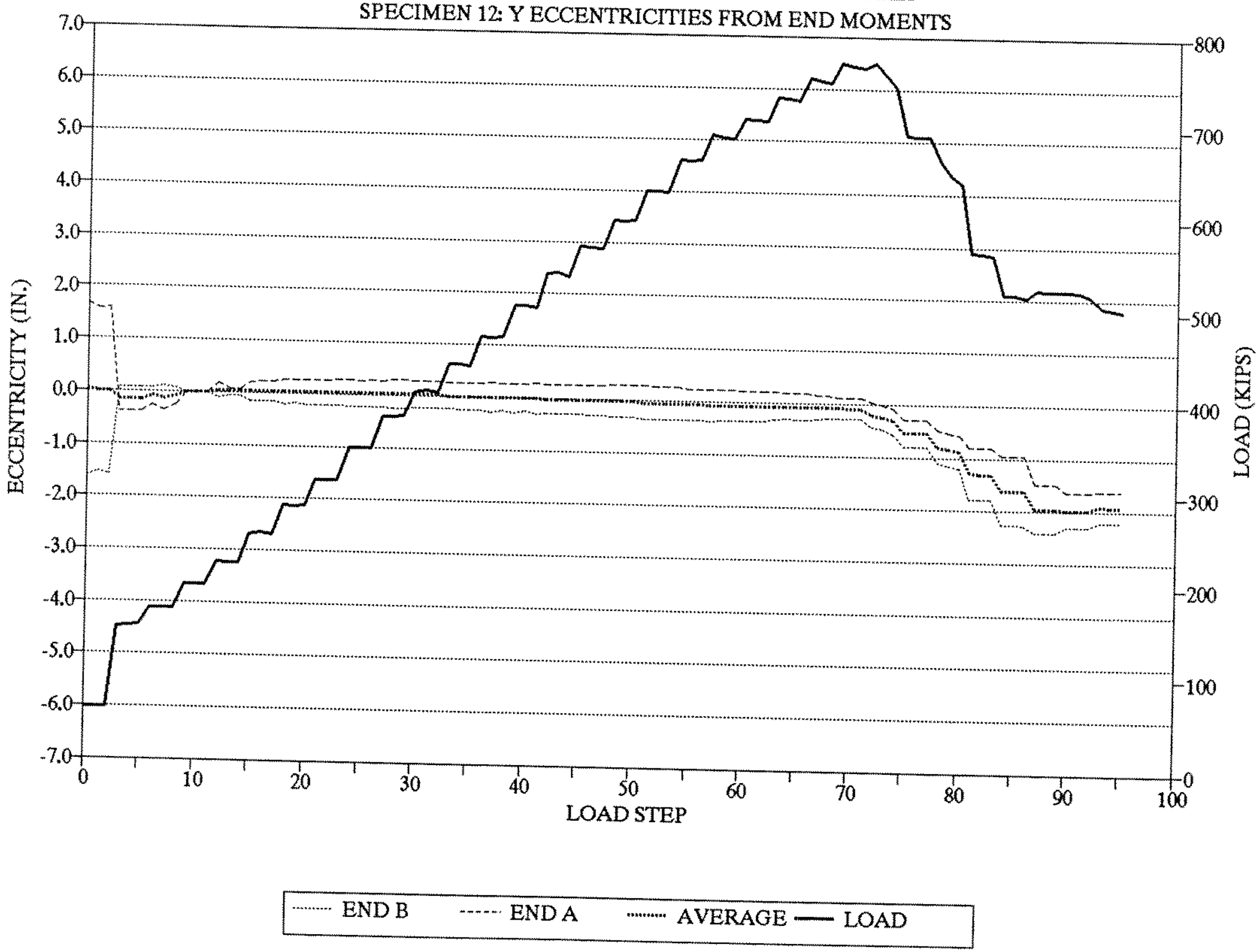
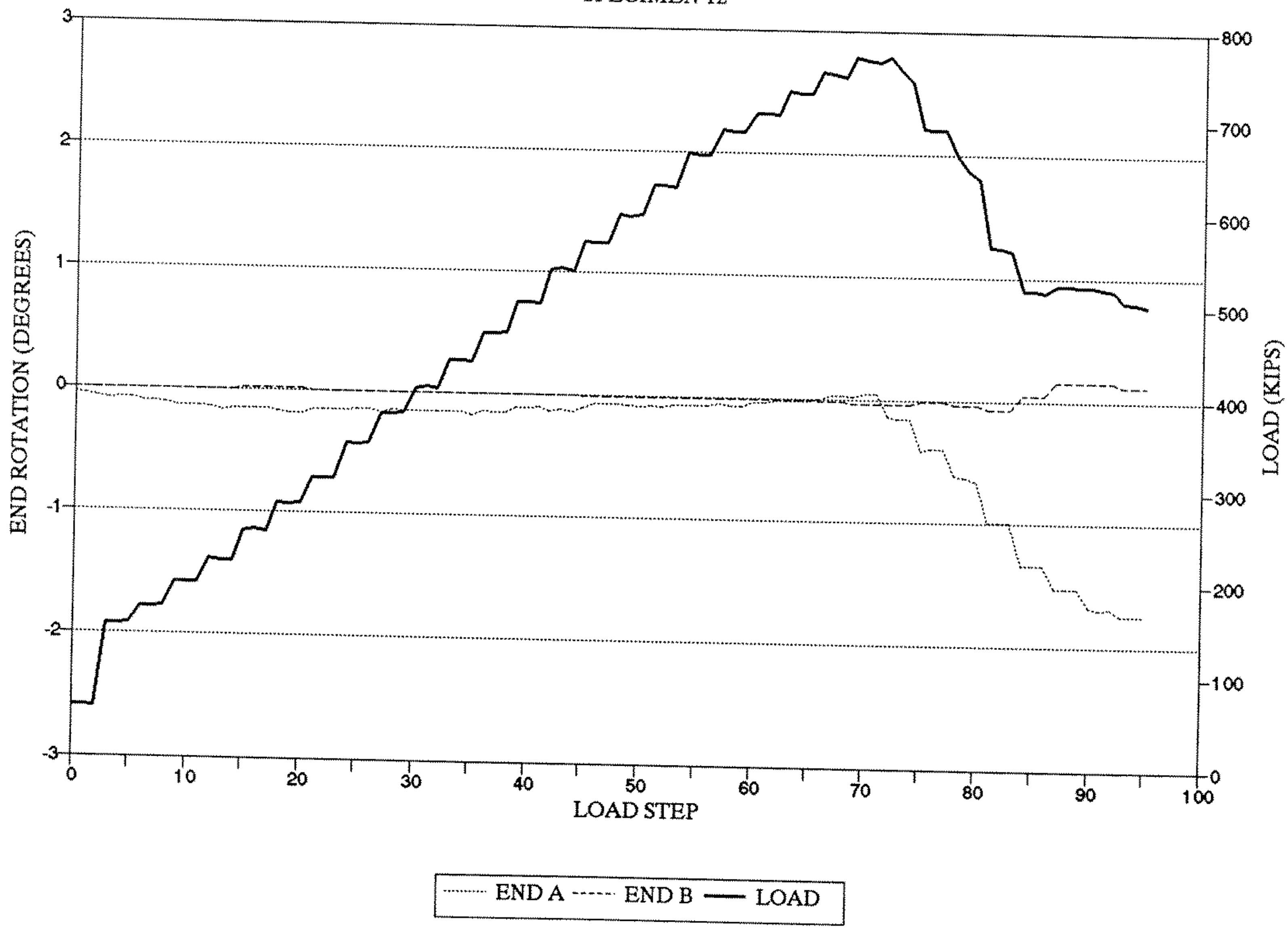


Figure A-120. END ROTATION AND LOAD VS. LOAD STEP
SPECIMEN 12



APPENDIX B

COMPUTER CODES USED FOR DATA REDUCTION

APPENDIX B
COMPUTER CODES USED FOR DATA REDUCTION

SGL

SGL converts the longitudinal and circumferential strain gage location measurements to x, y, and z coordinates corresponding to the full-scale test sign convention. The input consists of the total length, radius, measurements from the chalk line to the individual strain gage, and measurements from end B at each strain gage ring location. The output consists of the strain gage locations listed in the x, y, and z, coordinates.

DISPLAC

DISPLAC computes the resultant load, the chord shortening, the horizontal displacements, and the vertical displacements at each data step. The input consists of specimen length, distances from end A to the location of the horizontal and vertical displacement string pots, initial distances of the line extended out of the string pots for the horizontal and vertical displacement, and physical properties of the load frame. The input also consists of the calibration factors for the strain gages on the load frame used to calculate the load, chord shortening and chord shortening correction factor data. The output produced is the load and chord shortening data along with the true horizontal and vertical deflections.

CURVE

CURVE is a least squares algorithm which obtains the "best fit" for the strain gage and displacement data. The input consists of measured strains, the gage locations, measured displacement, distance to buckling point from end B, and the distances to the horizontal and vertical string pot locations. Output produced is the effective length, information on deleted gages, eccentricities, and the error of fit. This is explained further in Appendix C.

CHANGE

CHANGE arranges the output of CURVE into files for plotting. Input consists of load and chord shortening data. Also, the input consists of effective length, information on deleted gages, eccentricities, and the error of fit for each data step. The output consists of effective length, eccentricities, load, and total displacement data at each data step.

ECC

ECC computes end eccentricities from the end moments calculated by the CURVE algorithm. A further explanation of this is presented in Appendix D. Input consists of the load and effective length data. The output consists of a file that lists the eccentricities in tabular form for plotting purposes.

```
      PROGRAM SGL
*
C
C  PURPOSE:  THIS PROGRAM CONVERTS THE CIRCUMFERENTIAL MEASUREMENTS OF GAUGE
C            LOCATION RELATIVE TO THE CHALK LINE TO CARTESIAN COORDINATES.
C            CIRCUMFERENTIAL MEASUREMENTS ARE POSITIVE TO THE RIGHT OF THE
C            CHALK LINE AND NEGATIVE TO THE LEFT OF IT.  INPUT IS FROM THE
C            FILE SGLOC.INP, AND OUTPUT IS TO THE FILE SGLOC.OUT.
C
C  VARIABLE LIBRARY
C
C     ARCL = CIRCUMFERENTIAL ARCLENGTH AS MEASURED FROM THE CHALK LINE.
C            RIGHT IS POSITIVE; LEFT IS NEGATIVE.
C     I = A LOOP COUNTER
C     JUNK(I) = THE Z COORDINATE OF RING I
C     R = THE RADIUS OF THE PIPE
C     SPECNO = THE SPECIMEN NUMBER
C     THETA = THE ANGLE OF ROTATION MEASURED IN RADIANS AS POSITIVE
C             CLOCKWISE FROM THE CHALK LINE
C     X = THE X-COORDINATE OF THE GAUGE LOCATION
C     Y = THE Y-COORDINATE OF THE GAUGE LOCATION
C     Z = THE DISTANCE FROM END B TO THE GAUGE L
C
C  TYPE DECLARATIONS
C      IMPLICIT NONE
      INTEGER SPECNO, I
      DOUBLE PRECISION R, ARCL, THETA, X(30),
     1                 Y(30), Z(30),L, JUNK(5)
C
C  OPEN FILES
C
      OPEN(UNIT=10,FILE='SGLOC.INP',STATUS='OLD')
      OPEN(UNIT=20,FILE='SGLOC.OUT',STATUS='NEW')
C
C  READ DATA
C
      READ (10,*) SPECNO,R,L
      DO 10 I = 1,30
         READ (10,*) ARCL
         THETA = ARCL/R
         X(I) = R*SIN(THETA)
         Y(I) = R*COS(THETA)
   10 CONTINUE
      DO 20 I = 1,5
         READ (10,*) JUNK(I)
   20 CONTINUE
C
C   PUT IN Z LOCATIONS
C
      DO 30 I = 1,6
         Z(I) = JUNK(1)
   30 CONTINUE
      DO 40 I = 7,12
         Z(I) = JUNK(2)
```

```
   40 CONTINUE
      DO 50 I = 13,18è          Z(I) = JUNK(3)
   50 CONTINUE
      DO 60 I = 19,24
         Z(I) = JUNK(4)
   60 CONTINUE
      DO 70 I = 25,30
         Z(I) = JUNK(5)
   70 CONTINUE
C
C   PRINT DATA TO OUTPUT FILE
C
      DO 80 I = 1,30
         WRITE (20,100) X(I),Y(I),Z(I)
   80 CONTINUE
      WRITE (20,110) L
  100 FORMAT(' ',F8.4,3X,F8.4,3X,F8.4)
  110 FORMAT(' ',F8.4)
C
C  CLOSE FILES AND LEAVE
C
      CLOSE(UNIT=10)
      CLOSE(UNIT=20)
      END
```

```
      PROGRAM DISP
C
C     ******************
C     * Scott Moehlman *
C     *  PMB - Program *
C     *  June 20, 1989 *
C     ******************
C
C     PROGRAM DESCRIPTION
C            THIS IS A PROGRAM TO COMPUTE CHORD SHORTENING, LOAD, AND
C        RESULTANT HORIZONTAL AND VERTICAL DISPLACEMENTS.
C
C     .........................................................
C     .            DESCRIPTION OF THE VARIABLES               .
C     .                                                       .
C     .  A(I,J) = .......RESULTANT HORIZONTAL DISPLACEMENT    .
C     .  BO     = .......DISTANCE FROM WEB TO STRAIN GAUGE    .
C     .  B(I,J) = .......RESULTANT VERTICAL DISPLACEMENT      .
C     .  C(J)   = .......ORIGINAL HORIZONTAL DISPLACEMENT     .
C     .  CAL(I) = .......CALIBRATION FACTORS                  .
C     .  CS(I)  = .......CHORD SHORTENING AT TIME I           .
C     .  CSX(I,J) = .....CHANGE IN X DUE TO CHORD SHORTENING  .
C     .  CSY(I,J) = .....CHANGE IN Y DUE TO CHORD SHORTENING  .
C     .  D(I,J) = .......CHANGE IN "HORIZONTAL" DISPLACEMENT  .
C     .  DGA(I) = .......CHORD SHORTENING D.G. CORR. AT A     .
C     .  DGB(I) = .......CHORD SHORTENING D.G. CORR. AT B     .
C     .  E(J)   = .......ORIGINAL VERTICAL DISPLACEMENT       .
C     .  F(I,J) = .......CHANGE IN "VERTICAL" DISPLACEMENT    .
C     .  HO     = .......DISTANCE FROM WEB CENTER TO GAUGE    .
C     .  INERX  = .......MOMENT OF INERTIA ABOUT X-AXIS       .
C     .  INERY  = .......MOMENT OF INERTIA ABOUT Y-AXIS       .
C     .  L(I)   = .......DISTANCE TO HORIZ AND VERT POTS      .
C     .  LD(I,J) = ......INPUTTED LOADS FROM LOAD FRAME       .
C     .  LENGTH = .......ORIGINAL LENGTH OF PIPE              .
C     .  LOAD(I) = ......TOTAL APPLIED LOAD AT TIME I         .
C     .  MOD    = .......MODULUS OF ELASTICITY OF LOAD FRAME  .
C     .  N      = .......NUMBER OF DATA STEPS                 .
C     .  SP(I,J) = ......LONGITUDINAL STR[illegible]T READINGS        .
C     .  TIME(I) = ......TIME AT READING I                    .
C     .  TITLE  = .......DESCRIPTION OF PIPE                  .
C     .  U(I)   = .......LOCATION OF HORIZONTAL LOAD RESULT   .
C     .  V(I)   = .......LOCATION OF VERTICAL LOAD RESULTANT  .
C     .  W(I)   = .......DISTANCE FROM CENTER OF FRAME TO LEG.
C     .  X(I,J) = .......HORIZONTAL POT READINGS              .
C     .  Y(I,J) = .......VERTICAL POT READINGS                .
C     .........................................................
C
C
C     VARIABLE DECLARATIONS
      IMPLICIT REAL (A-H,O-Z)
      REAL A(150,3),B(150,3),C(3),D(150,3),E(3),BO,HO,CAL(9),
     1 F(150,3),SP(150,3),TIME(150),X(150,3),Y(150,3),CS(150),
     1 LOAD(150),LENGTH,L(3),CSY(150,3),CSX(150,3),LD(150,9),
     1 MOD,INERX,INERY,U(150),V(150),W(3),DGA(150),DGB(150)
      INTEGER N
```

```
      CHARACTER TITLE*30
C
C     --------------------------------
C     INPUT DATA WITH SUBROUTINE DATAIN
C     --------------------------------
C
      CALL DATAIN(LENGTH,L,TIME,TITLE,SP,X,Y,LD,C,E,CAL,MOD,
     1  INERX,INERY,BO,HO,W,DGA,DGB,N)
C
C     -----------------------------------
C     WRITE INPUT DATA TO FILE "SPEC##.INP
C     -----------------------------------
C
C     --------------------
C     OPEN FILE FOR OUTPUT
C     --------------------
C
      OPEN (UNIT=7, FILE='SPEC.INP', STATUS='UNKNOWN')
C
      DO 100 I = 1,N
         WRITE (7,1000) TIME(I),SP(I,1),SP(I,2),SP(I,3)
  100 CONTINUE
      WRITE (7,950)
      DO 110 I = 1,N
         WRITE (7,1010) X(I,1),Y(I,1),X(I,2),Y(I,2),X(I,3),
     1        Y(I,3)
  110 CONTINUE
      WRITE (7,950)
      DO 120 I = 1,N
         WRITE (7,1020) LD(I,1),LD(I,2),LD(I,3),LD(I,4),LD(I,5)
  120 CONTINUE
      WRITE (7,950)
      DO 130 I = 1,N
         WRITE (7,1030) LD(I,6),LD(I,7),LD(I,8),LD(I,9)
  130 CONTINUE
C
C     ----------------------------------------------------
C     COMPUTE CHORD SHORTENING, LOAD, AND CORRECTED READINGS
C     ----------------------------------------------------
C
      CALL CHORDS(LENGTH,L,LD,TIME,SP,X,Y,LOAD,CS,CSX,CSY,C,
     1 D,E,F,DGA,DGB,N)
C
C     ---------------------
C     COMPUTE LOAD RESULTANT
C     ---------------------
C
      CALL LOCAT(LD,CAL,MOD,INERX,INERY,BO,HO,U,V,W,
     1       TIME,LOAD,CS,TITLE,N)
C
C     --------------------------------
C     COMPUTE "RESULTANT" HORIZONTAL AND
C     VERTICAL DISPLACEMENTS
C     --------------------------------
```

```
C
      CALL RESULT(A,B,C,D,E,F,N)
C
C     -----------------
C     FORMAT STATEMENTS
C     -----------------
C
  950 FORMAT (' ')
 1000 FORMAT (' ',F9.2,',',F9.5,',',F9.5,',',F9.5)
 1010 FORMAT (' ',F9.5,',',F9.5,',',F9.5,',',F9.5,',',F9.5,
     1  ',',F9.5)
 1020 FORMAT (' ',F9.5,',',F9.5,',',F9.5,',',F9.5,',',F9.5)
 1030 FORMAT (' ',F9.5,',',F9.5,',',F9.5,',',F9.5)
      END
C
C
C     =================
C     SUBROUTINE DATAIN
C     =================
C
      SUBROUTINE DATAIN(LENGTH,L,TIME,TITLE,SP,X,Y,LD,C,E,
     1  CAL,MOD,INERX,INERY,BO,HO,W,DGA,DGB,N)
C
C     PURPOSE: INPUT PROBLEM DATA
C
C     DECLARE VARIABLES
      IMPLICIT REAL (A-H,O-Z)
      REAL SP(150,3),TIME(150),X(150,3),Y(150,3),CAL(9),MOD,
     1 LENGTH,L(3),LD(150,9),C(3),E(3),INERX,INERY,BO,HO,
     1 W(3),DGA(150),DGB(150)
      INTEGER N
      CHARACTER TITLE*30
C
C
C     --------------------
C     OPEN FILES FOR INPUT
C     --------------------
C
      OPEN (UNIT=1, FILE='LSP.DAT', STATUS='OLD')
      OPEN (UNIT=2, FILE='HVP.DAT', STATUS='OLD')
C
C     READ IN PROBLEM TITLE, PIPE LENGTH, DISTANCE TO HORIZ AND
C     VERT POTS, AND INITIAL POT EXTENSION.
C
      READ (1,*) TITLE
      READ (1,*) N
      READ (1,*) LENGTH, L(1), L(2), L(3)
      READ (1,*) C(1), E(1), C(2), E(2), C(3), E(3)
      READ (1,*) MOD,INERX,INERY,BO,HO
      READ (1,*) W(1),W(2),W(3)
C
C     READ IN CALIBRATION FACTORS
C
      DO 5 J = 1,9
```

```
         READ (1,*) CAL(J)
    5 CONTINUE
C
C     READ TIME, POT DISPLACEMENTS, AND LOADS.
C
      DO 10 I = 1,N
        READ (1,*) TIME(I),SP(I,1),SP(I,2),SP(I,3),DGA(I),
     1             DGB(I)
        READ (2,*) X(I,1),Y(I,1),X(I,2),Y(I,2),X(I,3),Y(I,3)
   10 CONTINUE
      CLOSE (UNIT=1)
      CLOSE (UNIT=2)
C
C     --------------------
C     OPEN FILES FOR INPUT
C     --------------------
C
      OPEN (UNIT=3, FILE='LOAD1.DAT', STATUS='OLD')
      OPEN (UNIT=4, FILE='LOAD2.DAT', STATUS='OLD')
C
      DO 15 I =1,N
        READ (3,*) LD(I,1),LD(I,2),LD(I,3),LD(I,4),LD(I,5)
        READ (4,*) LD(I,6),LD(I,7),LD(I,8),LD(I,9)
   15 CONTINUE
      CLOSE (UNIT=3)
      CLOSE (UNIT=4)
      RETURN
      END
C
C
C     ================
C     SUBROUTINE CHORDS
C     ================
C
      SUBROUTINE CHORDS(LENGTH,L,LD,TIME,SP,X,Y,LOAD,
     1  CS,CSX,CSY,C,D,E,F,DGA,DGB,N)
C
C     PURPOSE: COMPUTE CHORD SHORTENING, LOAD, AND HORIZ
C     AND VERT READINGS MINUS CHORD SHORTENING EFFECTS.
C
C     DECLARE VARIABLES
      IMPLICIT REAL (A-H,O-Z)
      REAL LENGTH,L(3),LD(150,9),TIME(150),
     1  SP(150,3),X(150,3),Y(150,3),LOAD(150),CS(150),
     1  CSX(150,3),CSY(150,3),C(3),D(150,3),E(3),F(150,3),
     1  THETA(2,3),R(3),DGA(150),DGB(150)
      INTEGER N
C
C     ----------------------------------------
C     COMPUTE CHORD SHORTENING, LOAD, AND CHORD
C     SHORTENING EFFECTS AT TIME I.
C     ----------------------------------------
C
      DO 20 I = 1,N
```

```
         CS(I) = (-(SP(I,1)+SP(I,2)+SP(I,3))/3)-DGA(I)-DGB(I)
         LOAD(I) = (LD(I,1)+LD(I,3)+LD(I,4)+LD(I,6)+LD(I,7)
     1         +LD(I,9))/2
   20 CONTINUE
C
      DO 30 I = 1,N
         DO 30 J = 1,3
          R(J) = CS(I)*(LENGTH-L(J))/LENGTH
C
          THETA(1,J) = ATAN(R(J)/C(J))
          THETA(2,J) = ATAN(R(J)/E(J))
C
          CSX(I,J) = C(J)*((1/COS(THETA(1,J)))-1)
          CSY(I,J) = E(J)*((1/COS(THETA(2,J)))-1)
C
          D(I,J) = X(I,J) - CSX(I,J)
          F(I,J) = Y(I,J) - CSY(I,J)
   30 CONTINUE
      RETURN
      END
C
C
C     ================
C     SUBROUTINE LOCAT
C     ================
C
      SUBROUTINE LOCAT(LD,CAL,MOD,INERX,INERY,BO,HO,U,V,W,
     1         TIME,LOAD,CS,TITLE,N)
C
C     PURPOSE:  TO COMPUTE THE LINE OF ACTION OF THE LOAD
C
C     DECLARE VARIABLES
      IMPLICIT REAL (A-H,O-Z)
      REAL LD(150,9),CAL(9),MOD,INERX,INERY,BO,HO,U(150),P(3),
     1  V(150),THEE(3),S(3),ALPHA(3),BETA(3),W(3),EX(3),EY(3),
     1  TIME(150),LOAD(150),CS(150)
      INTEGER N
      CHARACTER TITLE*30
C
C     ---------------------
C     OPEN FILES FOR OUTPUT
C     ---------------------
C
      OPEN (UNIT=8, FILE='SPEC1.OUT', STATUS='UNKNOWN')
C
      WRITE (8,*) TITLE
      WRITE (8,2010)
C
C     COMPUTE THE LOCATION OF THE LOAD RESULTANT
C
      DO 60 I = 1,N
C
C     COMPUTE THE RESULTANT LOCATION FOR EACH LEG
C
```

```
      IF (LD(I,6)+LD(I,4).EQ.0) THEN
         EX(1) = 0
         EY(1) = 0
      ELSE
         EX(1) = -(LD(I,5)/(CAL(5)*30.6)-LD(I,6)/(CAL(6)
     1            *30.6))*INERY/(BO*(LD(I,6)+LD(I,4)))
         EY(1) = (LD(I,5)/(CAL(5)*30.6)-LD(I,4)/(CAL(4)
     1            *30.6))*INERX/(HO*(LD(I,6)+LD(I,4)))
      ENDIF
      IF (LD(I,1)+LD(I,3).EQ.0) THEN
         EX(2) = 0
         EY(2) = 0
      ELSE
         EX(2) = -(LD(I,2)/(CAL(2)*30.6)-LD(I,3)/(CAL(3)
     1            *30.6))*INERY/(BO*(LD(I,1)+LD(I,3)))
         EY(2) = (LD(I,2)/(CAL(2)*30.6)-LD(I,1)/(CAL(1)
     1            *30.6))*INERX/(HO*(LD(I,1)+LD(I,3)))
      ENDIF
      IF (LD(I,7)+LD(I,9).EQ.0) THEN
         EX(3) = 0
         EY(3) = 0
      ELSE
         EX(3) = -(LD(I,7)/(CAL(7)*30.6)-LD(I,8)/(CAL(8)
     1            *30.6))*INERY/(BO*(LD(I,7)+LD(I,9)))
         EY(3) = -(LD(I,8)/(CAL(8)*30.6)-LD(I,9)/(CAL(9)
     1            *30.6))*INERX/(HO*(LD(I,7)+LD(I,9)))
      ENDIF
C
C     DETERMINE THE ANGLE THEE FOR LEGS 2 AND 3
C
         THEE(2) = ATAN(EY(2)/(W(2)-EX(2)))
         THEE(3) = ATAN(EY(3)/(W(3)+EX(3)))
C
C     FIND THE DISTANCE FROM THE RESULTANTS IN LEGS
C     2 AND 3  TO THE CENTER OF THE LOAD FRAME
C
         S(2) = W(2)-EX(2)/COS(THEE(2))
         S(3) = W(3)+EX(3)/COS(THEE(3))
C
C     COMPUTE X AND Y COMPONENTS OF DISTANCE TO CENTER
C     ALPHA(1) = X(1) AND BETA(1) = Y(1)
C
         ALPHA(1) = EY(1)
         BETA(1) = W(1) - EX(1)
         ALPHA(2) = -S(2)*COS(.5236-THEE(2))
         BETA(2) = -S(2)*SIN(.5236-THEE(2))
         ALPHA(3) = S(3)*COS(.5236-THEE(3))
         BETA(3) = -S(3)*SIN(.5236-THEE(3))
C
C     COMPUTE THE LOAD IN EACH LEG
C
         P(1) = (LD(I,4)+LD(I,6))/2
         P(2) = (LD(I,1)+LD(I,3))/2
         P(3) = (LD(I,7)+LD(I,9))/2
```

```
C
C     DETERMINE THE RESULTANT LOAD LOCATION
C
         U(I) = (P(1)*ALPHA(1)+P(2)*ALPHA(2)+P(3)*ALPHA(3))/
     1          (P(1)+P(2)+P(3))
         V(I) = (P(1)*BETA(1)+P(2)*BETA(2)+P(3)*BETA(3))/
     1          (P(1)+P(2)+P(3))
C
C
C     --------------------
C     WRITE OUTPUT TO FILE
C     --------------------
C
         WRITE (8,2020) TIME(I),LOAD(I),U(I),V(I),CS(I)
C
   60 CONTINUE
C
 2010 FORMAT (' ','"TIME"',',','"LOAD"',',','"Xr"',',',
     1   '"Yr"',',','"CHORD SH"')
 2020 FORMAT (' ',F9.2,',',F9.4,',',F9.5,',',F9.5,',',F9.5)
C
      RETURN
      END
C
C     =================
C     SUBROUTINE RESULT
C     =================
C
      SUBROUTINE RESULT(A,B,C,D,E,F,N)
C
C     PURPOSE:  COMPUTE RESULTANT HORIZONTAL AND VERTICAL
C     DISPLACEMENTS
C
C     DECLARE VARIABLES
      IMPLICIT REAL (A-H,O-Z)
      REAL A(150,3),B(150,3),C(3),D(150,3),E(3),
     1  F(150,3),P(150,3),Q(150,3),Z(150,3),K(2)
      INTEGER N
C
C     COMPUTE THE RESULTANT HORIZONTAL AND VERTICAL DISPLACEMENTS
C
C     --------------------
C     OPEN FILES FOR OUTPUT
C     --------------------
C
      OPEN (UNIT=9, FILE='SPEC2.OUT', STATUS='UNKNOWN')
C
      WRITE (9,2025)
      WRITE (9,2030)
C
      DO 51 I = 1, N
      K(1) = 0
      K(2) = 0
      DO 50 J = 1,3
```

```fortran
      P(I,J) = -F(I,J)**4-4*E(J)*F(I,J)**3+(-4*E(J)**2
     1  +2*D(I,J)**2+4*C(J)*D(I,J)+4*C(J)**2)*F(I,J)**2+(4*D(I,J)**2
     1  +8*C(J)*D(I,J)+8*C(J)**2)*E(J)*F(I,J)+(4*D(I,J)**2
     1  +8*C(J)*D(I,J)+4*C(J)**2)*E(J)**2-D(I,J)**4-4*C(J)*D(I,J)**3
     1  -4*C(J)**2*D(I,J)**2
C
      Q(I,J) = -F(I,J)**2-2*E(J)*F(I,J)+2*D(I,J)*F(I,J)
     1 +2*C(J)*F(I,J)+2*D(I,J)*E(J)+2*C(J)*E(J)-D(I,J)**2-2*C(J)
     1 *D(I,J)
C
      Z(I,J) = F(I,J)**2+2*E(J)*F(I,J)+2*D(I,J)*F(I,J)+2*C(J)
     1 *F(I,J)+2*D(I,J)*E(J)+2*C(J)*E(J)+D(I,J)**2+2*C(J)*D(I,J)
C
      IF (P(I,J).LT.0) THEN
      A(I,J) =-((-C(J)*F(I,J)**2-2*C(J)*E(J)*F(I,J)
     1  -2*C(J)*E(J)**2+C(J)*D(I,J)**2+2*C(J)**2*D(I,J))/(2*E(J)**2
     1  +2*C(J)**2))
      K(1) = 1
      ELSE
      A(I,J) = -((E(J)* SQRT(-F(I,J)**4-4*E(J)*F(I,J)**3+(-4*E(J)**2
     1  +2*D(I,J)**2+4*C(J)*D(I,J)+4*C(J)**2)*F(I,J)**2+(4*D(I,J)**2
     1  +8*C(J)*D(I,J)+8*C(J)**2)*E(J)*F(I,J)+(4*D(I,J)**2
     1  +8*C(J)*D(I,J)+4*C(J)**2)*E(J)**2-D(I,J)**4-4*C(J)*D(I,J)**3
     1  -4*C(J)**2*D(I,J)**2)-C(J)*F(I,J)**2-2*C(J)*E(J)*F(I,J)
     1  -2*C(J)*E(J)**2+C(J)*D(I,J)**2+2*C(J)**2*D(I,J))/(2*E(J)**2
     1  +2*C(J)**2))
      ENDIF
C
      IF (Q(I,J).LT.0.OR.Z(I,J).LT.0) THEN
      B(I,J) = -((E(J)*F(I,J)**2+2*E(J)**2*F(I,J)+(-D(I,J)**2-2*C(J)
     1 *D(I,J)-2*C(J)**2)*E(J))/(2*E(J)**2+2*C(J)**2))
      K(2) = 1
      ELSE
      B(I,J) = -((C(J)*SQRT(-F(I,J)**2-2*E(J)*F(I,J)+2*D(I,J)*F(I,J)
     1 +2*C(J)*F(I,J)+2*D(I,J)*E(J)+2*C(J)*E(J)-D(I,J)**2-2*C(J)
     1 *D(I,J))*SQRT(F(I,J)**2+2*E(J)*F(I,J)+2*D(I,J)*F(I,J)+2*C(J)
     1 *F(I,J)+2*D(I,J)*E(J)+2*C(J)*E(J)+D(I,J)**2+2*C(J)*D(I,J))
     1 +E(J)*F(I,J)**2+2*E(J)**2*F(I,J)+(-D(I,J)**2-2*C(J)*D(I,J)
     1 -2*C(J)**2)*E(J))/(2*E(J)**2+2*C(J)**2))
      ENDIF
C
   50 CONTINUE
C
C     --------------------
C     WRITE OUTPUT TO FILE
C     --------------------
C
      IF (K(1).EQ.1.OR.K(2).EQ.1) THEN
         WRITE (9,2040) A(I,1),B(I,1),A(I,2),B(I,2),A(I,3)
     1               ,B(I,3)
      ELSE
         WRITE (9,2050) A(I,1),B(I,1),A(I,2),B(I,2),A(I,3)
     1               ,B(I,3)
      ENDIF
```

```
   51 CONTINUE
 2025 FORMAT (' ')
 2030 FORMAT (' ','"HORIZ 1"',',','"VERT 1"',',','"HORIZ 2"'
     1   ,',','"VERT 2"',',','"HORIZ 3"',',','"VERT 3"')
 2040 FORMAT (' ',F9.5,',',F9.5,',',F9.5,',',F9.5,',',F9.5,
     1       ',',F9.5,',','*')
 2050 FORMAT (' ',F9.5,',',F9.5,',',F9.5,',',F9.5,',',F9.5,
     1       ',',F9.5)
      RETURN
      END
```

```
      PROGRAM CURVE                                                    *
C
C  PURPOSE:  THIS PROGRAM ATTEMPTS TO FIND THE EFFECTIVE LENGTH OF THE PIPE.
C            IN ORDER TO DO THIS, IT FITS A COSINE WAVE, A SINE WAVE, AND A
C            LINEAR TERM TO THE CURVATURE OF THE SPECIMEN BY USING THE STRAIN
C            GAUGE DATA AND A LEAST SQUARES METHOD.
C
C  VARIABLE LIBRARY
C
C     A = THE COEFFICIENT OF THE COSINE WAVE TERM
C     Aij = THE Aij COEFFICIENT OF THE CURVE FITTING MATRIX
C         = THE Aji COEFFICIENT OF THE CURVE FITTING MATRIX
C     AMIN = THE A ASSOCIATED WITH ERRMIN
C     B = THE COEFFICIENT OF THE SINE WAVE TERM
C     BETAX = THE COEFFICIENT FOR THE LINEAR TERM OF THE X DISPLACEMENTS
C     BETAY = THE COEFFICIENT FOR THE LINEAR TERM OF THE Y DISPLACEMENTS
C     BMIN = THE B ASSOCIATED WITH ERRMIN
C     BUKLPT = THE POINT OF THE HINGE IN THE PIPE WHEN IT BUCKLES
C     C = THE COEFFICIENT OF THE AXIAL STRAIN TERM
C     CMIN = THE C ASSOCIATED WITH ERRMIN
C     COORD(I,1) = THE X COORDINATE OF STRAIN GAUGE I
C     COORD(I,2) = THE Y COORDINATE OF STRAIN GAUGE I
C     COORD(I,3) = THE Z COORDINATE OF STRAIN GAUGE I
C     DEN = THE DENOMINATOR OF THE EXPRESSION USED TO CALCULATE BETAX AND BETAY
C     DET = THE DETERMINANT OF THE CURVE FITTING MATRIX
C     DOAGIN = LOGICAL VARIABLE USED TO DETERMINE IF A, B, AND C SHOULD BE RE-
C              COMPUTED WITH OUTLYING STRAIN GAUGE READINGS ELIMINATED FROM A
C              TIME STEP
C     DUM1 = A DUMMY VARIABLE THAT TAKES ON DIFFERENT VALUES IN DIFFERENT PARTS
C            OF THE PROGRAM
C     DUM2 = A DUMMY VARIABLE THAT TAKES ON DIFFERENT VALUES IN DIFFERENT PARTS
C            OF THE PROGRAM
C     DX(NN,I) = THE MEASURED X DISPLACEMENT AT LOCATION I AND LOAD STEP NN
C     DY(NN,I) = THE MEASURED Y DISPLACEMENT AT LOCATION I AND LOAD STEP NN
C     ERRMIN = THE MINIMUM ERROR OF FIT FOUND FOR THE CURVATURE
C     ERRX = THE SQUARED ERROR OF THE COMPUTED X DISPLACEMENTS
C     ERRY = THE SQUARED ERROR OF THE COMPUTED Y DISPLACEMENTS
C     EX = THE ROOT MEAN SQUARED ERROR OF THE COMPUTED X DISPLACEMENTS
C     EY = THE ROOT MEAN SQUARED ERROR OF THE COMPUTED Y DISPLACEMENTS
C     F(I) = THE TRANSCENDENTAL FUNCTION USED IN COMPUTING DISPLACEMENTS
C     FIRST = LOGICAL VARIABLE USED TO PREVENT MORE THAN ONE SET OF OUTLYING
C             STRAIN GAUGE READINGS FROM BEING ELIMINATED IN A LOAD STEP
C     GEC = THE LINEAR FUNCTION USED IN COMPUTING DISPLACEMENTS AT INFLECTION
C           POINTS
C     G(I) = THE LINEAR FUNCTION USED IN COMPUTING DISPLACEMENTS
C     H(I) = THE COMPUTED HORIZONTAL DISPLACEMENT AT LOCATION I
C     I = A LOOP COUNTER
C     J = A LOOP COUNTER
C     JJ = A LOOP COUNTER
C     K = A LOOP COUNTER
C     KK = A LOOP COUNTER
C     L = THE LENGTH OF THE PIPE
C     LEFF = THE EFFECTIVE LENGTH OF THE PIPE
C     LMIN = THE L ASSOCIATED WITH ERRMIN
```

```
C     MSR  = THE SUM OF THE SQUARED X AND Y DISPLACEMENTS
C     MSS = MEAN SQUARED STRAIN
C     NDS = THE NUMBER OF DATA STEPS
C     NN = A LOOP COUNTER
C     NUMX = THE NUMERATOR OF THE EXPRESSION USED TO CALCULATE BETAX
C     NUMY = THE NUMERATOR OF THE EXPRESSION USED TO CALCULATE BETAY
C     PI = 3.141592654
C     PSI = THE ARGUMENT OF THE SINE AND COSINE TERMS
C     R = THE RATIO BETWEEN THE Y CURVATURES AND THE X CURVATURES
C     RHSi = THE RIGHT HAND SIDE OF EQUATION i
C     RMIN = THE R ASSOCIATED WITH ERRMIN
C     RMS = ROOT MEAN SQUARED ERROR
C     SDEV = STANDARD DEVIATION OF THE NORMALIZED STRAIN GAUGE READING ERRORS
C            FOR A LOAD STEP
C     STRAIN(I) = THE MEASURED STRAIN OF GAUGE I
C     STRER = AVERAGE NORMALIZED STRAIN GAUGE READING ERROR FOR A LOAD STEP
C     STRER(I) = NORMALIZED STRAIN GAUGE READING ERROR FOR GAUGE I
C     V(I) = THE COMPUTED VERTICAL DISPLACEMENT AT LOCATION I
C     XECi = THE COMPUTED X ECCENTRICITY OF THE LOAD AT LOCATION i
C     XEFF = THE LOCATION OF THE INFLECTION POINT RELATIVE TO THE ORIGIN
C            OF THE COORDINATE SYSTEM
C     XEFF1 = THE LOCATION OF THE INFLECTION POINT CLOSEST TO THE ORIGIN OF THE
C             COORDINATE SYSTEM
C     XEFF2 = THE LOCATION OF THE INFLECTION POINT FURTHEST FROM THE ORIGIN OF
C             THE COORDINATE SYSTEM
C     YECi = THE COMPUTED Y ECCENTRICITY OF THE LOAD AT LOCATION i
C     Z(I) = THE Z COORDINATE OF THE VERTICAL AND HORIZONTAL DISPLACEMENT
C            MEASUREMENTS AT LOCATION I
C
      IMPLICIT NONE
      INTEGER I, J, K, NDS, NN, JJ, KK
      REAL COORD(0:29,3), A11, A12, A22, RHS1, RHS2, STRAIN(0:29), LEFF,
     +   L, PI, DUM1, A, B, R, PSI, ERRMIN, RMS, AMIN, BMIN, STRER,
     +   RMIN, MSS, LMIN, C, CMIN, RHS3, A13, A23, A33, DET, G(3),
     +   BUKLPT, Z(3), DX(150,3), DY(150,3), F(3), BETAX, BETAY, NUMX,
     +   NUMY, DEN, DUM2, MSR, ERRX, ERRY, EX, EY, V(3), H(3), SDEV,
     +   GEC, XEFF1, XEFF2, XEC1, XEC2, YEC1, YEC2, XEFF, STRERR(0:29)
      LOGICAL DOAGIN, FIRST
C
      OPEN(UNIT=10,FILE='RING1.STR',STATUS='OLD')
      OPEN(UNIT=20,FILE='RING2.STR',STATUS='OLD')
      OPEN(UNIT=30,FILE='RING3.STR',STATUS='OLD')
      OPEN(UNIT=40,FILE='RING4.STR',STATUS='OLD')
      OPEN(UNIT=50,FILE='RING5.STR',STATUS='OLD')
      OPEN(UNIT=60,FILE='SGLOC.OUT',STATUS='OLD')
      OPEN(UNIT=70,FILE='CURVE.OUT',STATUS='NEW')
C
      PI = 3.141592654
C
C  READ IN GAUGE LOCATIONS, L, AND NUMBER OF DATA STEPS
C
      READ(60,*) ((COORD(I,J),J=1,3),I=0,29), L ,NDS
C
      CLOSE(UNIT=60)
```

```
      OPEN(UNIT=80,FILE='HVDISP.INP',STATUS='OLD')
C
C  READ IN THE Z DISTANCES TO THE STRINGPOTS AND THE BUCKLED POINT
C  READ ALL THE HORIZONTAL AND VERTICAL DISPLACEMENTS
C
      READ(80,*) BUKLPT
      READ(80,*) (Z(I),I=1,3)
      DO 125 I = 1,NDS
      READ(80,*) DX(I,1),DY(I,1),DX(I,2),DY(I,2),DX(I,3),DY(I,3)
  125 CONTINUE
      CLOSE(UNIT=80)
C  COMPUTE THE FUNCTION G(I) FOR USE IN COMPUTING DISPLACEMENTS
C
      DO 120 I =1,3
      IF (Z(I).LT.BUKLPT)THEN
         G(I) = Z(I)/BUKLPT
      ELSE
         G(I) = (L-Z(I))/(L-BUKLPT)
      ENDIF
  120 CONTINUE
C
C  READ IN THE STRAINS AND HORIZONTAL AND VERTICAL DISPLACEMENTS
C
      DO 1000 NN = 1, NDS
      JJ=NN-1
      PRINT 110, JJ, NDS-1
  110 FORMAT(' ','TIMESTEP',I3,'  OF  ',I3)
      READ(10,*) (STRAIN(I),I=0,5)
      READ(20,*) (STRAIN(I),I=6,11)
      READ(30,*) (STRAIN(I),I=12,17)
      READ(40,*) (STRAIN(I),I=18,23)
      READ(50,*) (STRAIN(I),I=24,29)
C
C  DIVIDE THE INPUTTED STRAINS BY 10**6
C
      DO 150 I = 0,29
          STRAIN(I) = STRAIN(I)/10**6
  150 CONTINUE
C
C  ITERATE FROM LEFF = 0.5*L TO 2.0L
C
      FIRST = .TRUE.
    5 ERRMIN = 100.0
      LMIN = L
      AMIN = 0.0
      BMIN = 0.0
      CMIN = 0.0
      RMIN = 0.0
      KK=0
C
C  CALCULATE MSS
C
      MSS = 0.0
      DO 20 I=0,29
```

```
         IF (ABS(STRAIN(I)).GT.0.003) THEN
            GO TO 20
         ELSE
            MSS = MSS+STRAIN(I)**2
         END IF
   20 CONTINUE
C
      DO 35 J=0,84
         KK=KK+1
         LEFF = (0.32+FLOAT(J)/50.0)*L
C
C FIND BEST A, B, AND C
C
         R=DX(NN,2)/DY(NN,2)
C
C  THE FOLLOWING LOOP FINDS THE VALUES OF A, B, AND C
C
         A11 = 0.0
         A12 = 0.0
         A13 = 0.0
         A22 = 0.0
         A23 = 0.0
         A33 = 0.0
         RHS1 = 0.0
         RHS2 = 0.0
         RHS3 = 0.0
         DO 10 I=0,29
            IF (ABS(STRAIN(I)).GT.0.003) THEN
               GO TO 10
            ELSE
               PSI = PI/LEFF*(COORD(I,3)-L/2.0)
               DUM1 = COORD(I,2)+R*COORD(I,1)
               A11 = A11+(COS(PSI)*DUM1)**2
               A12 = A12+SIN(PSI)*COS(PSI)*DUM1**2
               A13 = A13-DUM1*COS(PSI)
               A22 = A22+(SIN(PSI)*DUM1)**2
               A23 = A23-DUM1*SIN(PSI)
               A33 = A33+1
               RHS1 = RHS1-STRAIN(I)*COS(PSI)*DUM1
               RHS2 = RHS2-STRAIN(I)*SIN(PSI)*DUM1
               RHS3 = RHS3+STRAIN(I)
            END IF
   10    CONTINUE
C
C  CRAMER'S RULE TO FIND A, B AND C (NOTE: A12 = A21, A23=A32, A13=A31)
C
         DET = A11*A22*A33+2*A12*A13*A23-A22*A13**2
     +         -A33*A12**2-A11*A23**2
         A = (RHS1*A22*A33+RHS2*A13*A23+RHS3*A12*A23
     +        -RHS1*A23**2-RHS2*A12*A33-RHS3*A22*A13)/DET
         B = (RHS1*A13*A23+RHS2*A11*A33+RHS3*A12*A13
     +        -RHS1*A12*A33-RHS2*A13**2-RHS3*A23*A11)/DET
         C = (RHS1*A12*A23+RHS2*A12*A13+RHS3*A11*A22
     +        -RHS1*A13*A22-RHS2*A23*A11-RHS3*A12**2)/DET
```

```
C
C  FIND ERROR OF FIT FOR A, B, AND R
C
         RMS = 0.0
         DO 30 I=0,29
            IF (ABS(STRAIN(I)).GT.0.003) THEN
               GO TO 30
            ELSE
               PSI = PI/LEFF*(COORD(I,3)-L/2.0)
               RMS = RMS+(STRAIN(I)-C+(A*COS(PSI)+B*SIN(PSI))
     +                  *(COORD(I,2)+R*COORD(I,1)))**2
            END IF
   30    CONTINUE
         RMS = SQRT(RMS/MSS)*100.0
         IF (RMS.LT.ERRMIN) THEN
            ERRMIN = RMS
            LMIN = LEFF
            AMIN = A
            BMIN = B
            CMIN = C
         END IF
   35 CONTINUE
      LEFF = LMIN
      A = AMIN
      B = BMIN
      C = CMIN
C
C  DETERMINE IF ANY OF THE GAUGES SHOULD BE THROWN OUT
C
      IF (FIRST) THEN
         FIRST = .FALSE.
         STRER = 0.0
         RMS = 0.0
         KK = 30
      DO 50 I=0,29
         IF (ABS(STRAIN(I)).GT.0.003) THEN
            KK = KK-1
            GO TO 50
         ELSE
            PSI = PI/LEFF*(COORD(I,3)-L/2.0)
            STRERR(I) = STRAIN(I)-C+(A*COS(PSI)+B*SIN(PSI))
     +                 *(COORD(I,2)+R*COORD(I,1))
            STRER = STRER+STRERR(I)
         END IF
   50 CONTINUE
      RMS = SQRT(MSS/KK)
      STRER = STRER/KK/RMS
C
C  CALCULATE THE STANDARD DEVIATION OF THE ERRORS
C
      SDEV = 0.0
      DO 60 I=0,29
         IF (ABS(STRAIN(I)).GT.0.003) THEN
            GO TO 60
```

```
            ELSE
               SDEV = SDEV+(STRERR(I)/RMS-STRER)**2
            END IF
   60 CONTINUE
         SDEV = SQRT(SDEV/(KK-1))
C
C  THROW OUT POINTS OVER TWO STANDARD DEVIATIONS OF ERROR FROM THE AVERAGE
C     ERROR
C
         DOAGIN = .FALSE.
         DO 70 I=0,29
            IF (ABS(STRAIN(I)).GT.0.003) THEN
               GO TO 70
            ELSE IF (ABS(STRERR(I)/RMS-STRER).GT.2.0*SDEV) THEN
               STRAIN(I) = 0.0031
               DOAGIN = .TRUE.
            END IF
   70 CONTINUE
C
C  RECALCULATE A, B, AND C IF ONE OF THE GAUGES WAS THROWN OUT
C
         IF (DOAGIN) THEN
            GO TO 5
         END IF
         END IF
C
C   COMPUTE THE COEFFICIENTS OF THE LINEAR PORTION OF THE DISPLACED SHAPE
C
         NUMX = 0.0
         NUMY = 0.0
         DEN  = 0.0
         DUM1 = PI/2.0*L/LEFF
         DO 130 I = 1,3
             PSI = PI/LEFF*(Z(I)-L/2.0)
             DUM2 = (L/2.0-Z(I))/(L/2.0)
             F(I) = -(A*(COS(PSI)-COS(DUM1))+B*(SIN(PSI)+DUM2
     +               *SIN(DUM1)))*(LEFF/PI)**2
             NUMX = NUMX+(DX(NN,I)-R*F(I))*G(I)
             NUMY = NUMY+(DY(NN,I)-F(I))*G(I)
             DEN = DEN+(G(I)**2)
  130 CONTINUE
         BETAX = NUMX/DEN
         BETAY = NUMY/DEN
C
C  COMPUTE X AND Y DISPLACEMENT ERRORS
C
         MSR  = 0.0
         ERRX = 0.0
         ERRY = 0.0
         DO 170 I = 1,3
            H(I) = R*F(I) + BETAX*G(I)
            V(I) = F(I) + BETAY*G(I)
            MSR =  MSR+DX(NN,I)**2+DY(NN,I)**2
            ERRX = ERRX+(H(I)-DX(NN,I))**2
```

```
         ERRY = ERRY+(V(I)-DY(NN,I))**2
  170 CONTINUE
      EX = 100.0*SQRT(ERRX/MSR)
      EY = 100.0*SQRT(ERRY/MSR)
C
C  COMPUTE THE POINTS OF INFLECTION AND ECCENTRICITIES BASED ON CURVATURE
C
         XEFF = L/2.0-LEFF/PI*ATAN(A/B)
         IF(XEFF.GT.L/2.0) THEN
            XEFF2 = XEFF
            XEFF1 = XEFF2-LEFF
         ELSE
            XEFF1 = XEFF
            XEFF2 = XEFF1+LEFF
         END IF
         IF(XEFF1.LT.BUKLPT) THEN
            GEC = XEFF1/BUKLPT
         ELSE
            GEC = (L-XEFF1)/(L-BUKLPT)
         END IF
         DUM1 = PI/LEFF*(XEFF1-L/2.0)
         DUM2 = PI/2.0*L/LEFF
         XEC1 = BETAX*GEC-(A*(COS(DUM1)-COS(DUM2))+B*(SIN(DUM1)-2.0/L*
     +          (XEFF1-L/2.0)*SIN(DUM2)))*R*((LEFF/PI)**2)
         YEC1 = BETAY*GEC-(A*(COS(DUM1)-COS(DUM2))+B*(SIN(DUM1)-2.0/L*
     +          (XEFF1-L/2.0)*SIN(DUM2)))*((LEFF/PI)**2)
         IF(XEFF2.LT.BUKLPT) THEN
            GEC = XEFF2/BUKLPT
         ELSE
            GEC = (L-XEFF2)/(L-BUKLPT)
         END IF
         DUM1 = PI/LEFF*(XEFF2-L/2.0)
         XEC2 = BETAX*GEC-(A*(COS(DUM1)-COS(DUM2))+B*(SIN(DUM1)-2.0/L*
     +          (XEFF2-L/2.0)*SIN(DUM2)))*R*((LEFF/PI)**2)
         YEC2 = BETAY*GEC-(A*(COS(DUM1)-COS(DUM2))+B*(SIN(DUM1)-2.0/L*
     +          (XEFF2-L/2.0)*SIN(DUM2)))*((LEFF/PI)**2)
C
C  PRINT OUT FINAL RESULTS
C
      WRITE(70,100) JJ
  100 FORMAT(' '//'STEP NO. = ',I3)
C
C  PRINT OUT THE GAUGES THROWN OUT
C
      DO 250 I=0,29
         IF (STRAIN(I).EQ.0.0031) THEN
            WRITE(70,230) I
  230       FORMAT(' ','GAUGE NO. ',I2,' ELIMINATED DUE TO DEVIATION',
     +' ERROR')
         ELSE IF (ABS(STRAIN(I)).GT.0.003) THEN
            WRITE(70,240) I
  240       FORMAT(' ','GAUGE NO. ',I2,' ELIMINATED DUE TO MAX READING')
         END IF
  250 CONTINUE
```

```
      PRINT 36, LEFF/L, A, B, C, R, ERRMIN
      PRINT 300
  300 FORMAT(/)
      WRITE(70,36) LEFF/L, A, B, C, R, ERRMIN
   36 FORMAT('LEFF/L = ',F4.2,3X,'A = ',G12.5,3X,'B = ',G12.5,3X,
     +'C = ',G12.5,/'R = ',G12.5,3X,'STRAIN ERROR = ',F6.2,'%')
      WRITE(70,160) BETAX, BETAY
  160 FORMAT(' ','BETAX = ',G12.5,3X,'BETAY = ',G12.5)
      DO 200 I = 1,3
      WRITE(70,190) I, H(I), I, V(I)
  190 FORMAT(' ','X',I1,' = ',G12.5,3X,'Y',I1,' = ',G12.5)
  200 CONTINUE
      WRITE(70,180) EX, EY
  180 FORMAT(' ','X DISP ERROR = ',F6.2,'%',3X, 'Y DISP ERROR = ',
     +          F6.2,'%')
      WRITE(70,210) XEFF1/L, XEC1, YEC1, XEFF2/L, XEC2, YEC2
  210 FORMAT(' ','ZEFF1/L = ',F9.4,3X,'XEC1 = ',F9.4,3X,'YEC1 = ',F9.4,
     +/' ZEFF2/L = ',F9.4,3X,'XEC2 = ',F9.4,3X,'YEC2 = ',F9.4)
 1000 CONTINUE
C
C  CLOSE FILES AND LEAVE
C
      DO 40 I=10,50,10
         CLOSE(UNIT=I)
   40 CONTINUE
      CLOSE(UNIT=70)
      END
```

```
      PROGRAM CHANGE
*
C
C     PURPOSE:  TO ARRANGE THE OUTPUT OF THE PROGRAM CURVE.FOR INTO FILES
C               FOR PLOTTING
C
C     VARIABLE LIST:
C
C     A = COEFFICIENT OF DISPLACEMENT CURVE
C     B = COEFFICIENT OF DISPLACEMENT CURVE
C     BETAX = LINEAR PORTION OF X-DISPLACEMENT
C     BETAY = LINEAR PORTION OF Y-DISPLACEMENT
C     BUKLPT = POINT OF BUCKLING MEASURED FROM END B
C     C = AVERAGE AXIAL STRAIN
C     LEFF = COMPUTED EFFECTIVE LENGTH
C     LOAD = LOAD IN SPECIMEN
C     NS = NUMBER OF STEPS
C     R = RATIO OF X TO Y DISPLACEMENTS AT MIDSPAN
C     STEPNO = STEP NUMBER
C     TEST = A VARIABLE USED TO READ PAST DELETED GAUGE INFORMATION
C     XEC = MIDSPAN ECCENTRICITY IN THE X DIRECTION FROM TRY6.FOR
C     YEC = MIDSPAN ECCENTRICITY IN THE Y DIRECTION FROM TRY6.FOR
C
C     DECLARE VARIABLES
C
      IMPLICIT NONE
      REAL LEFF, XEC1, XEC2, YEC1, YEC2, XEC, YEC, C, A, B, LOAD, R,
     1     PI, BETAX, BETAY, BUKLPT, L, DUM1, DUM2, PSI, F, FR, BR,
     1     TD
      INTEGER NS, STEPNO, I
      CHARACTER TEST*1
C
C     OPEN FILES FOR INPUT AND OUTPUT
C
      OPEN (UNIT=10, FILE='CURVE.OUT', STATUS='OLD')
      OPEN (UNIT=20, FILE='CHANGE.OUT', STATUS='NEW')
      OPEN (UNIT=30, FILE='SPEC1.OUT', STATUS='OLD')
      OPEN (UNIT=40, FILE='ECC.INP', STATUS='NEW')
      OPEN (UNIT=50, FILE='ECCIP.PLT', STATUS='NEW')
      OPEN (UNIT=60, FILE='LOAD.PLT', STATUS='NEW')
      OPEN (UNIT=70, FILE='BETA.PLT', STATUS='NEW')
C
C     READ AND ARRANGE DATA
C
      READ (10,*) NS, BUKLPT, L
      DO 50 I = 1,NS+1
         READ (10,10) STEPNO
    4    READ(10,5) TEST
         IF (ICHAR(TEST).EQ.71) GO TO 4
         BACKSPACE(UNIT=10)
         READ (10,20) LEFF, A, B, C
         READ (10,22) R
         READ (10,23) BETAX, BETAY
         READ (10,25) XEC1, YEC1
```

```
        READ (10,30) XEC2, YEC2
        READ (30,55) LOAD
           XEC = (XEC1+XEC2)/2
           YEC = (YEC1+YEC2)/2
        PI = 3.14159
        DUM1 = PI/2.0*L/LEFF
        DUM2 = (L/2-BUKLPT)/(L/2)
        PSI = PI/LEFF*(BUKLPT-L/2)
        F = -(A*(COS(PSI)-COS(DUM1))+B*(SIN(PSI)+DUM2*SIN(DUM1)))
     1       *(LEFF/PI)**2
        FR = F*SQRT(1+R**2)
        BR = SQRT(BETAX**2+BETAY**2)
        TD = FR+BR
        WRITE (20,40) STEPNO, LEFF, XEC, YEC, C
        WRITE (40,60) LEFF, A, B, R, LOAD
        WRITE (50,65) XEC1, XEC2, XEC, YEC1, YEC2, YEC
        WRITE (60,70) STEPNO, LOAD
        WRITE (70,75) FR, BR, TD
   50 CONTINUE
C
C     FORMAT STATEMENTS
C
    5 FORMAT(1X,A1)
   10 FORMAT(11X,I3)
   20 FORMAT(9X,F4.2,3(7X,G12.5))
   22 FORMAT(4X,G12.5)
   23 FORMAT(9X,G12.5,11X,G12.5,////)
   25 FORMAT(30X,F9.4,10X,F9.4)
   30 FORMAT(30X,F9.4,10X,F9.4,//)
   40 FORMAT(' ',I3, 3X, F4.2, 3X,F7.4,3X, F7.4, 3X, G12.5)
   55 FORMAT(11X,F9.4)
   60 FORMAT(' ',F4.2,3X,G12.5,3X,G12.5,3X,G12.5,3X,F9.4)
   65 FORMAT(' ',6(G12.5,1X))
   70 FORMAT(' ',I3,3X,F9.4)
   75 FORMAT(' ',3(G12.5,3X))
      END
```

```
      PROGRAM ECC
*
C
C  PURPOSE:  THIS PROGRAM CALCULATES THE END ECCENTRICITES OF THE PIPE AND
C            AVERAGES THEM.
C
C  VARIABLE LIBRARY
C
C     A = THE COEFFICIENT OF THE COSINE TERM USED TO FIT THE DISPLACED
C         SHAPE IN CURVE.FOR
C     B = THE COEFFICIENT OF THE SINE TERM USED TO FIT THE DISPLACED
C         SHAPE IN CURVE.FOR
C     EI = YOUNG'S MODULUS TIMES THE MOMENT OF INERTIA
C     EX1 = THE X-ECCENTRICITY AT Z = 0
C     EX2 = THE X-ECCENTRICITY AT Z = L
C     EY1 = THE Y-ECCENTRICITY AT Z = 0
C     EY2 = THE Y-ECCENTRICITY AT Z = L
C     I = A LOOP COUNTER
C     KE = THE LENGTH OF THE PIPE DIVIDED BY THE EFFECTIVE LENGTH OF THE
C          PIPE
C     NOSTEP = THE NUMBER OF TIME STEPS
C     P = LOAD
C     PI = 3.141592654
C     R = Y-CURVATURE/X-CURVATURE
C
C  TYPE DECLARATIONS
C
      IMPLICIT NONE
      INTEGER I, NOSTEP
      REAL A, B, EI, EX1, EX2, EY1, EY2, KE, P, PI, R
C
C  OPEN INPUT AND OUTPUT FILES
C
      OPEN(UNIT=10,FILE='ECC.INP',STATUS='OLD')
      OPEN(UNIT=20,FILE='ECC.OUT',STATUS='NEW')
      OPEN(UNIT=30,FILE='ECC.PLT',STATUS='NEW')
C
C  READ IN THE NUMBER OF TIME STEPS AND EI
C
      READ(10,*) NOSTEP, EI
C
C  CALCULATE THE ECCENTRICITIES AND WRITE THEM TO THE OUTPUT FILE
C
      PI = 3.141592654
      DO 30 I=0,NOSTEP
         READ(10,*) KE, A, B, R, P
         EY1 = EI/P*(A*COS(PI/(2.0*KE))-B*SIN(PI/(2.0*KE)))
         EY2 = EI/P*(A*COS(PI/(2.0*KE))+B*SIN(PI/(2.0*KE)))
         EX1 = EY1*R
         EX2 = EY2*R
         WRITE(20,25) I,EX1,EY1,EX2,EY2,(EX1+EX2)/2.0,(EY1+EY2)/2.0
         WRITE(30,20) EX1, EX2, (EX1+EX2)/2.0, EY1, EY2, (EY1+EY2)/2.0
   30 CONTINUE
C
```

```
C  FORMAT STATEMENTS
C
   20 FORMAT(' ',6(G12.5,1X))
   25 FORMAT(' ','STEP NO.',I3/'EX1 = ',G12.5,3X,'EY1 = ',G12.5/'EX2 = '
     +,G12.5,3X,'EY2 = ',G12.5/'AVERAGE EX = ',G12.5,3X,'AVERAGE EY = ',
     +G12.5/)
C
C  CLOSE FILES AND LEAVE
C
      CLOSE(UNIT=10)
      CLOSE(UNIT=20)
      CLOSE(UNIT=30)
      END
```

APPENDIX C

DERIVATION OF FORMULATION OF THE LEAST SQUARES ERROR ANALYSIS FOR CURVE

APPENDIX C
DERIVATION OF FORMULATION OF THE LEAST SQUARES ERROR ANALYSIS FOR CURVE

At any location on the test specimen, the strain may be expressed as a function of the specimen curvatures and the coordinates of the location. This relationship may be written as:

$$\varepsilon = -yk_x(z) - xk_y(z) + C \qquad \text{C-1)}$$

where: ε = total strain at a point in the specimen

x,y,z = coordinates of point

k_x = curvature about the specimen x-axis = $\frac{d^2y}{dz^2}$

k_y = curvature about the specimen y-axis = $\frac{d^2x}{dz^2}$

C = strain due to axial load, constant for a given axial load, P.

The curvature for a buckled member can be written as:

$$k_x = A \cos\left[\frac{\pi}{L_e}\left(z-\frac{L}{2}\right)\right] + B \sin\left[\frac{\pi}{L_e}\left(z-\frac{L}{2}\right)\right] \qquad \text{C-2)}$$

where: A,B = constants

L = length of specimen

L_e = distance between inflection points (locations of zero moment).

The "effective length" of a buckled member can then be computed as the distance between inflection points divided by the length of the column or (L_e/L). The y-axis curvature was related to the x-axis curvature using the relationship:

$$k_y(z) = rk_x(z)$$

where: $r = \frac{\Delta x(2)}{\Delta y(2)}$ C-3)

and $\Delta x(2)$ = measured x displacement at or near midspan

$\Delta y(2)$ = measured y displacement at or near midspan.

The constants A, B, C, and L_e were determined to provide the least-square error to the 30 measured strains (ε_m).

Substituting Eq. C-3 into Eq. C-1 results in:

$$\varepsilon = -(y + rx)k_x(z) + C. \qquad \text{C-4)}$$

Eq. C-2 can also be written as:

$$k_x = A \cos\psi + B \sin\psi \qquad \text{C-5)}$$

where $\psi = \frac{\pi}{L_e}(z - \frac{L}{2})$.

Substituting Eq. C-5 into Eq. C-4 results in an expression for computing the total strain:

$$\varepsilon = -(y + rx)(A \cos\psi + B \sin\psi) + C. \qquad \text{C-6)}$$

Subtracting the calculated strain, ε, from the measured strain, ε_m, at each gage location results in the fit error, *EFIT*, or:

$$EFIT = \varepsilon_m - \varepsilon. \qquad \text{C-7)}$$

The total error of the data fit was computed by summing the square of the errors of all individual measurements:

$$\xi = \sum_{i=1,n} [EFIT(i)]^2 \qquad \text{C-8)}$$

where: n = number of measured strains.

Eq. C-8 is an expression of the error, ξ, which was minimized to obtain the best fit to the measured strains. Typically n = 30; however, strain readings from gages in a yielded region, i.e., gages with $|\varepsilon_m| > 3000$, and readings which were statistical outliers were excluded from the data fit. To determine the statistical outliers, the strain error for each gage with $\varepsilon_m < 3000$ was computed at each data step. The average and the standard deviation of these strain errors were also calculated at each data step. Any gage with a strain error greater than two standard deviations from the average strain error was considered a statistical outlier and was eliminated from the data for that load step.

The constants *A*, *B*, *C*, and L_e were determined to calculate the strain at a given location at each load step. To obtain the best fit for the measured strains, L_e was varied from $0.32L$ to $2.00L$. This corresponds to an effective length between 0.32 and 2.00 which were believed to be acceptable lower and upper bound values for the end conditions in this study. For each value of L_e, the constants *A*, *B*, and *C* were computed that resulted in the least-square error. This error was then compared to the error for the other values of L_e. The L_e that resulted in the minimum least-square error was determined to be the effective length of the specimen for that load step. Values for L_e were determined at all data steps.

In order to obtain the least-square error, the partial derivative of the error, ξ, was taken with respect to the constants *A*, *B*, and *C* and set equal to zero. This results in three equations:

$$\frac{\partial \xi}{\partial A} = 2\,\Sigma\, EFIT * \frac{\partial(-\varepsilon)}{\partial A} = 0$$

$$\frac{\partial \xi}{\partial A} = 2\,\Sigma\, EFIT * (y + rx)\cos\psi = 0 \qquad \text{C-9)}$$

$$\frac{\partial \xi}{\partial B} = 2\,\Sigma\, EFIT * \frac{\partial(-\varepsilon)}{\partial B} = 0$$

$$\frac{\partial \xi}{\partial B} = 2\,\Sigma\, EFIT * (y + rx)\sin\psi = 0 \qquad \text{C-10)}$$

$$\frac{\partial \xi}{\partial C} = 2\,\Sigma\, EFIT * \frac{\partial(-\varepsilon)}{\partial C} = 0$$

$$\frac{\partial \xi}{\partial C} = 2\,\Sigma\, EFIT * (-1) = 0 \qquad \text{C-11)}$$

which can be solved simultaneously to obtain A, B, and C.

Substituting Eq. C-6 into Eq. C-7 results in an expression for $EFIT$:

$$EFIT = \varepsilon_m + (y + rx)(A \cos\psi + B \sin\psi) - C. \quad \text{C-12)}$$

Substituting Eq. C-12 into Eq. C-9 gives:

$$m_{11}A + m_{12}B + m_{13}C = a_1 \quad \text{C-13)}$$

where:

$$m_{11} = \Sigma(y_i + rx_i)^2 \cos^2\psi_i$$

$$m_{12} = \Sigma (y_i + rx_i)^2 \sin\psi_i \cos\psi_i$$

$$m_{13} = - \Sigma (y_i + rx_i) \cos\psi_i$$

$$a_1 = - \Sigma \varepsilon_{m_i} (y_i + rx_i) \cos\psi_i .$$

Similarly, substituting Eq. C-12 into Eq. C-10 gives:

$$m_{21}A + m_{22}B + m_{23}C = a_2 \quad \text{C-14)}$$

where:

$$m_{21} = m_{12}$$

$$m_{22} = \Sigma (y_i + rx_i)^2 \sin^2\psi_i$$

$$m_{23} = - \Sigma (y_i + rx_i) \sin\psi_i$$

$$a_2 = - \Sigma \varepsilon_{m_i} (y_i + rx_i) \sin\psi_i .$$

Finally, substituting Eq. C-12 into Eq. C-11 gives:

$$m_{31}A + m_{32}B + m_{33}C = a_3 \quad \text{C-15)}$$

where:

$$m_{31} = m_{13}$$

$$m_{32} = m_{23}$$

$$m_{33} = n$$

$$a_3 = \Sigma \varepsilon_{m_i} .$$

Writing Eqs. C-13, C-14, and C-15 in matrix form:

$$\begin{bmatrix} m_{11} & m_{12} & m_{13} \\ m_{12} & m_{22} & m_{23} \\ m_{13} & m_{23} & m_{33} \end{bmatrix} \begin{Bmatrix} A \\ B \\ C \end{Bmatrix} = \begin{Bmatrix} a_1 \\ a_2 \\ a_3 \end{Bmatrix}. \qquad \text{C-16)}$$

Applying Cramer's Rule to Eq. C-16, the unknown constants are obtained by:

$$\det = m_{11}m_{22}m_{33} + 2m_{12}m_{13}m_{23} - m_{13}^2 m_{22} - m_{12}^2 m_{33} - m_{23}^2 m_{11}$$

$$A = \frac{1}{\det}[a_1 m_{22} m_{33} + a_2 m_{13} m_{23} + a_3 m_{12} m_{23} - a_1 m_{23}^2 - a_2 m_{12} m_{33} - a_3 m_{22} m_{13}]$$

$$B = \frac{1}{\det}[a_1 m_{13} m_{23} + a_2 m_{11} m_{33} + a_3 m_{12} m_{13} - a_1 m_{12} m_{33} - a_2 m_{13}^2 - a_3 m_{23} m_{11}]$$

$$C = \frac{1}{\det}[a_1 m_{12} m_{23} + a_2 m_{12} m_{13} + a_3 m_{11} m_{22} - a_1 m_{13} m_{22} - a_2 m_{23} m_{11} - a_3 m_{12}^2].$$

If the strain gages are evenly spaced around the circumference of the specimen and if all gages are included, then $m_{13} = m_{23} = 0$ so that $C = a_3/n$. The curvature about the x and y axis was calculated using Eq. C-5 and C-3.

The expression for curvature was integrated twice to determine the deflection of the specimen due to bending. Integrating Eq. C-2 twice and applying the boundary conditions, f(0) = 0 and f(L) = 0, results in:

$$f(z) = \frac{-L_e^2}{\pi^2}\left\{ k_x(z) - A\cos\left[\frac{\pi}{L_e}\left(\frac{L}{2}\right)\right] + B\sin\left[\frac{\pi}{L_e}\left(\frac{L}{2}\right)\left(\frac{\frac{L}{2} - z}{\frac{L}{2}}\right)\right]\right\} \qquad \text{C-17)}$$

where: $f(z)$ = y deflection at location z from origin of coordinate system.

It was observed during the full-scale testing that a hinge often forms at some location along the specimen. Thus, a rigid body component was included in the total deflection expression. The total deflection at any location on the specimen was then calculated as:

$$\Delta x(z) = rf(z) + \beta_x g(z)$$

and **C-18)**

$$\Delta y(z) = f(z) + \beta_y g(z)$$

where: β_x and β_y = constants equal to the rigid body deflections at the point of hinging in x and y directions, respectively

$g(z)$ = function relating the hinging location and any location on the specimen

$$g(z) = \begin{cases} \dfrac{z}{z_b} & \textit{for } z \le z_b \\[2ex] \dfrac{L - z}{L - z_b} & \textit{for } z \ge z_b \end{cases}$$

z_b = location of hinge.

The rigid body deflection constants, β_x and β_y, were determined to produce calculated displacements with a least-square error to the measured displacements. This was done by computing an error term for the calculated displacements, setting the derivatives of the error term with respect to β_x and β_y to zero, and solving the resulting equations.

Taking z_j to be the location of a measured displacement, then:

$$f_j = f(z_j)$$

$$g_j = g(z_j).$$ **C-19)**

If the measured displacements at z_j are denoted by Δx_j and Δy_j, the error term for the displacement in the x direction, $EDISP$, becomes:

$$EDISP = rf_j + \beta_x g_j - \Delta x_j. \qquad \text{C-20)}$$

The total error for the x-displacements, ζ, was calculated as the sum of the squares of the individual *EDISP* errors, so that:

$$\zeta = \sum_{j=1,m} (rf_j + \beta_x g_j - \Delta x_j)^2 \qquad \text{C-21)}$$

where: m = number of locations where x displacement was measured = 3.

Taking the partial derivative of Eq. C-21 with respect to β_x:

$$\frac{\partial \zeta}{\partial \beta_x} = 2 \Sigma (rf_j + \beta_x g_j - \Delta x_j)\, g_j. \qquad \text{C-22)}$$

To minimize the x displacement error, set Eq. C-22 equal to zero and solve for β_x so that:

$$\beta_x = \frac{\Sigma (\Delta x_j - rf_j)\, g_j}{\Sigma g_j^2}. \qquad \text{C-23)}$$

Similarly, the error was minimized for the y displacements by taking the partial derivative of ζ with respect to β_y and setting it equal to zero, where:

$$\zeta = \sum_{j=1,m} (f_j + \beta_y g_j - \Delta y_j)^2. \qquad \text{C-24)}$$

The resulting equation is:

$$\beta_y = \frac{\Sigma (\Delta y_j - f_j)\, g_j}{\Sigma g_j^2}. \qquad \text{C-25)}$$

A FORTRAN computer code, CURVE, was written to perform the analysis described in this appendix and is listed on the following pages. In addition to determining the effective length of the specimen, the x and y eccentricities of the applied load was also computed. This was accomplished by computing the x and y displacements at the two inflection locations. Since the moment must be zero at an inflection location, the line of action of the load must pass through the centroid of the cross section at that location. Therefore, the x and y displacements at the inflection locations must be equal to the x and y eccentricities of the applied load.

APPENDIX D

ECCENTRICITY AS COMPUTED FROM APPLIED LOADS AND END MOMENTS

APPENDIX D
ECCENTRICITY AS COMPUTED FROM APPLIED LOADS AND END MOMENTS

In the experimental program, the line of action of the applied compressive load was located as near to the centroid of the cross section as possible. Since the ends of the specimens were not attached to the load frame, it was possible for the ends to rotate if the specimen failed in an overall buckling mode. If the ends rotated, the compressive load was no longer applied through the centroid of the cross section, but rather, was applied eccentrically. The eccentricity of loading was determined by computing the displacements at the inflection points of the buckled specimen as described in Appendix C. In addition, the load eccentricity may also be calculated using the end moments as computed from the curvature of the buckled specimen. This appendix contains a detailed description of this method for computing the load eccentricity.

An eccentric compressive load induces an applied bending moment at the ends of the specimen. This applied bending moment is:

$$M = Pe \qquad \text{D-1)}$$

where: P = applied compressive load

e = eccentricity of applied load.

From fundamental mechanics, the bending moment can be expressed in terms of the curvature at any location along a member by:

$$M_i = k_i E I_i \qquad \text{D-2)}$$

where: M_i = bending moment with respect to the i axis

k_i = specimen curvature with respect to the i axis

E = modulus of elasticity (29,500 ksi)

I_i = moment of inertia with respect to the i axis.

APPENDIX C
DERIVATION OF FORMULATION OF THE LEAST SQUARES ERROR ANALYSIS FOR CURVE

At any location on the test specimen, the strain may be expressed as a function of the specimen curvatures and the coordinates of the location. This relationship may be written as:

$$\varepsilon = -yk_x(z) - xk_y(z) + C \qquad \text{C-1)}$$

where: ε = total strain at a point in the specimen

x,y,z = coordinates of point

k_x = curvature about the specimen x-axis = $\dfrac{d^2y}{dz^2}$

k_y = curvature about the specimen y-axis = $\dfrac{d^2x}{dz^2}$

C = strain due to axial load, constant for a given axial load, P.

The curvature for a buckled member can be written as:

$$k_x = A\cos\left[\frac{\pi}{L_e}\left(z-\frac{L}{2}\right)\right] + B\sin\left[\frac{\pi}{L_e}\left(z-\frac{L}{2}\right)\right] \qquad \text{C-2)}$$

where: A,B = constants

L = length of specimen

L_e = distance between inflection points (locations of zero moment).

The "effective length" of a buckled member can then be computed as the distance between inflection points divided by the length of the column or (L_e/L). The y-axis curvature was related to the x-axis curvature using the relationship:

$$k_y(z) = rk_x(z)$$

where: $r = \dfrac{\Delta x(2)}{\Delta y(2)}$ C-3)

and $\Delta x(2)$ = measured x displacement at or near midspan

$\Delta y(2)$ = measured y displacement at or near midspan.

The constants A, B, C, and L_e were determined to provide the least-square error to the 30 measured strains (ε_m).

Substituting Eq. C-3 into Eq. C-1 results in:

$$\varepsilon = -(y + rx)k_x(z) + C. \qquad \text{C-4)}$$

Eq. C-2 can also be written as:

$$k_x = A \cos\psi + B \sin\psi \qquad \text{C-5)}$$

where $$\psi = \frac{\pi}{L_e}(z - \frac{L}{2}).$$

Substituting Eq. C-5 into Eq. C-4 results in an expression for computing the total strain:

$$\varepsilon = -(y + rx)(A \cos\psi + B \sin\psi) + C. \qquad \text{C-6)}$$

Subtracting the calculated strain, ε, from the measured strain, ε_m, at each gage location results in the fit error, *EFIT*, or:

$$EFIT = \varepsilon_m - \varepsilon. \qquad \text{C-7)}$$

The total error of the data fit was computed by summing the square of the errors of all individual measurements:

$$\xi = \sum_{i=1,n} [EFIT(i)]^2 \qquad \text{C-8)}$$

where: n = number of measured strains.

Eq. C-8 is an expression of the error, ξ, which was minimized to obtain the best fit to the measured strains. Typically n = 30; however, strain readings from gages in a yielded region, i.e., gages with $|\varepsilon_m| > 3000$, and readings which were statistical outliers were excluded from the data fit. To determine the statistical outliers, the strain error for each gage with $\varepsilon_m < 3000$ was computed at each data step. The average and the standard deviation of these strain errors were also calculated at each data step. Any gage with a strain error greater than two standard deviations from the average strain error was considered a statistical outlier and was eliminated from the data for that load step.

The constants *A*, *B*, *C*, and L_e were determined to calculate the strain at a given location at each load step. To obtain the best fit for the measured strains, L_e was varied from $0.32L$ to $2.00L$. This corresponds to an effective length between 0.32 and 2.00 which were believed to be acceptable lower and upper bound values for the end conditions in this study. For each value of L_e, the constants *A*, *B*, and *C* were computed that resulted in the least-square error. This error was then compared to the error for the other values of L_e. The L_e that resulted in the minimum least-square error was determined to be the effective length of the specimen for that load step. Values for L_e were determined at all data steps.

In order to obtain the least-square error, the partial derivative of the error, ξ, was taken with respect to the constants *A*, *B*, and *C* and set equal to zero. This results in three equations:

$$\frac{\partial \xi}{\partial A} = 2 \sum EFIT * \frac{\partial(-\varepsilon)}{\partial A} = 0$$

$$\frac{\partial \xi}{\partial A} = 2 \sum EFIT * (y + rx)\cos\psi = 0 \qquad \text{C-9)}$$

$$\frac{\partial \xi}{\partial B} = 2 \sum EFIT * \frac{\partial(-\varepsilon)}{\partial B} = 0$$

$$\frac{\partial \xi}{\partial B} = 2 \sum EFIT * (y + rx)\sin\psi = 0 \qquad \text{C-10)}$$

$$\frac{\partial \xi}{\partial C} = 2 \sum EFIT * \frac{\partial(-\varepsilon)}{\partial C} = 0$$

$$\frac{\partial \xi}{\partial C} = 2 \sum EFIT * (-1) = 0 \qquad \text{C-11)}$$

which can be solved simultaneously to obtain ***A, B,*** and ***C***.

Substituting Eq. C-6 into Eq. C-7 results in an expression for *EFIT*:

$$EFIT = \varepsilon_m + (y + rx)(A \cos\psi + B \sin\psi) - C. \qquad \text{C-12)}$$

Substituting Eq. C-12 into Eq. C-9 gives:

$$m_{11}A + m_{12}B + m_{13}C = a_1 \qquad \text{C-13)}$$

where:

$$m_{11} = \Sigma(y_i + rx_i)^2 \cos^2\psi_i$$

$$m_{12} = \Sigma\,(y_i + rx_i)^2 \sin\psi_i \cos\psi_i$$

$$m_{13} = -\Sigma\,(y_i + rx_i) \cos\psi_i$$

$$a_1 = -\Sigma\,\varepsilon_{m_i}\,(y_i + rx_i) \cos\psi_i.$$

Similarly, substituting Eq. C-12 into Eq. C-10 gives:

$$m_{21}A + m_{22}B + m_{23}C = a_2 \qquad \text{C-14)}$$

where:

$$m_{21} = m_{12}$$

$$m_{22} = \Sigma\,(y_i + rx_i)^2 \sin^2\psi_i$$

$$m_{23} = -\Sigma\,(y_i + rx_i) \sin\psi_i$$

$$a_2 = -\Sigma\,\varepsilon_{m_i}\,(y_i + rx_i) \sin\psi_i.$$

Finally, substituting Eq. C-12 into Eq. C-11 gives:

$$m_{31}A + m_{32}B + m_{33}C = a_3 \qquad \text{C-15)}$$

where:

$$m_{31} = m_{13}$$

$$m_{32} = m_{23}$$

$$m_{33} = n$$

$$a_3 = \Sigma\,\varepsilon_{m_i}.$$

Writing Eqs. C-13, C-14, and C-15 in matrix form:

$$\begin{bmatrix} m_{11} & m_{12} & m_{13} \\ m_{12} & m_{22} & m_{23} \\ m_{13} & m_{23} & m_{33} \end{bmatrix} \begin{Bmatrix} A \\ B \\ C \end{Bmatrix} = \begin{Bmatrix} a_1 \\ a_2 \\ a_3 \end{Bmatrix}. \qquad \text{C-16)}$$

Applying Cramer's Rule to Eq. C-16, the unknown constants are obtained by:

$$\det = m_{11}m_{22}m_{33} + 2m_{12}m_{13}m_{23} - m_{13}^2m_{22} - m_{12}^2m_{33} - m_{23}^2m_{11}$$

$$A = \frac{1}{\det}[a_1m_{22}m_{33} + a_2m_{13}m_{23} + a_3m_{12}m_{23} - a_1m_{23}^2 - a_2m_{12}m_{33} - a_3m_{22}m_{13}]$$

$$B = \frac{1}{\det}[a_1m_{13}m_{23} + a_2m_{11}m_{33} + a_3m_{12}m_{13} - a_1m_{12}m_{33} - a_2m_{13}^2 - a_3m_{23}m_{11}]$$

$$C = \frac{1}{\det}[a_1m_{12}m_{23} + a_2m_{12}m_{13} + a_3m_{11}m_{22} - a_1m_{13}m_{22} - a_2m_{23}m_{11} - a_3m_{12}^2].$$

If the strain gages are evenly spaced around the circumference of the specimen and if all gages are included, then $m_{13} = m_{23} = 0$ so that $C = a_3/n$. The curvature about the x and y axis was calculated using Eq. C-5 and C-3.

The expression for curvature was integrated twice to determine the deflection of the specimen due to bending. Integrating Eq. C-2 twice and applying the boundary conditions, f(0) = 0 and f(L) = 0, results in:

$$f(z) = \frac{-L_e^2}{\pi^2}\left\{k_x(z) - A\cos\left[\frac{\pi}{L_e}\left(\frac{L}{2}\right)\right] + B\sin\left[\frac{\pi}{L_e}\left(\frac{L}{2}\right)\left(\frac{\frac{L}{2} - z}{\frac{L}{2}}\right)\right]\right\} \qquad \text{C-17)}$$

where: $f(z)$ = y deflection at location z from origin of coordinate system.

It was observed during the full-scale testing that a hinge often forms at some location along the specimen. Thus, a rigid body component was included in the total deflection expression. The total deflection at any location on the specimen was then calculated as:

$$\Delta x(z) = rf(z) + \beta_x g(z)$$

and C-18)

$$\Delta y(z) = f(z) + \beta_y g(z)$$

where: β_x and β_y = constants equal to the rigid body deflections at the point of hinging in x and y directions, respectively

$g(z)$ = function relating the hinging location and any location on the specimen

$$g(z) = \left\{ \begin{array}{ll} \dfrac{z}{z_b} & \textit{for } z \le z_b \\ \dfrac{L - z}{L - z_b} & \textit{for } z \ge z_b \end{array} \right\}$$

z_b = location of hinge.

The rigid body deflection constants, β_x and β_y, were determined to produce calculated displacements with a least-square error to the measured displacements. This was done by computing an error term for the calculated displacements, setting the derivatives of the error term with respect to β_x and β_y to zero, and solving the resulting equations.

Taking z_j to be the location of a measured displacement, then:

$$f_j = f(z_j)$$

$$g_j = g(z_j). \qquad \text{C-19)}$$

If the measured displacements at z_j are denoted by Δx_j and Δy_j, the error term for the displacement in the x direction, *EDISP*, becomes:

$$EDISP = rf_j + \beta_x g_j - \Delta x_j. \qquad \text{C-20)}$$

The total error for the x-displacements, ζ, was calculated as the sum of the squares of the individual *EDISP* errors, so that:

$$\zeta = \sum_{j=1,m} (rf_j + \beta_x g_j - \Delta x_j)^2 \qquad \text{C-21)}$$

where: m = number of locations where x displacement was measured = 3.

Taking the partial derivative of Eq. C-21 with respect to β_x:

$$\frac{\partial \zeta}{\partial \beta_x} = 2 \Sigma (rf_j + \beta_x g_j - \Delta x_j) g_j. \qquad \text{C-22)}$$

To minimize the x displacement error, set Eq. C-22 equal to zero and solve for β_x so that:

$$\beta_x = \frac{\Sigma (\Delta x_j - rf_j) g_j}{\Sigma g_j^2}. \qquad \text{C-23)}$$

Similarly, the error was minimized for the y displacements by taking the partial derivative of ζ with respect to β_y and setting it equal to zero, where:

$$\zeta = \sum_{j=1,m} (f_j + \beta_y g_j - \Delta y_j)^2. \qquad \text{C-24)}$$

The resulting equation is:

$$\beta_y = \frac{\Sigma (\Delta y_j - f_j) g_j}{\Sigma g_j^2}. \qquad \text{C-25)}$$

A FORTRAN computer code, CURVE, was written to perform the analysis described in this appendix and is listed on the following pages. In addition to determining the effective length of the specimen, the x and y eccentricities of the applied load was also computed. This was accomplished by computing the x and y displacements at the two inflection locations. Since the moment must be zero at an inflection location, the line of action of the load must pass through the centroid of the cross section at that location. Therefore, the x and y displacements at the inflection locations must be equal to the x and y eccentricities of the applied load.

APPENDIX D

ECCENTRICITY AS COMPUTED FROM APPLIED LOADS AND END MOMENTS

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ECCENTRICITY AS COMPUTED FROM APPLIED LOADS AND END MOMENTS

In the experimental program, the line of action of the applied compressive load was located as near to the centroid of the cross section as possible. Since the ends of the specimens were not attached to the load frame, it was possible for the ends to rotate if the specimen failed in an overall buckling mode. If the ends rotated, the compressive load was no longer applied through the centroid of the cross section, but rather, was applied eccentrically. The eccentricity of loading was determined by computing the displacements at the inflection points of the buckled specimen as described in Appendix C. In addition, the load eccentricity may also be calculated using the end moments as computed from the curvature of the buckled specimen. This appendix contains a detailed description of this method for computing the load eccentricity.

An eccentric compressive load induces an applied bending moment at the ends of the specimen. This applied bending moment is:

$$M = Pe \qquad \text{D-1)}$$

where: P = applied compressive load

e = eccentricity of applied load.

From fundamental mechanics, the bending moment can be expressed in terms of the curvature at any location along a member by:

$$M_i = k_i E I_i \qquad \text{D-2)}$$

where: M_i = bending moment with respect to the i axis

k_i = specimen curvature with respect to the i axis

E = modulus of elasticity (29,500 ksi)

I_i = moment of inertia with respect to the i axis.

Substituting Eq. D-2 into Eq. D-1 results in:

$$Pe_j = k_i EI_i. \qquad \text{D-3)}$$

Solving Eq. D-3 for eccentricity results in:

$$e_j = EI_i \frac{k_i}{P} \qquad \text{D-4)}$$

where: j axis is perpendicular to the i axis.

The modulus of elasticity and moment of inertia were assumed constant along the length of each specimen for all load steps. The moment of inertia was computed based on nominal section properties while the applied compressive load was computed from the measured data at each load step. The curvature at each end of the specimen was determined by substituting z = 0 and z = L into Eq. C-3 and C-5 of Appendix C. Using Eq. D-4, the eccentricity in the x and y directions at each end of the specimen was then computed for each load step.

The computer program ECC was written and utilized to perform these calculations. A listing of this program can be found in Appendix B.