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CYCLIC MECHANICAL TESTS AND AN APPROPRIATE ANALYTICAL STRESS-STRAIN MODEL FOR A36 STEEL

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This report establishes the monotonic and steady-state cyclic stress-strain properties for smooth, uniaxially-loaded specimens of A36 steel. Transient characteristics of cyclic hardening and softening and cyclic relaxation of mean stress are investigated. Deflection versus load and strain versus load are reported for a simple beam subjected to three-point bending. Six computer programs are included. These programs were developed to fit specific needs of the finite element program for determining energy dissipation in dynamically loaded structures.

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FOREWORD

The work was performed by the Construction Engineering Research Laboratory (CERL) for the Directorate of Military Construction, Office of the Chief of Engineers, under Project 4A161102B52E, "Research in Military Engineering and Construction," Task 09, "Analytical and Theoretical Studies of Complex Structural Systems," Work Unit 002, "Energy Dissipation in Dynamically Loaded Structures." This work was performed under Purchase Order No. DACA88-72-M-1178, with Mr. Fred B. Plummer as contracting officer. The OCE Technical Monitor was Mr. William Heitmann.

Mr. J. J. Healy is Chief of the Materials Systems and Science Division. Dr. L. R. Shaffer is Director of CERL.

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CYCLIC MECHANICAL TESTS AND AN APPROPRIATE ANALYTICAL STRESS-STRAIN MODEL FOR A36 STEEL

1 INTRODUCTION

A total of 15 uniaxial specimens were tested to characterize the monotonic, cyclic steady-state and transient properties of A36 steel. Table 1 describes the test program. One beam specimen was tested in three-point bending. A total of six computer programs are supplied with three of these programs based on a series rheological model and the other three based on a parallel model. A listing of the programs can be found in Appendix B.

2 TEST APPARATUS AND PROCEDURES

All testing was performed on a closed-loop, servo-controlled testing machine. Definitions and terminology concur with the manual by Raske and Morrow.[1] Smooth specimen configuration is shown in Figure 1a; the beam geometry and loading is described in Figure 1b.

3 MONOTONIC TENSION

Similar to other mild steels, A36 steel exhibits pronounced upper and lower yield points followed by relatively flat-top behavior. Strain hardening is seen only after an appreciable strain has been reached. Figure 2 is a reproduction of the original X-Y plot for monotonic tension. The difference between engineering stress-strain and true stress-strain can be seen in Figure 3.

The stress-strain behavior of a metal may be expressed by:

$$\varepsilon_p = (\sigma/K)^{1/n}. \qquad \text{[Eq 1]}$$

The constants for Eq 1 were determined by least square fits of the data shown in Figure 4. A single fit for these data would not be appropriate; therefore, the stress-strain curve was divided into two segments. Although the slope of the initial portion of the curve is negative, a line with a very small slope (n = 0.001) would also be accurate. Figure 5 demonstrates the accuracy of Eq 2 to predict the actual stress-strain behavior:

$$\varepsilon = \sigma/E + (\sigma/K)^{1/n}. \qquad \text{[Eq 2]}$$

Table 2 lists the properties obtained from this tension test.

4 STEADY-STATE CYCLIC STRESS-STRAIN

The steady-state cyclic behavior of a metal may be characterized by the cyclic stress-strain curve (Eq 2), which is defined as a curve passing through the locus of tips of a set of stable hysteresis loops. Similar to the monotonic tension stress-strain curve, the cyclic curve may also be expressed by a power function. Averaging the tension and compression tips for individual loops, Eq 1 and 2 become:

$$\Delta \varepsilon_p/2 = (\Delta\sigma/2K)^{1/n} \qquad \text{[Eq 3]}$$

$$\Delta \varepsilon/2 = \Delta\sigma/2E + (\Delta\sigma/2K)^{1/n}. \qquad \text{[Eq 4]}$$

The cyclic stress-strain curve was determined by two methods: an incremental step test and monotonic tension after precycling. Figures 6 and 7 show the stable stress-strain response from an incremental step test. To determine constants for Eq 3 and 4, the data from Figures 6 and 7 were plotted (Figure 8) and a least squares fit made. Figure 9 shows the stress-strain curve for monotonic tension after precycling. This curve was obtained immediately after the load sequence (Figure 7) and on the same specimen. Although the curve in Figure 7 is for monotonic tension, it represents stable cyclic behavior. Figure 10 shows the data fit to Eq 1. Table 2 lists the properties obtained from this test.

A comparison of the cyclic stress-strain curves obtained by these two methods is shown in Figure 11. Also included in Figure 11 is the monotonic curve. The ability of Eq 4 to simulate actual data from the incremental step test is shown in Figure 12.

Ideally, Eq 3 and 4 should be able to describe a stable hysteresis loop at any strain range. To check this assumption, a set of stable loops was recorded

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[1] D. T. Raske and JoDean Morrow, "Mechanics of Materials in Low Cycle Fatigue Testing," *Manual on Low Cycle Fatigue Testing*, ASTM STP 465 (American Society for Testing and Materials, 1969), pp 1-25.

Table 1

Specimens in Test Program

Specimen No.	Purpose	Remarks
C2	Monotonic tension	
C9, C4, C5	Incremental step test followed by monotonic to fracture	Spec. C9 was the only specimen used in the analysis
C7, C6, C8, C12, C10, C1	Constant strain controlled for cyclic hardening or softening	Spec. C1 was started in compression
C3, C14	Incremental step test followed by constant strain for cyclic relaxation of mean stress	
C11	Frequency effect, return of the yield point after heating, elimination of the yield point for load control below the monotonic yield strength	
C13	Transient and stable stress-strain response for computer model verification, common loop tips, frequency effect	
C15	Block loading	

Table 2

Monotonic Tensile Properties of Uncycled and Precycled Specimens

Property	Spec. C2 (Uncycled)	Spec. C9 (Precycled)
Upper tensile yield point, ksi	52.9	— —
Lower tensile yield point, ksi	40.6	— —
0.2% offset yield strength, ksi	— —	42.7
Ultimate tensile strength, S_u, ksi	65.0	69.0
Modulus of elasticity, E, X10^3 ksi	29.9	28.0
True fracture strength, σ_f, ksi*	132/112	139/118
True fracture ductility, ϵ_f	1.04	1.06
Percent reduction in area, % RA	64.7	65.4
Strength coefficient, K, ksi	40.0/85.1**	103
Strain hardening exponent, n	0.0001/0.158**	0.142

*The first value is the load just before it suddenly decreased prior to fracture divided by the final area of the fractured specimen. The second value is corrected for triaxiality.

**The first value represents the initial portion of the plastic strain-stress curve, i.e., for plastic strain ranging from 0.0001 to 0.017. The second value is for plastic strains from 0.017 to 0.22.

(Figure 13). The zero of the X-Y recorder was changed for each loop to produce a common lower tip. Data were obtained for loops 6, 10 and 14 and from the tips of all loops. These data are shown in Figure 14 with the cyclic curve obtained from the incremental step test.

5 CYCLIC HARDENING OR SOFTENING

Cyclic hardening and softening were studied by constant strain data. An example of one of the tests is shown in Figure 15. Although the metal may initially behave in an elastic manner, after cycling, plastic strain becomes evident. As a rule, cyclic hardening occurs at strains larger than where the cyclic and monotonic curves intersect (Figure 11). Cyclic softening occurs at strains smaller than the intersecting point. Six constant strain tests were performed; the data from these tests are shown in Figure 16. To simplify Figure 16, only the data after plastic strain became evident were plotted (Figure 17). Because of the complicated behavior shown in Figures 16 and 17, several stress-strain curves for two tests were examined. The data from the second and third reversals of Specimen C9 are shown in Figure 18. Specimen C9 was under constant strain control for these first reversals. As seen, continuous hardening occurred. The strain limits for Specimen C6 were small enough to produce only cyclic softening. The data from reversals 100 and 20,000 for Specimen C6 are plotted in Figure 18. The least square fits for the individual loops produce quite different constants. However, for the small strain range data, deviation from the cyclic curve is not too great in the range of the actual data. Figure 19 compares the stress-strain curve for reversals 2 and 3 to steady-state curve, all were obtained from Specimen C9. For large strains where cyclic hardening occurs, a three-step hardening approach might be appropriate. For smaller strain ranges for which cyclic softening occurs, the stable curve might be used.

6 CYCLIC RELAXATION OF MEAN STRESS

Constant strain data were also used to characterize cyclic relaxation which was separated from cyclic hardening or softening by initially prestraining the specimen to obtain a relatively stable state and then starting with new strain limits to induce an initial mean stress. An example is shown in Figure 20. Two specimens were used for this part of the investigation. Figures 21 through 23 demonstrate symmetry for the relaxation of both tensile and compressive mean stresses. Figure 23 also shows good agreement for companion specimens strained at the same range and mean strain. Figure 24 shows the cyclic relaxation for a variety of different strain limits.

7 BEAM IN THREE-POINT BENDING

Reversed loading was accomplished by rotating the beam 180°. The first three reversals of the load-deflection plot for the beam in three-point bending are shown in Figure 25. Subsequent reversals are in the original data. The strain-load plot is shown in Figure 26.

8 COMPUTER SIMULATION

Successful computer-based simulation of the cyclic stress-strain behavior of 2024-T4 aluminum was accomplished and reported in *Materials Research and Standards.*[2] This same type of approach was attempted for A36 steel. Success on 2024-T4 aluminum was mainly due to the relatively simple transient behavior of the material. This aluminum alloy, only cyclically hardened and hysteresis loops for any strain range, followed the cyclic stress-strain curve. The behavior of A36 steel was quite different.

Both the series and the parallel rheological models were programmed. The basic mathematical form for the rheological models produces the memory effect necessary for complicated cyclic loading. Cyclic hardening and softening and cyclic relaxation are accomplished by fitting experimental data. Appendix A gives a brief description of both models without any transient characteristics. The procedure for including cyclic hardening and softening and cyclic relaxation are described in *Materials Research and Standards.*[3] In brief, hardening and

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[2] J. F. Martin, T. H. Topper, and G. M. Sinclair, "Computer Based Simulation of Cyclic Stress-Strain Behavior with Applications to Fatigue," *Materials Research and Standards*, Vol II, No. 2 (February 1971), p 23.

[3] J. F. Martin, T. H. Topper, and G. M. Sinclair, "Computer Based Simulation of Cyclic Stress-Strain Behavior with Applications to Fatigue."

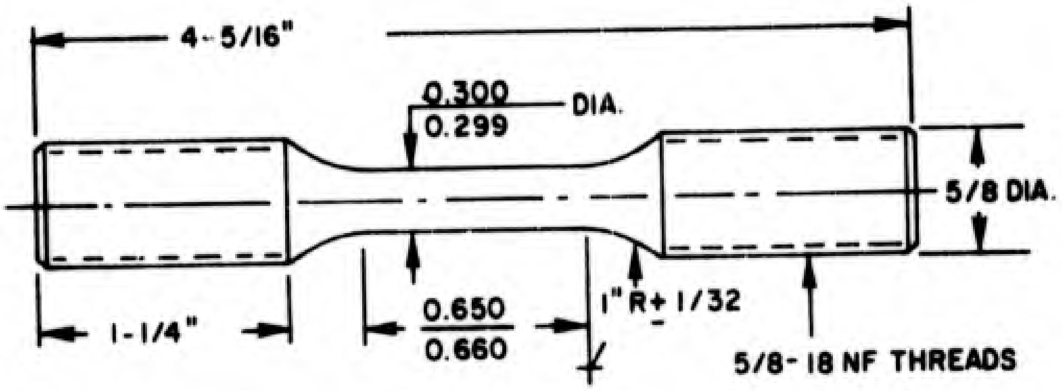
softening are accomplished by establishing a new stress-strain curve for each cycle and fitting to it parameters of the rheological model. Relaxation can be incorporated by multiplying each of the spring stiffnesses by a relaxation function dependent on stress. For each type of rheological model, three programs are included in Appendix B. One set of programs does not include transient characteristics. The second set includes hardening of the same form as used in *Materials Research and Standards*, and the third set is written especially for A36 steel.

9 DISCUSSION

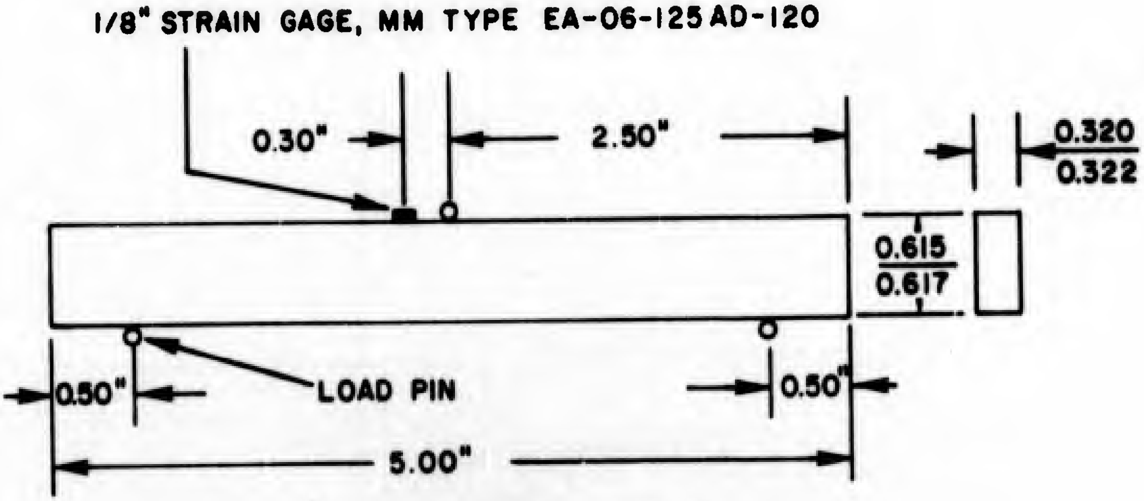
The A36 steel tested in this report demonstrates much the same characteristics as other mild steels. The first reversal beyond the elastic limit produces stress-strain behavior far different from any other subsequent reversals. Cyclic hardening or softening is possible depending on strain range. A truly stable state is never reached as shown from the data for Specimen C15. For example, after a specimen has exhausted more than half its life, a change in strain range will produce hardening or softening. If a sample is cycled at a stress level below the upper or lower yield point for a sufficient number of cycles, cyclic softening will occur, i.e., the metal is no longer strictly elastic. All of these characteristics make it rather difficult to predict the response of a mild steel, such as A36, given a complicated load history.

Because of the above-mentioned characteristic, modeling of the stress-strain behavior of this metal would be quite difficult if exact accuracy is necessary. However, various models could be developed depending on the application. Consequently, three sets of programs were written ranging from the most simple steady-state model to a model specifically for use in this program. Another program similar to the one used in *Materials Research and Standards* is also supplied, however, no appropriate empirical expressions are given.

In summary, data were produced to show characteristics of A36 steel. These data were reduced to a form useful for constructing a computer-based model. Computer programs were written regarding their application.



a. Uniaxial specimen.



b. Beam in three-point bending.

Figure 1. Test specimens.

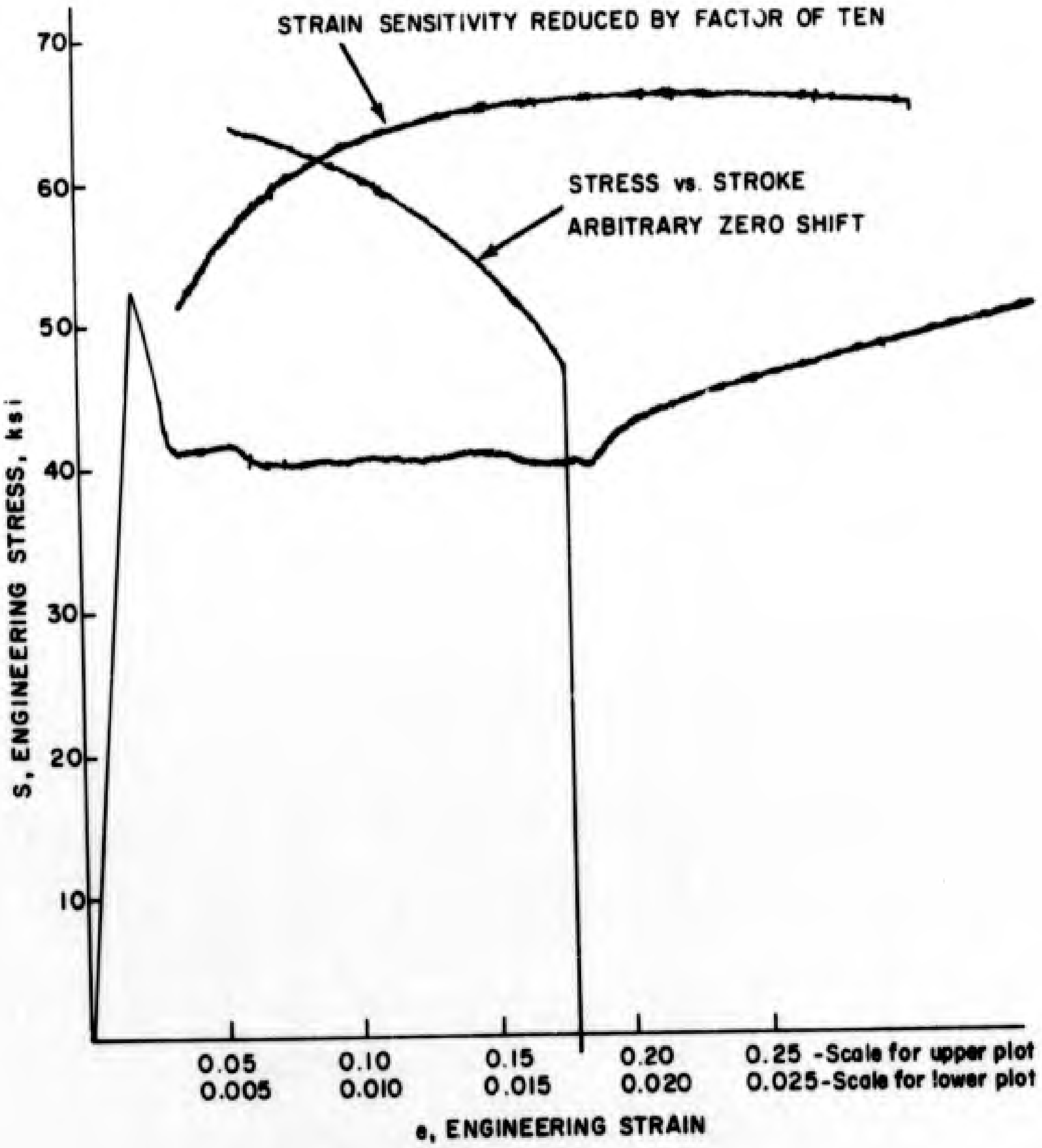
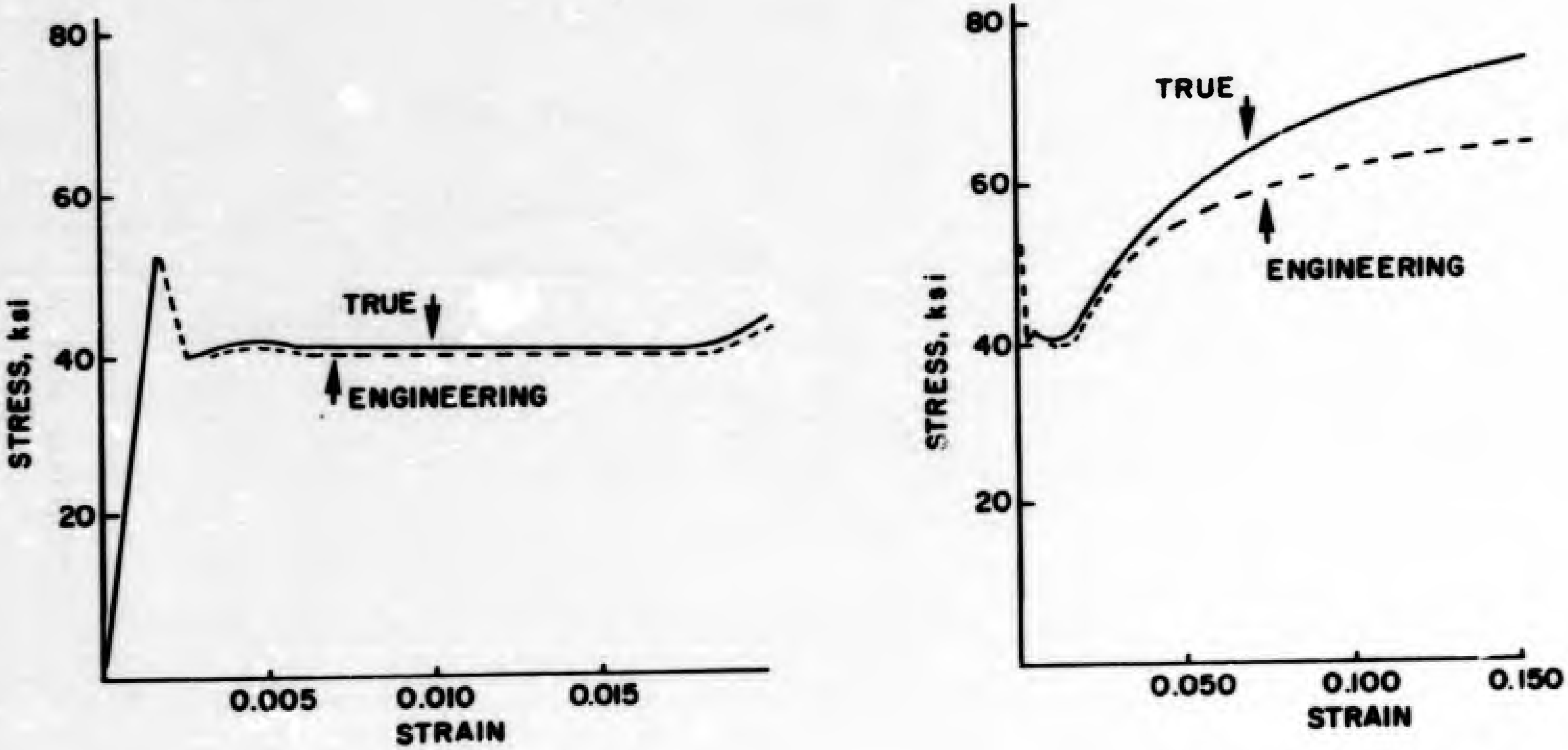


Figure 2. Monotonic tension test.



a. Initial portion of curve.

b. Total curve.

Figure 3. Monotonic tension [True/Engineering] stress-strain.

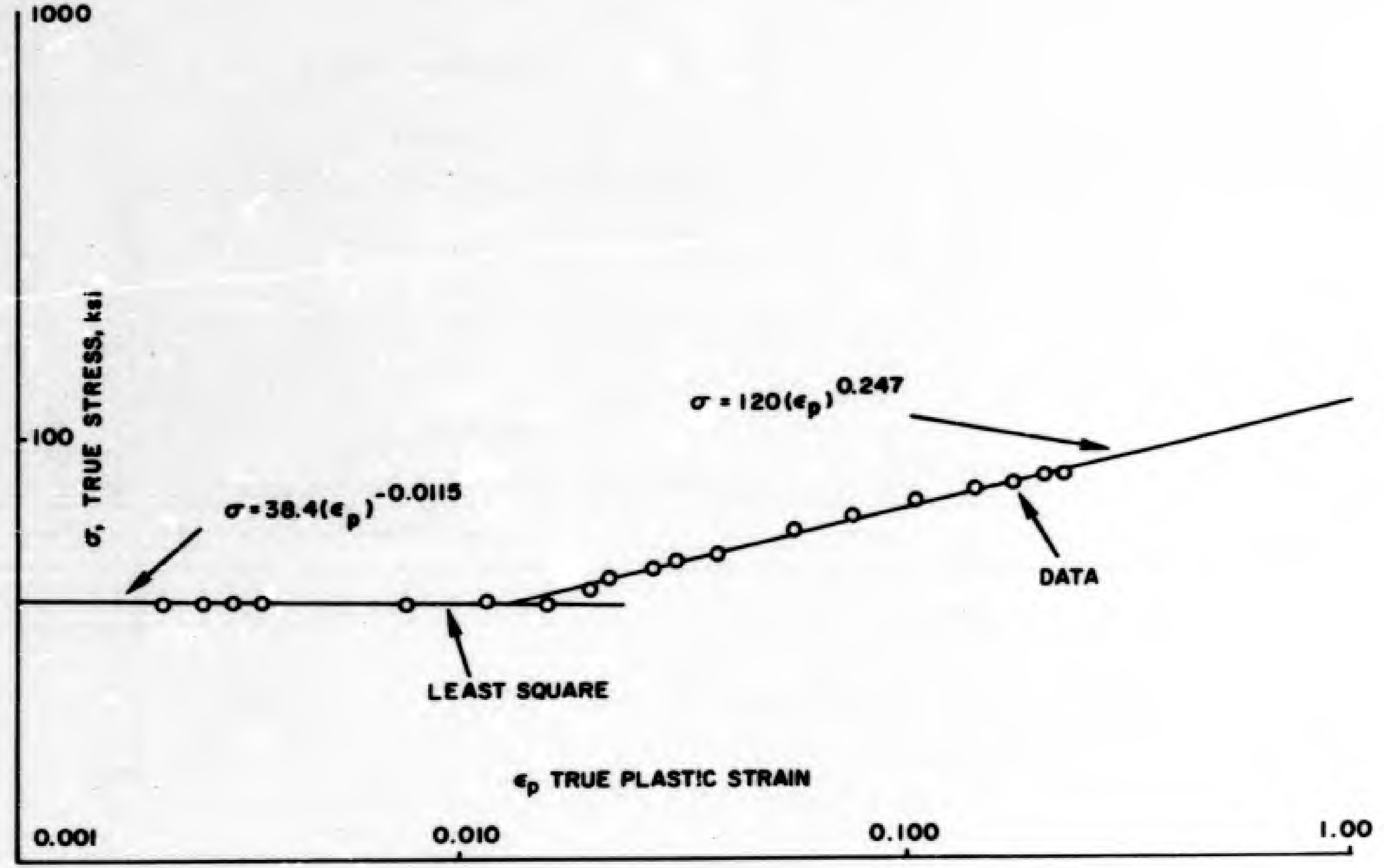
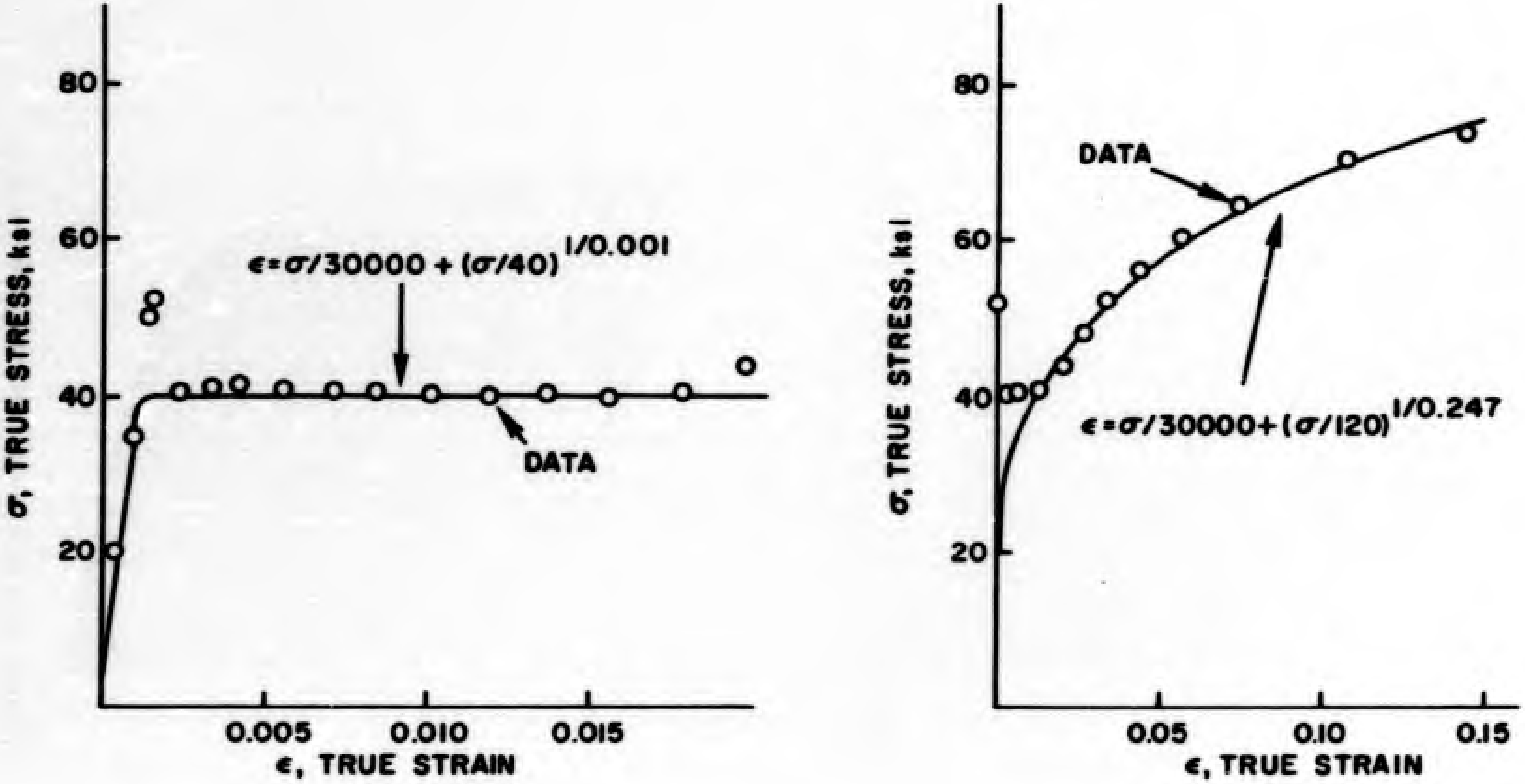


Figure 4. Monotonic tension true stress-true plastic strain.



a. Initial portion of curve.

b. Total curve.

Figure 5. Monotonic true stress-true strain—actual and predicted.

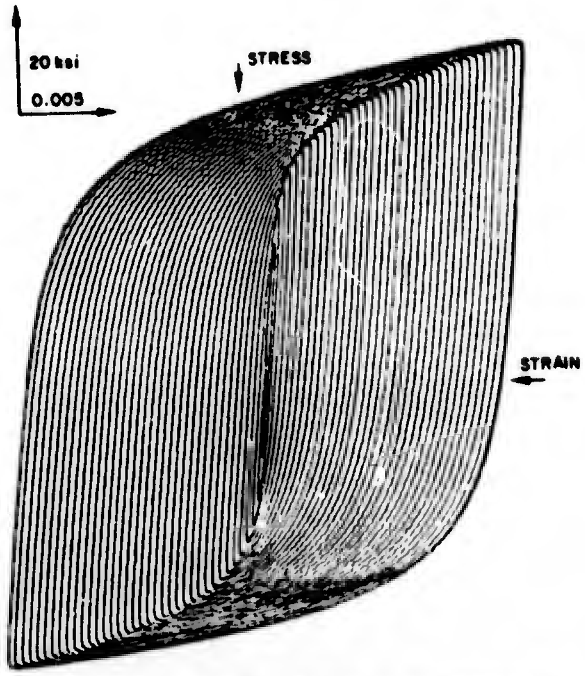


Figure 6. Incremental step test—decreasing increments (A).

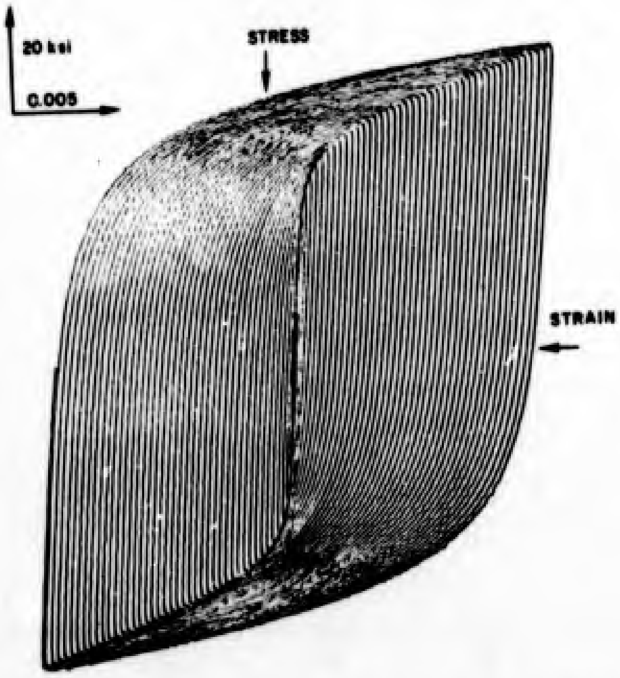


Figure 7. Incremental step test—decreasing increments (B).

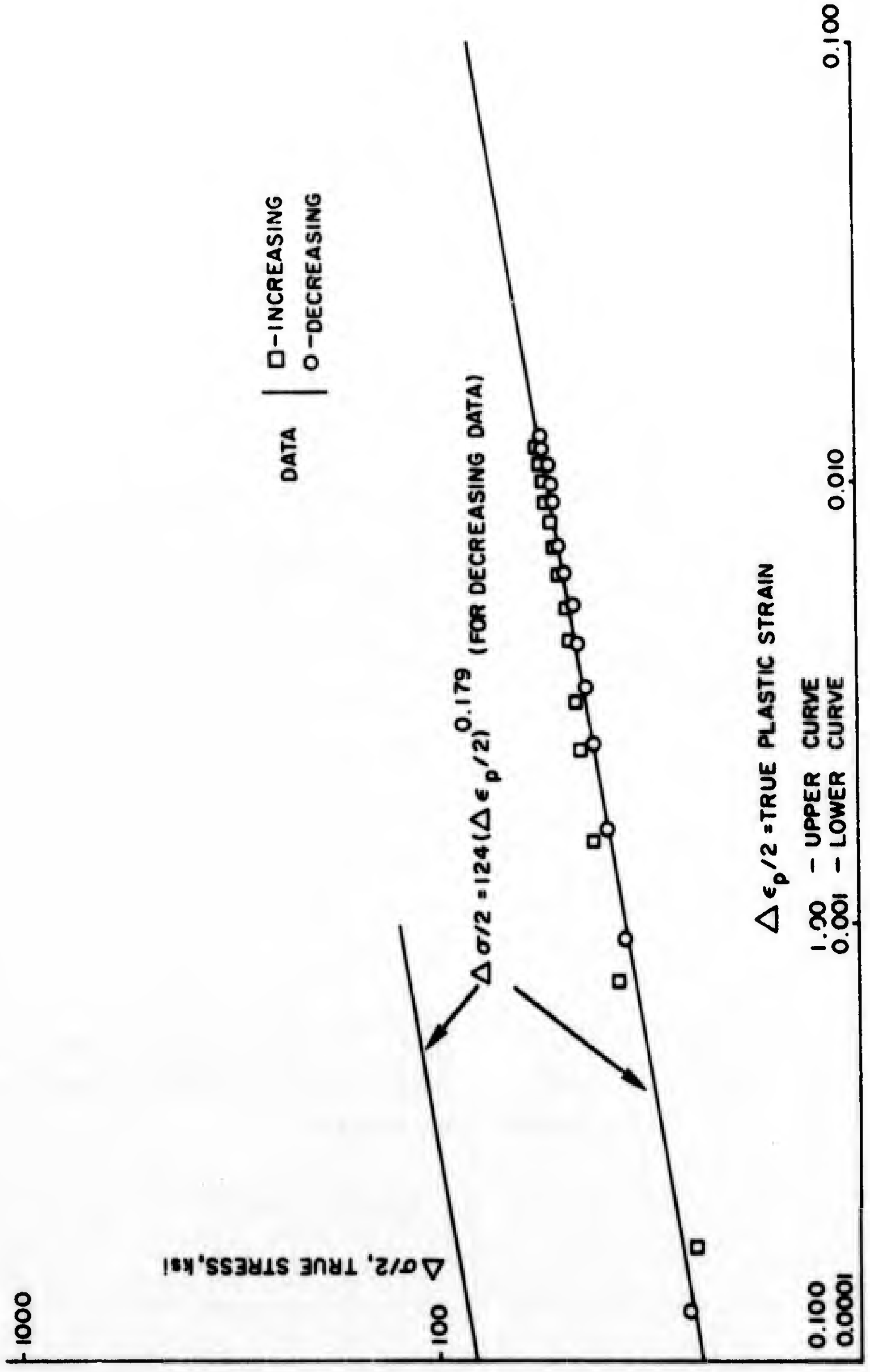


Figure 8. Incremental step test.

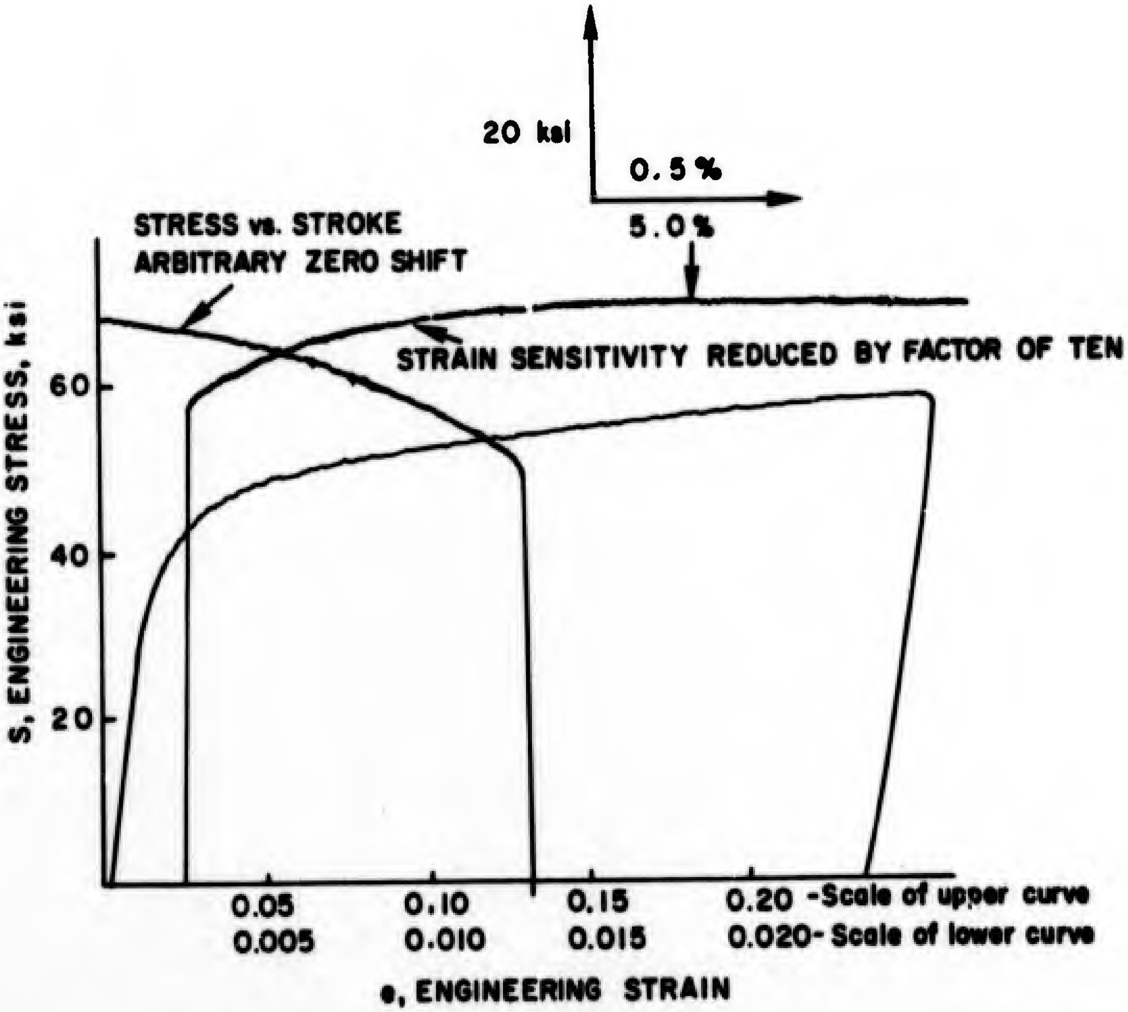


Figure 9. Monotonic tension after precycling (A).

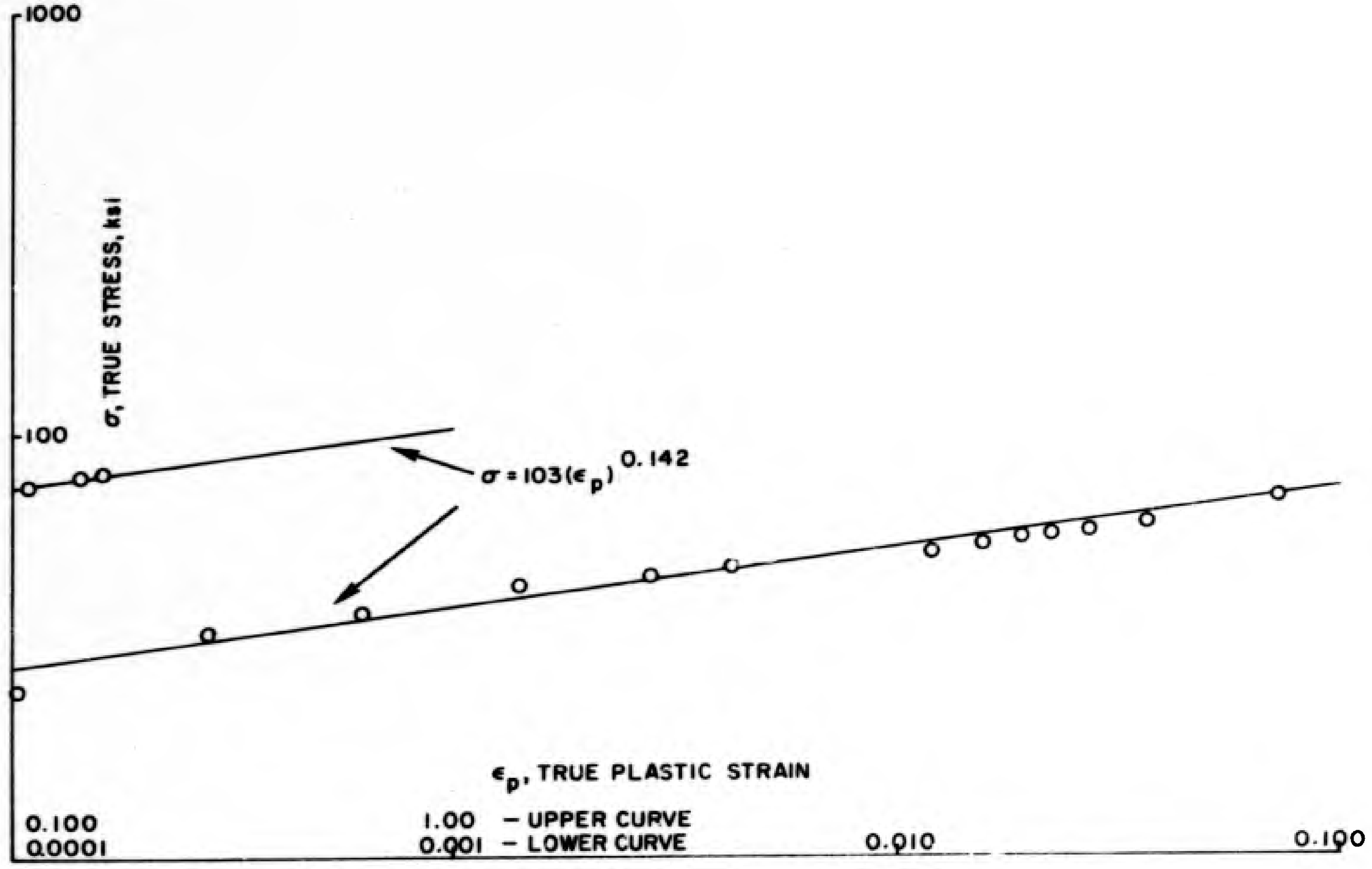


Figure 10. Monotonic tension after precycling (B).

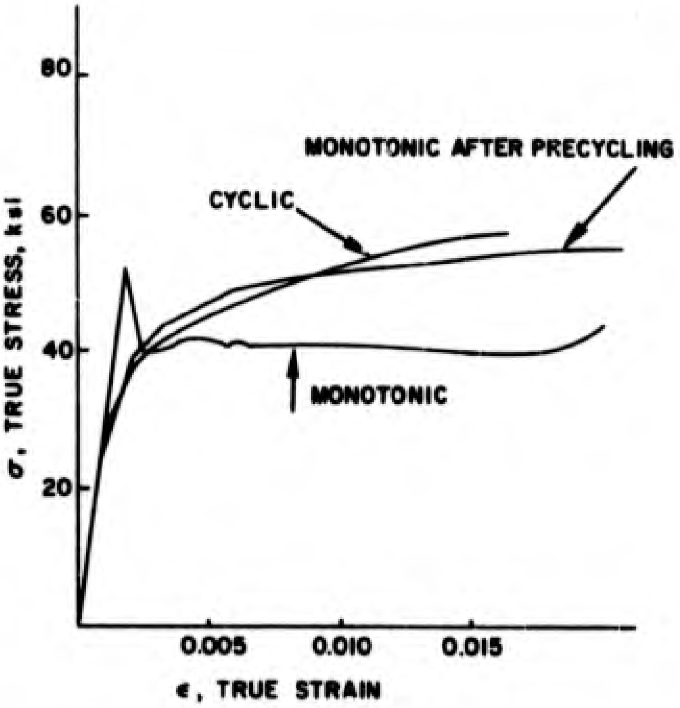


Figure 11. Monotonic and cyclic true stress-true strain.

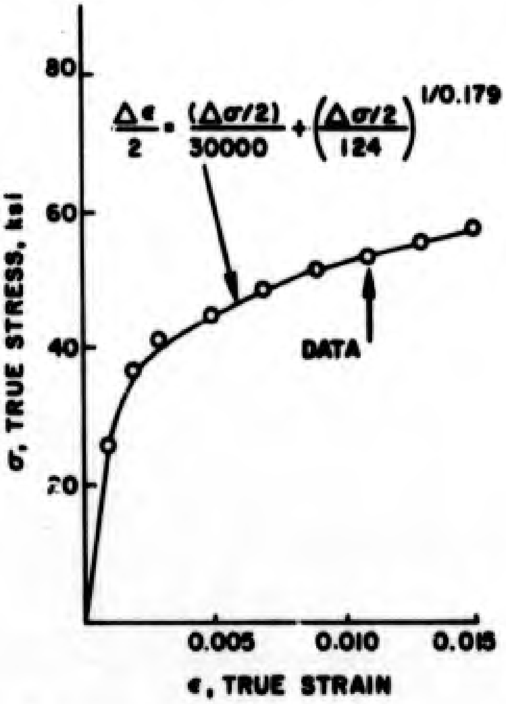


Figure 12. Cyclic true stress-true strain actual and predicted.

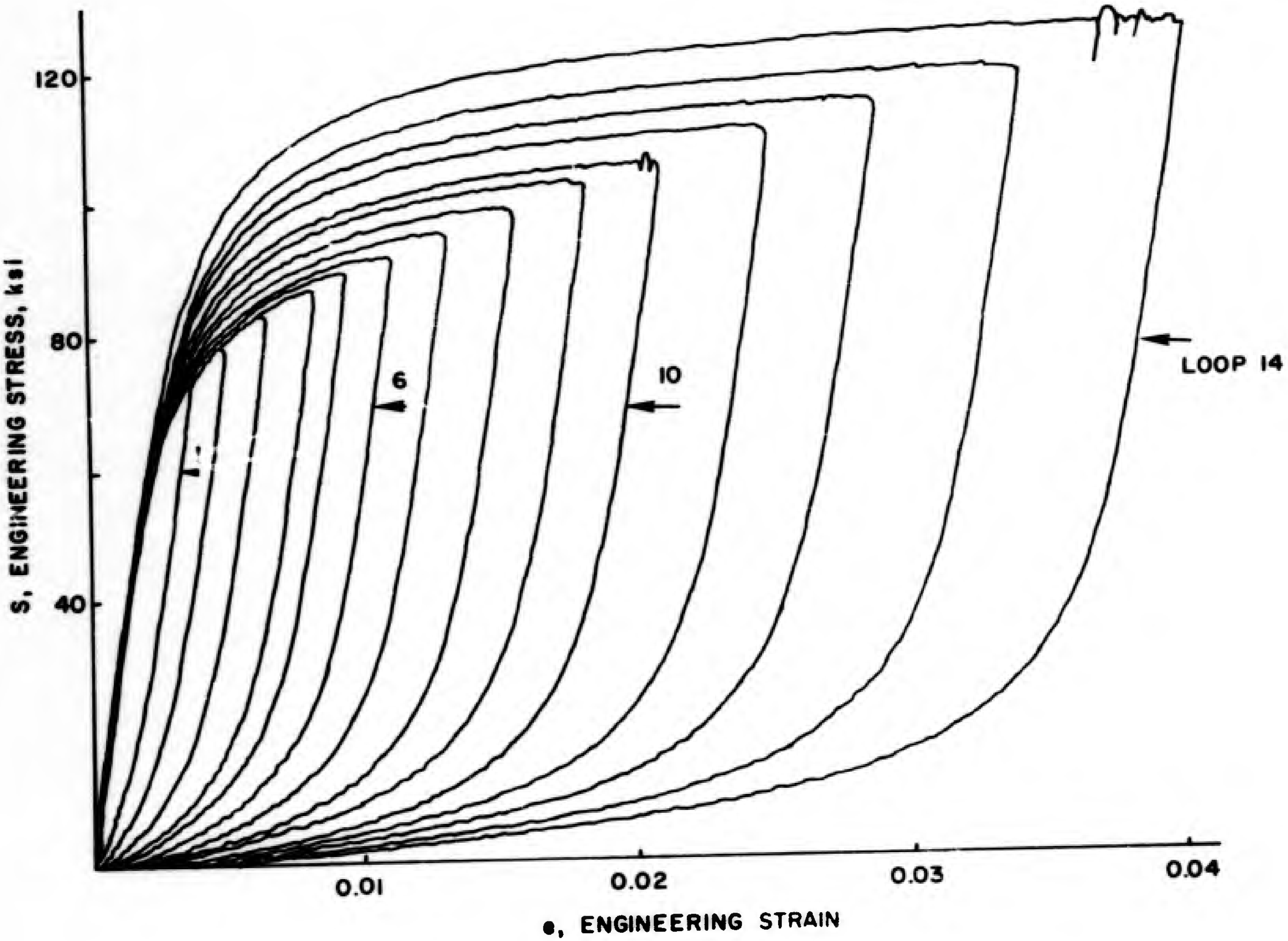


Figure 13. Individual stable hysteresis loops with a common origin.

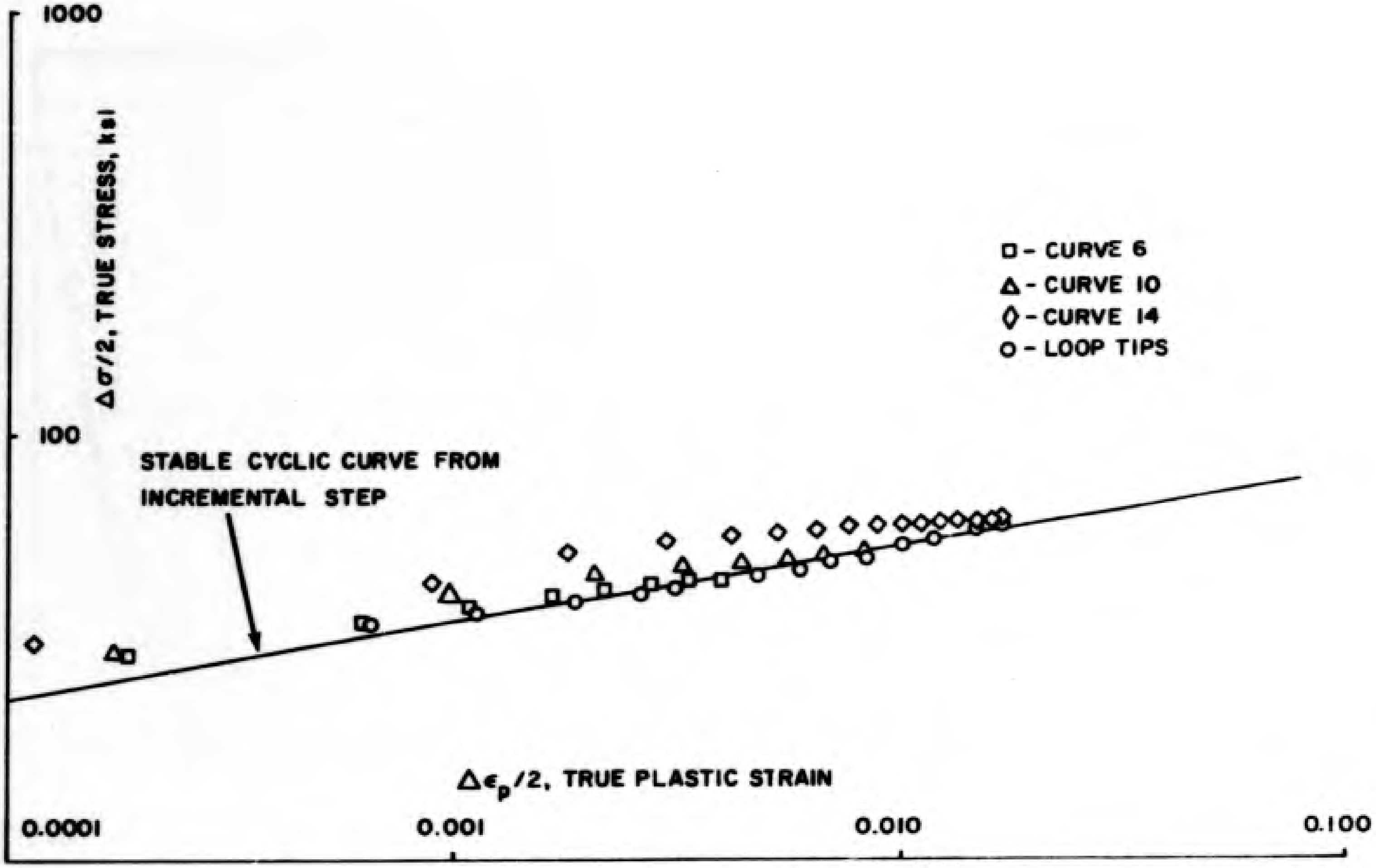


Figure 14. True stress-true plastic strain for individual loops and loop tips.

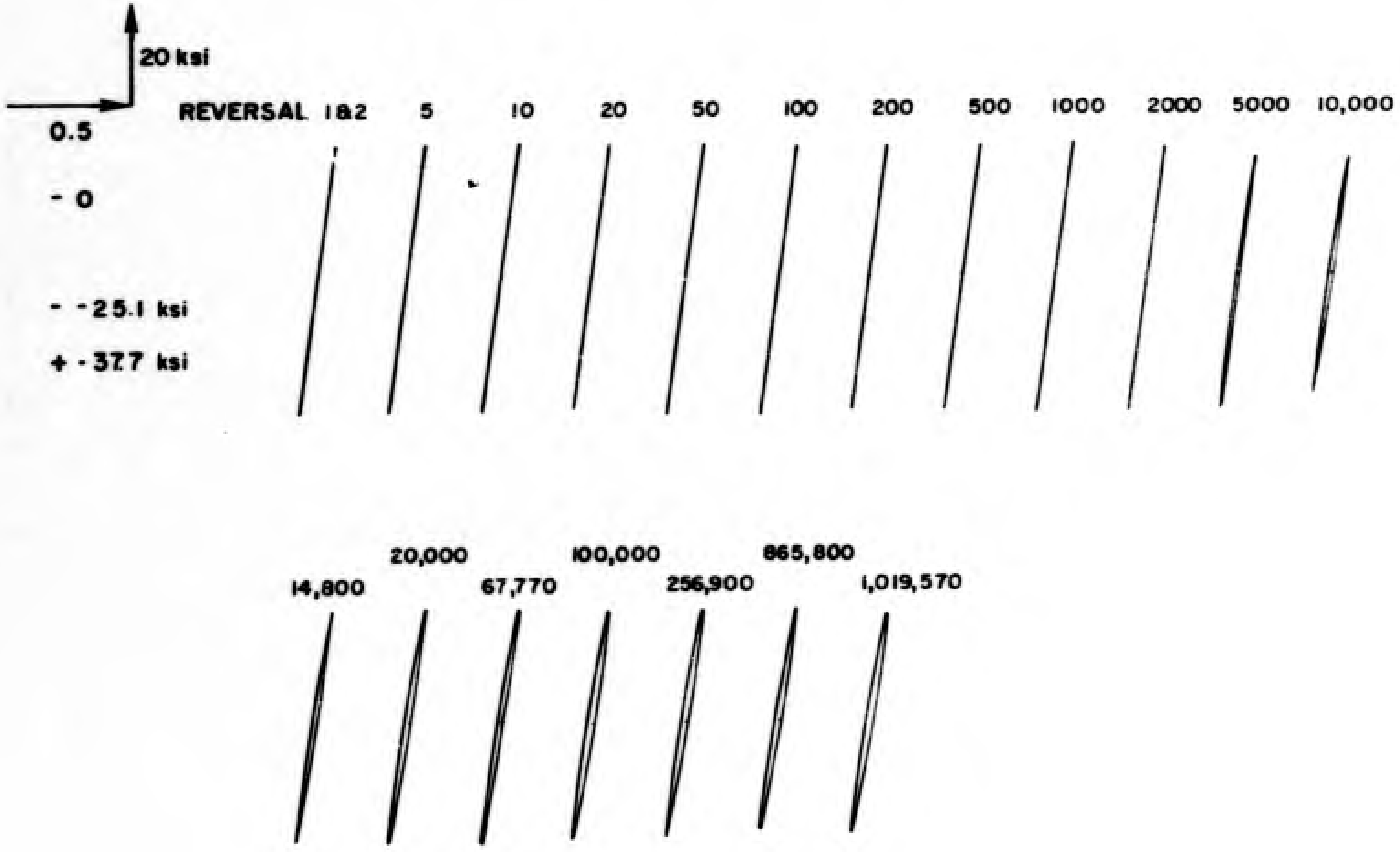


Figure 15. Constant strain controlled test—example of cyclic softening.

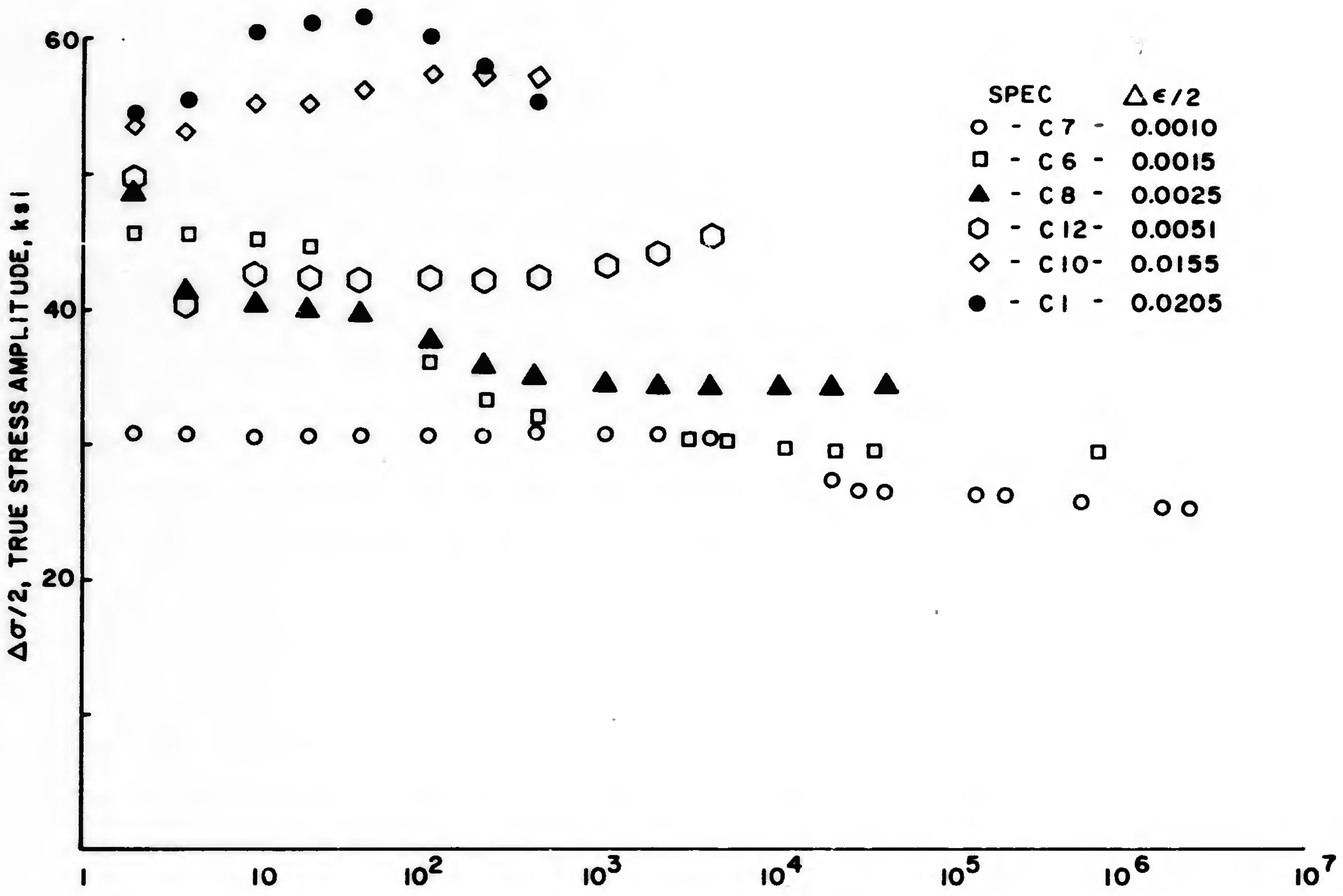


Figure 16. Constant strain tests.

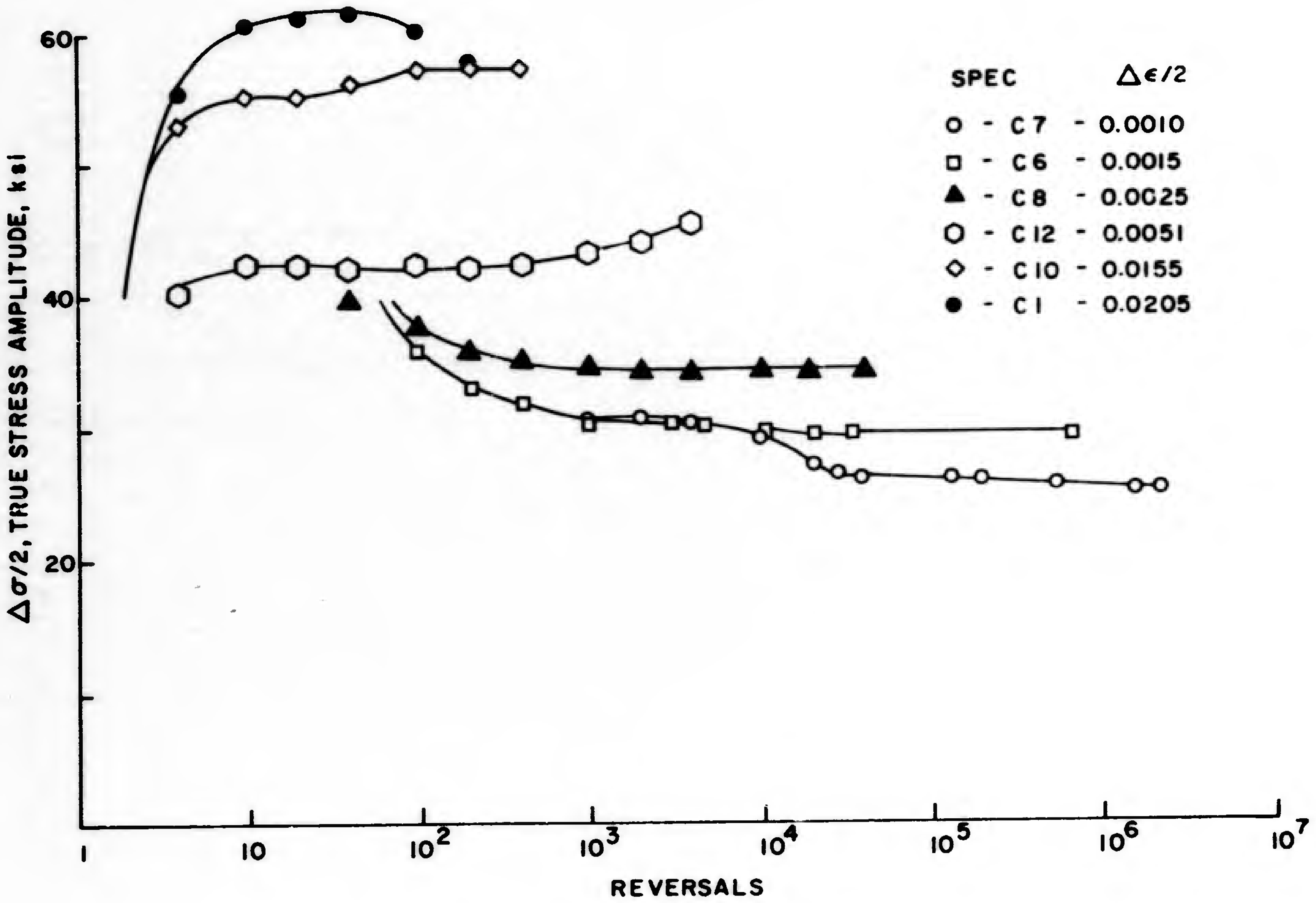


Figure 17. Constant strain data ignoring the first reversal and elastic behavior.

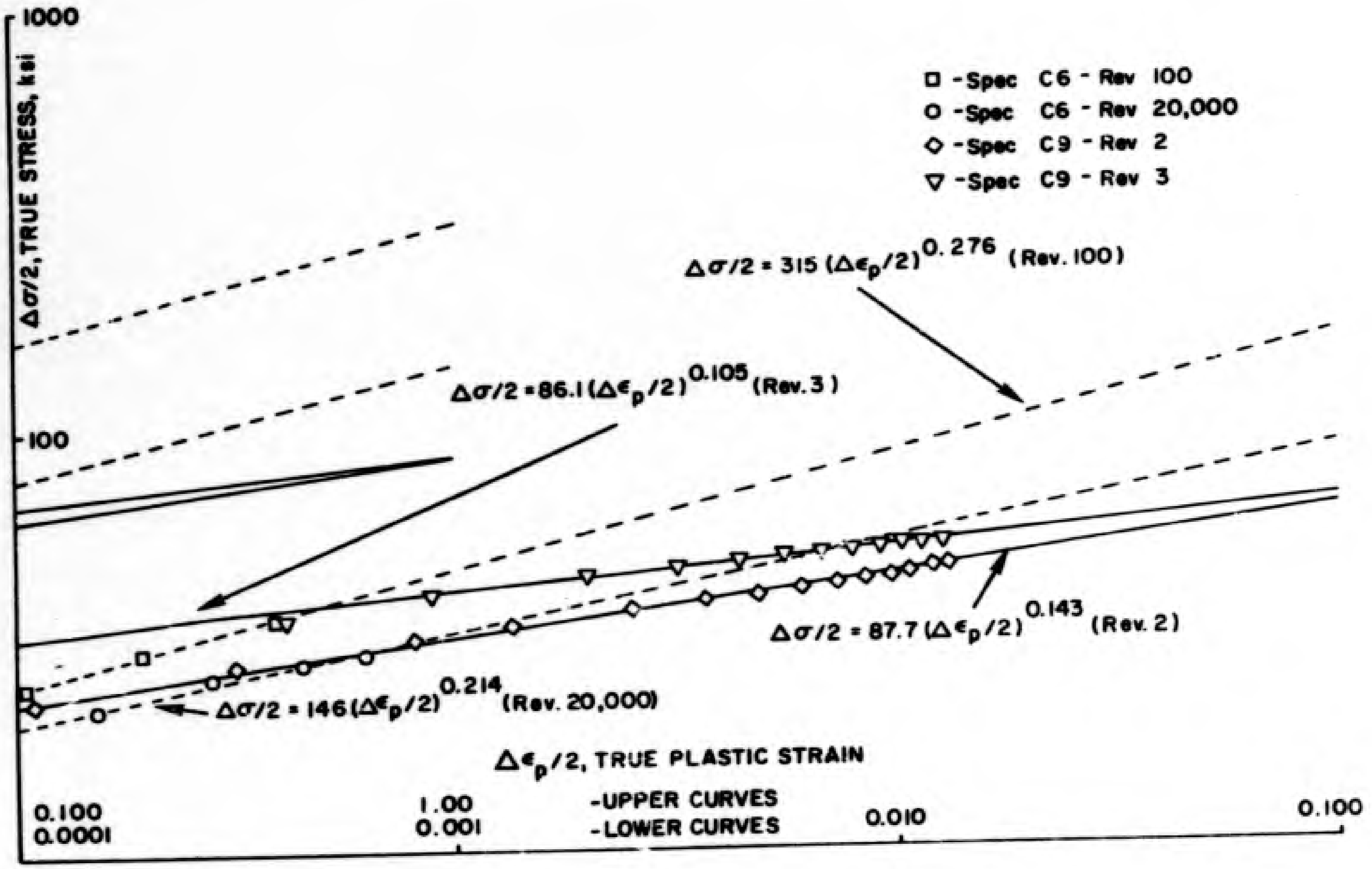


Figure 18. Individual curve for hardening and softening.

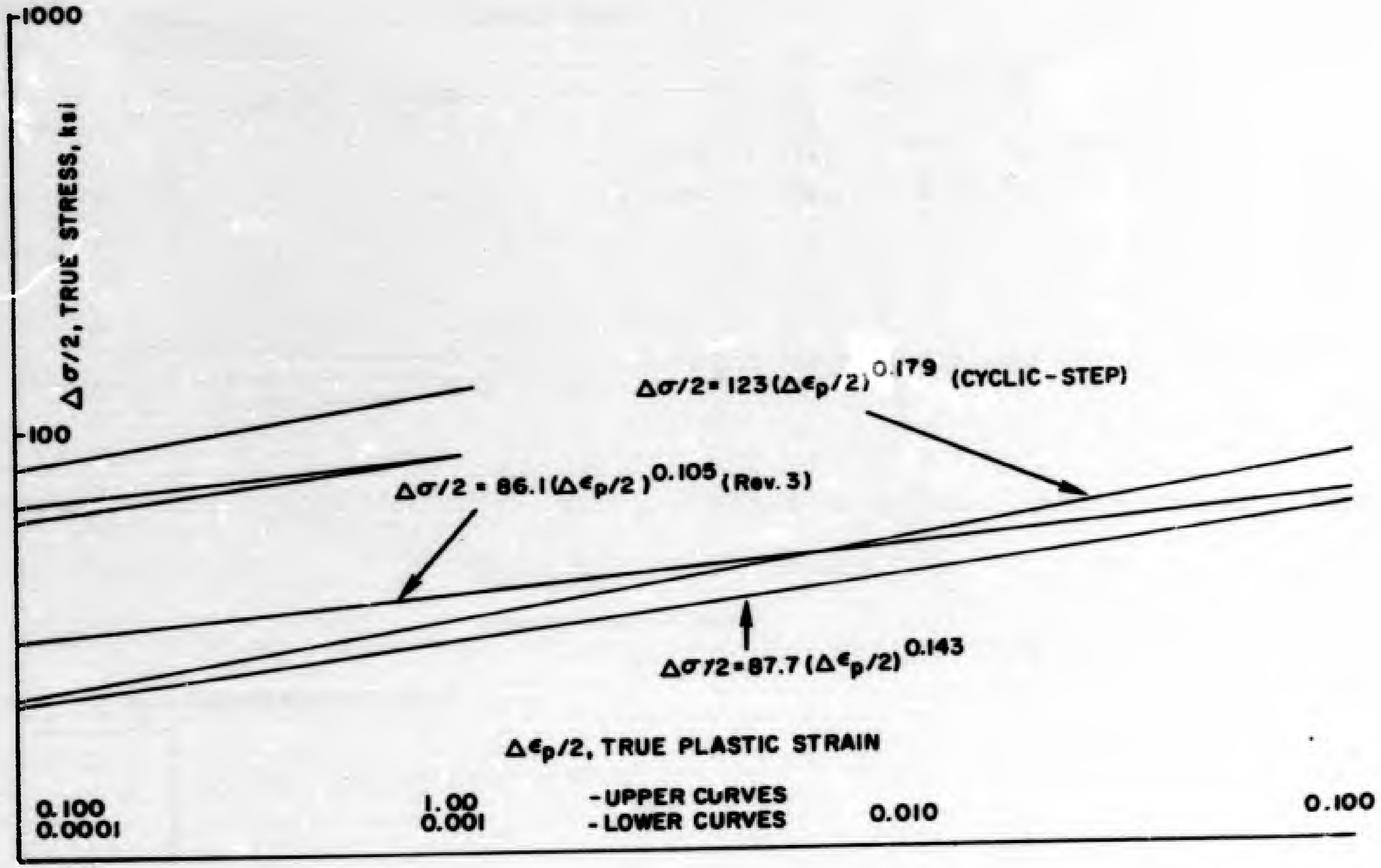


Figure 19. True stress-true plastic strain curves for reversals 2 and 3 and the cyclic stable state for Specimen C9.

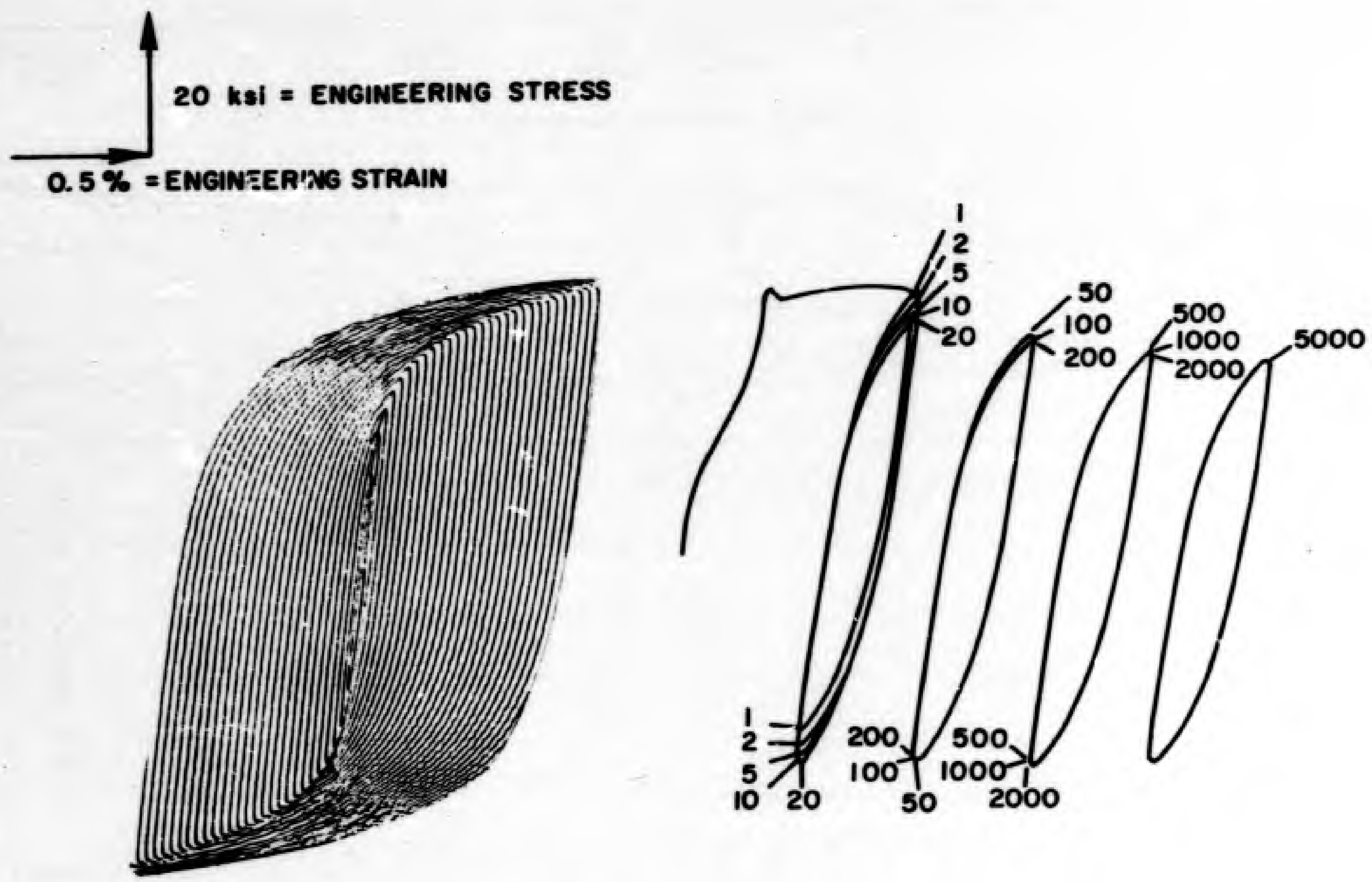


Figure 20. Cyclic relaxation of mean stress.

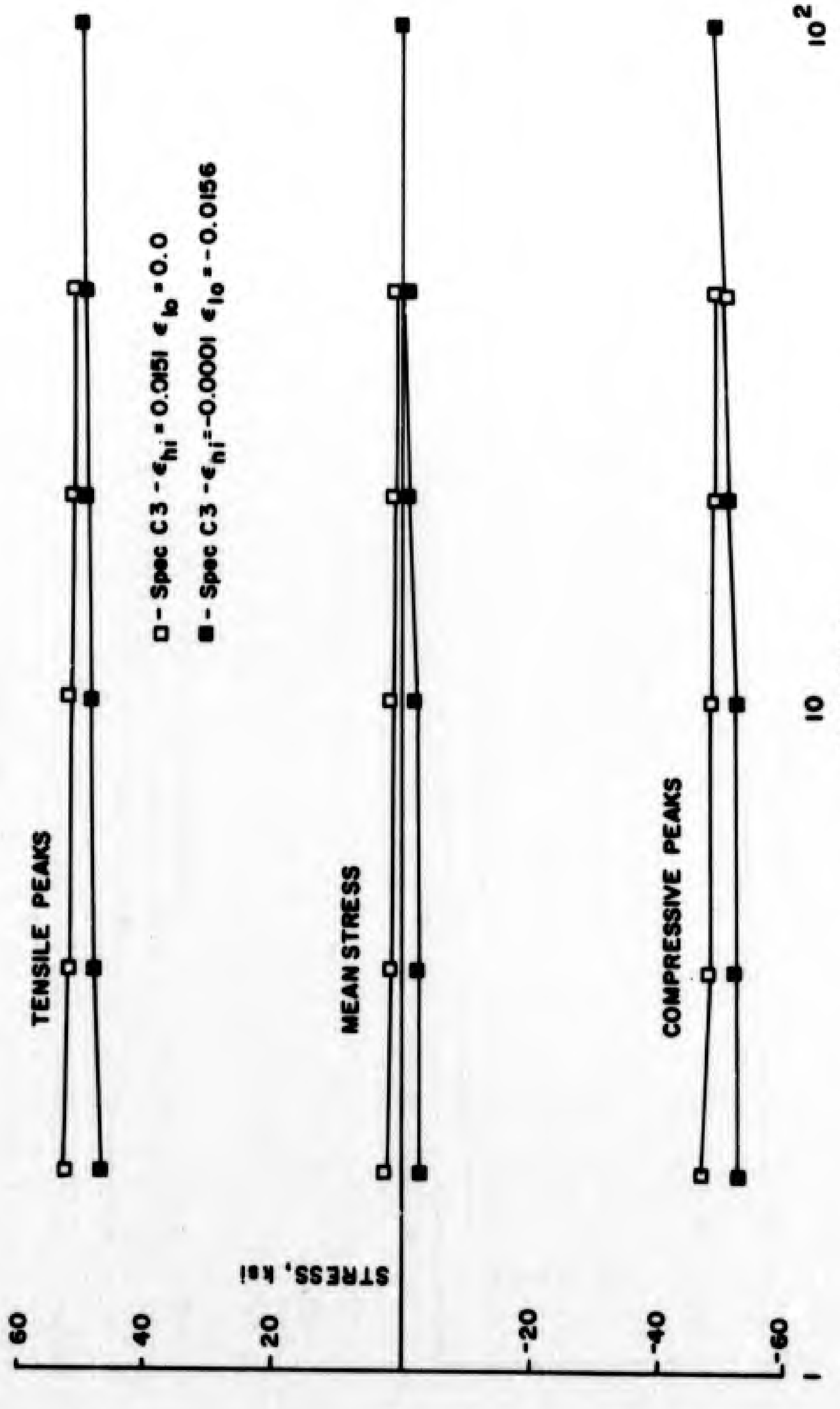


Figure 21. Relaxation data for two-strain amplitudes (A).

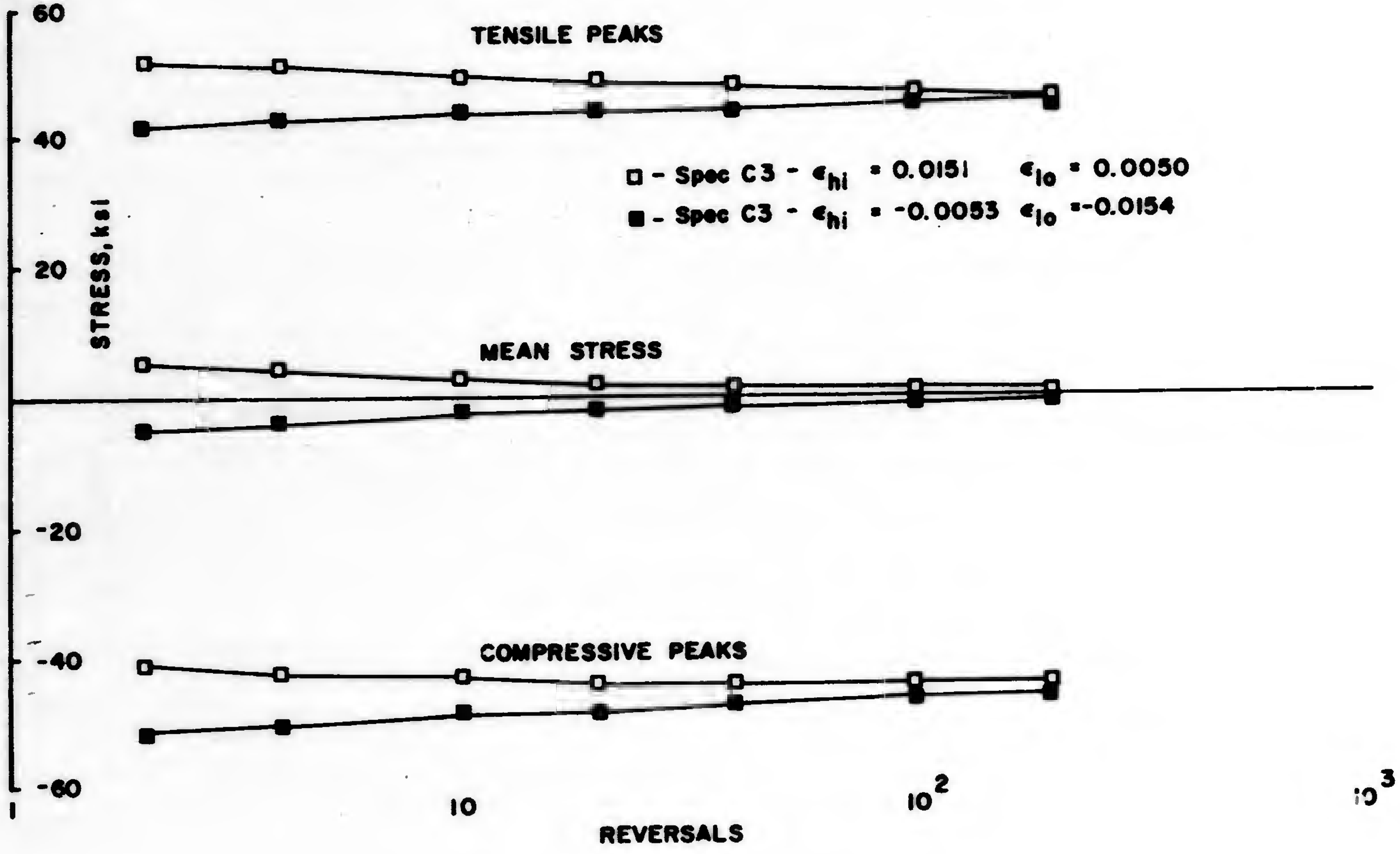


Figure 22. Relaxation data for two-strain amplitudes (B).

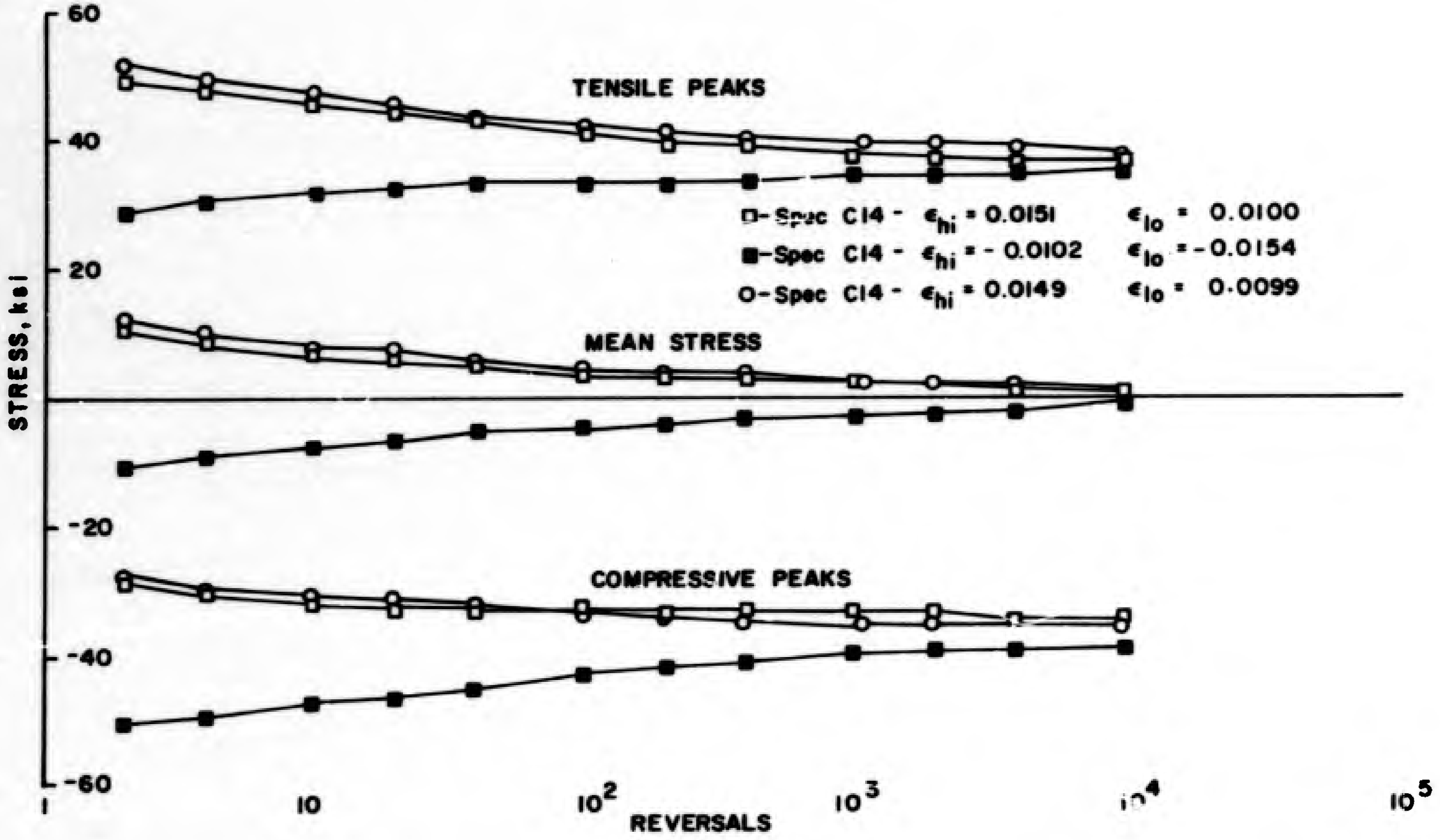


Figure 23. Relaxation data for three-strain amplitudes (A).

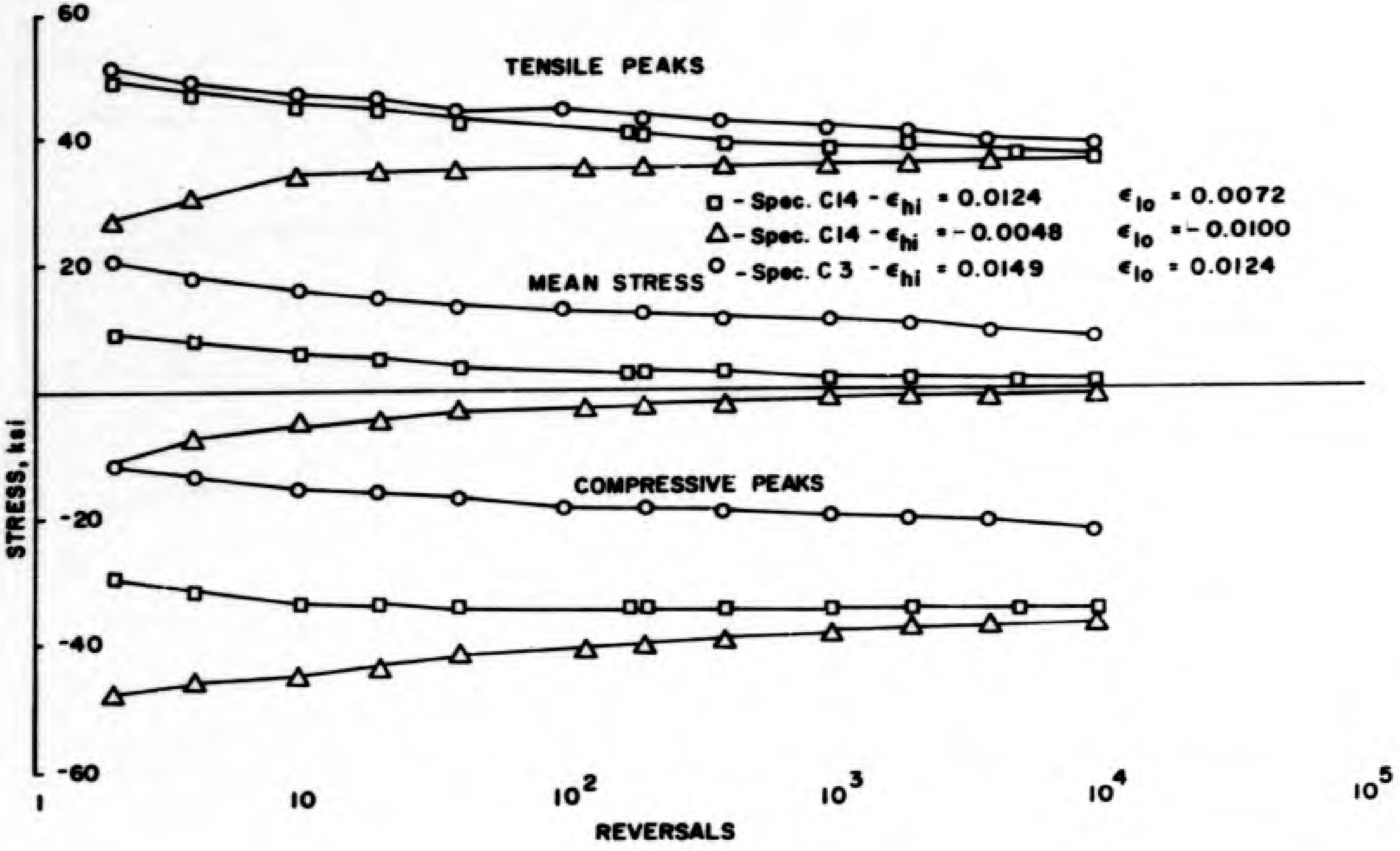


Figure 24. Relaxation data for three-strain amplitudes.

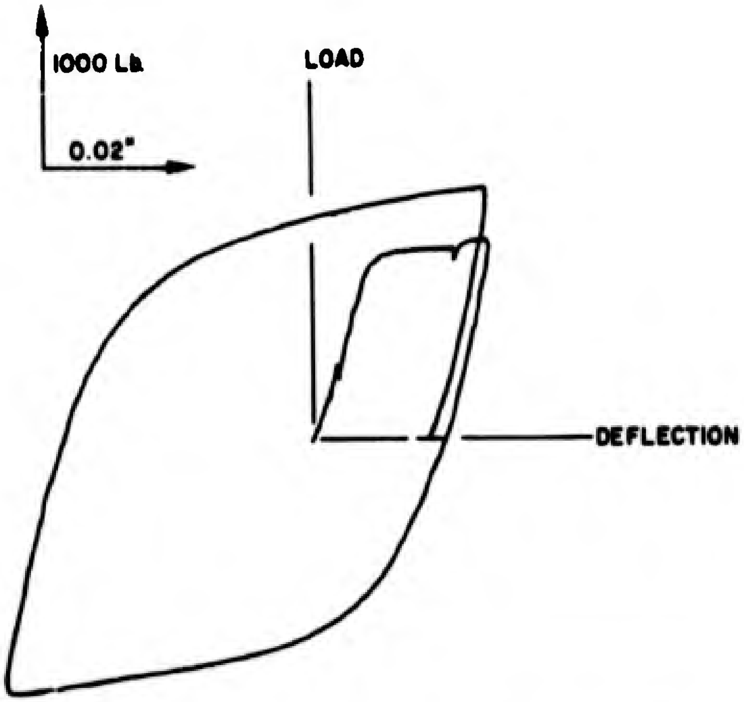


Figure 25. First three reversals of beam in three-point bending.

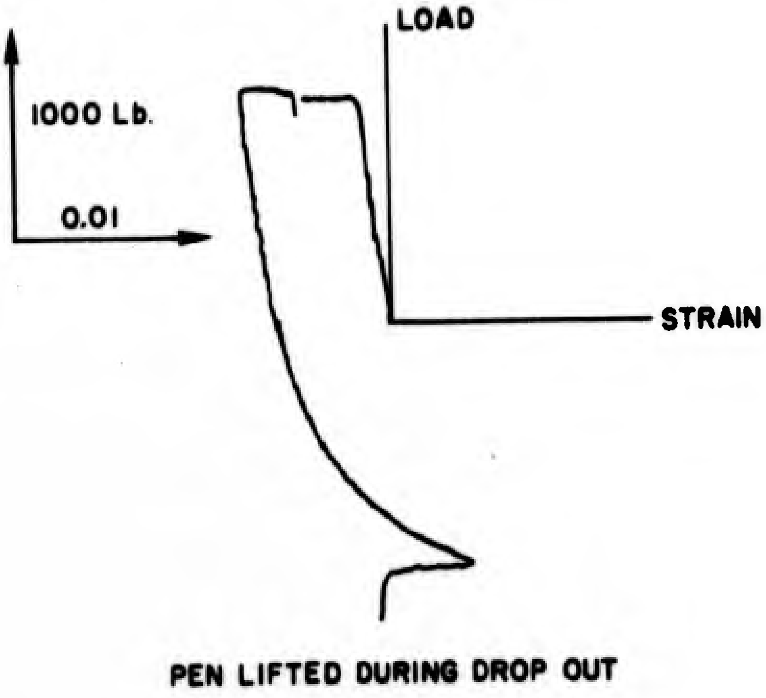


Figure 26. Load vs strain for beam.

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Martin, J. F., T. H. Topper, and G. M. Sinclair, "Computer Based Simulation of Cyclic Stress-Strain Behavior with Applications to Fatigue," *Materials Research and Standards*, Vol 11, No. 2 (February 1971), p 23.

Raske, D. T. and JoDean Morrow, "Mechanics of Materials in Low Cycle Fatigue Testing," *Manual on Low Cycle Fatigue Testing*, ASTM STP 465 (American Society for Testing and Materials, 1969), pp 1-25.

APPENDIX A: RHEOLOGICAL MODELS

This appendix describes utilization of both the series and the parallel rheological models to simulate cyclic stress-strain behavior. Determination of the parameters in the model is also described. Symbols are kept as close as possible to those used in the programs. Cyclic hardening or softening and cyclic relaxation are not included in the model.

1 DETERMINATION OF PARAMETERS FOR THE SERIES MODEL

Figure A1 shows the piece-wise approximation that can be obtained by the series rheological model (Figure A2) for the stress-strain Eq 4. The first yield stress, SB(3), is determined by the offset plastic strain, YPPS, where yielding occurs:

SB(3) = AK*YPPS**(1/SHE) [Eq A1]

All consecutive yield stresses, SB(I), are incremented by a set value of stress, DELS.

The reciprocal of the slope of a line segment in Figure A1 is:

1/ET(I) = 1/E + 1/E(3) + ... + 1/E(I) [Eq A2]

or

1/ET(I) = 1/E + EDR(I). [Eq A3]

The parameter EDR(I) is determined by:

EDR(I) = DELEP/DELS - 1/E. [Eq A4]

The value of DELEP for any segment, except the third, is calculated by:

DELEP = DELS/E + (ST(I)/AK)**(1/SHE)

- (ST(I-1)/AK)**(1/SHE). [Eq A5]

For the third segment:

DELEP=DELS/E+(ST(3)/AK)**(1/SHE).[Eq A6]

With the values of SB(I) and EDR(I) determined, the model may be used to simulate the cyclic behavior of the metal which is characteristic of the stress-strain curve.

2 DETERMINATION OF PARAMETERS OF THE PARALLEL MODEL

Parameters for the parallel model, Figure A3, are determined in much the same manner as for the series model. As before, the stress ending the elastic range, ST(2), is determined from the yield plastic strain, YPPS:

ST(2) = AK*YPPS**(1/SHE) [Eq A7]

and

DELEP = ST(2)/E. [Eq A8]

The slope of a line segment is:

ET(I) = E - E(3) - E(4) - ...... - E(I-1) [Eq A9]

or ET(I) = E - ESUM(I). [Eq A10]

The parameter ESUM(I) is determined by:

ESUM(I) = E - DELS/DELEP. [Eq A11]

The parameter DELEP is calculated by:

DELEP = DELS/E + (ST(I)/AK)**(1/SHE)

- (ST(I-1)/AK)**(1/SHE) [Eq A12]

or

DELEP = DELS/E + (ST(3)/AK)**(1/SHE). [Eq A13]

Instead of determining the yield stress of each element, only the strain at which the element yields, EPB(I), is calculated. The value of EPB(I) is calculated by continuously summing DELEP for each segment.

EPB(I) = EPB(I-1) + DELEP [Eq A14]

or

EPB(I) = EPT(I). [Eq A15]

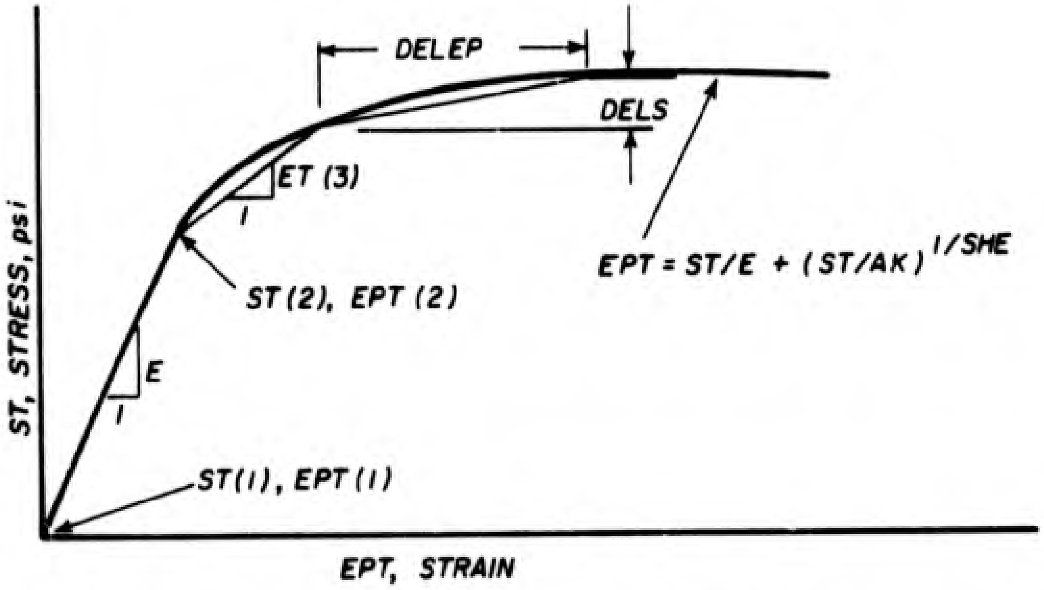

Figure A1. Rheological model approximation of stress-strain curve.

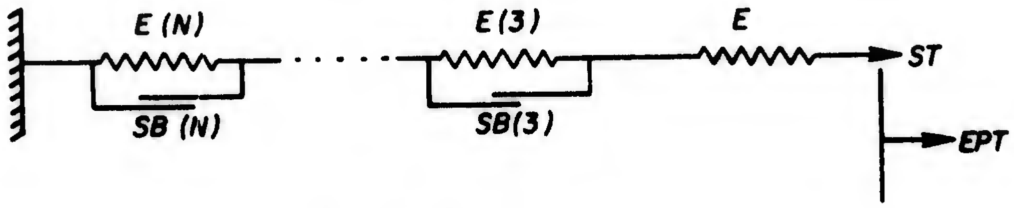

Figure A2. Series rheological model.

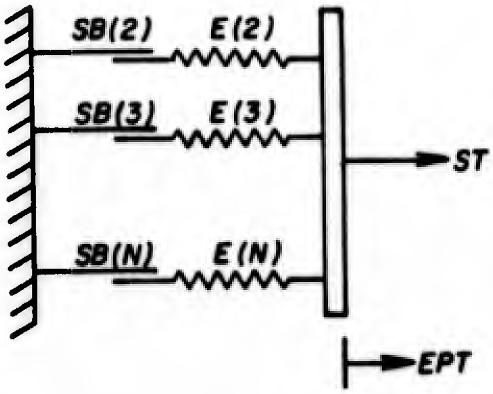

Figure A3. Parallel rheological model.

3 STRESS-STRAIN RELATION FROM THE SERIES MODEL

From the previous reversals, the residual stresses, S(I), were calculated. The final stress and strain values from the last reversal become ST(1) and EPT(1). All subsequent stresses are:

$$\mathrm{ST(I) = -\,SB(I+1) - S(I+1).} \qquad \text{[Eq A16]}$$

For segment two:

$$\mathrm{EPT(2) = (ST(I) - ST(1)\ )/E + EPT(1).} \qquad \text{[Eq A17]}$$

For all remaining segments:

$$\mathrm{1/ET(I) = 1/E + EDR(I)} \qquad \text{[Eq A18]}$$

and

$$\mathrm{EPT(I) = (ST(i) - ST(I-1)\ )/ET(I) + EPT(I-1).} \qquad \text{[Eq A19]}$$

This is continued until the desired strain range has been reached. Finally, all residual stresses for the elements activated on this reversal are reset.

$$\mathrm{S(I) = -\,ST(I) - SB(I)} \qquad \text{[Eq A20]}$$

and the sign of all SB(I) is changed.

4 STRESS-STRAIN RELATION FROM THE PARALLEL MODEL

The parallel model is strain based. From previous reversals, the plastic strain, EPP(I), is known. The strains are calculated from:

$$\mathrm{EPT(I) = EPB(I) + EPP(I).} \qquad \text{[Eq A21]}$$

If the strain limit is exceeded, EPT(I) is set equal to that limit. For segment two:

$$\mathrm{ST(I) = (EPT(2) - EPT(1)\ )*E + ST(1).} \qquad \text{[Eq A22]}$$

For the remaining segments:

$$\mathrm{ET(I) = E - ESUM(I)}$$

and

$$\mathrm{ST(I) = (EPT(I) - EPT\ (I-1)\ )*ET(I) + EPT(I-1).} \qquad \text{[Eq A23]}$$

When the strain limit is reached, all plastic strains for the elements activated for this reversal are reset:

$$\mathrm{EPP(I) = EPT(I) - EPB(I).} \qquad \text{[Eq A24]}$$

The sign of all EPB(I) is changed.

APPENDIX B: COMPUTER PROGRAM LISTINGS

Six computer program listings with accompanying sample data cards are given in the following order:

1. Series Model
2. Parallel Model
3. Series Model with Cyclic Hardening or Softening and Relaxation
4. Parallel Model with Cyclic Hardening or Softening and Relaxation
5. Series Model Characteristic of A36 Steel
6. Parallel Model Characteristic of A36 Steel

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SERIES MODEL

```
C
C*****************************************************
C     STRAIN CONTROL - SERIES MODEL (1)
C     SIMPLIFIED INPUT-OUTPUT
C*****************************************************
C
      REAL KS
    1 FORMAT ('1')
    2 FORMAT (///////)
    5 FORMAT (4E12.4)
    8 FORMAT  (E12.4)
   10 FORMAT (2E12.4)
   19 FORMAT  (I10)
   31 FORMAT (T55,' INPUT INFORMATION'///T3,' CONSTANTS FORMING STRESS-S
     1TRAIN RELATION'//T24,'STRENGTH COEFFICIENT =',
     1 F11.1,T84,'STRAIN HARDENING EXPONENT =',F14.4/
     2 T23,'MODULUS OF ELASTICITY =',F11.1/)
   36 FORMAT (T30,'YIELD STRENGTH =',F11.1,T88,'PLASTIC',
     1 ' STRAIN OFFSET =',F17.7/)
   37 FORMAT (T20,' MAXIMUM STRESS REQUIRED =',F11.1,T92,' STRESS INCREM
     1ENT =',F11.1/T25,' NUMBER OF ELEMENTS =',I9////)
   55 FORMAT (////' PROGRAM HAS EXCEEDED THE ALLOTTED',I5,'  ELEMENTS ON
     1THE',I5,'  REVERSAL')
   58 FORMAT (T5,'STRAIN PEAKS:'/T05,'ORDER',T20,'STRAIN')
   60 FORMAT (I10,1PE16.6)
   65 FORMAT  (T11,'REV.',T25,'POINT',T39,'STRAIN',T55,'STRESS',
     1 T66,'DEL. P. STRAIN',T84,'P. STRAIN',T098,
     2 'MEAN STRESS')
   67 FORMAT (I13,T29,'1',1PE16.4,2PE16.4,1P2E16.4,
     1 2PE16.4)
   69 FORMAT (I29,1PE16.4,2PE16.4,1PE16.4,1PE16.4)
      DIMENSION SB(300),ST(300),S(300),EPT(300),EDR(300),
     1 EPLL(300),DELPEP(300)
      COMMON  EPT,ST,EI,YPS,DELS,KH,H,SHEI,SHEC,RC,
     1 EPP,STM,EDR,EPPS,AK,A1,SB,PM,
     2       N,NSKIP,MSKIP,NREV,      I,NSKIP1
      PRINT 1
C******************
C*** INPUT DATA ***
C******************
C     DATA INPUT
  100 READ 5,  SULT,DELS,E,YPPS
      READ 10, SHES,KS
      READ 19,  NREV
      READ 8,  (EPLL(J),  J=1,NREV)
      YPSM = KS*YPPS**SHES
      N    = (SULT - YPSM)/DELS
      PRINT 31,  KS,SHES,E
      PRINT 36,  YPSM,YPPS
      PRINT 37,  SULT,DELS,N
      PRINT 58
      PRINT 60,  (J,EPLL(J),  J=1,NREV)
C**********************
C*** INITIAL VALUES ***
C**********************
      DO  200   J = 3,N
  200 S(J) = 0.0
      AK = KS
      SHEI = 1.0/SHES
```

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```
      EI = 1.0/E
      A1 = YPPS**SHES
      I = 1
      PRINT 2
      PM = -1.0
      EPL = 0.0
      ST(I) = 0.0
C**************************************
C*** CONSTRUCT STRESS-STRAIN CURVE ***
C**************************************
C*** SET SLIDER STRESSES & SPRING STIFFNESSES ***
      CALL FORMSS
C*** START CYCLING ***
      DO 500  M = 1,NREV
      EPT(1) = EPL
      EPL = EPLL(M)
C*** FOR FIRST SEGMANT ***
  240 ST(1) = ST(I)
      PM = -PM
      I = 2
      ST(2) = -S(3) - SB(3)
      EPT(2) = (ST(2) - ST(1))*EI + EPT(1)
      DIFF = PM*(EPT(2) - EPL)
      DELPEP(2) = 0.0
      IF (DIFF)  310,344,305
  305 DELEP = EPL - EPT(1)
      ST(2) = DELEP*E + ST(1)
      EPT(2) = EPL
      GO TO  344
C*** FOR REMAINING SEGMENTS ***
  310 I = I + 1
      IF (I .LE. N)  GO TO 312
      PRINT 55,  N,NREV
      PRINT 1
      GO TO  1000
  312 ST(I) = -S(I+1) - SB(I+1)
      ETDS = EI + EDP(I)
      EPT(I) = (ST(I) - ST(I-1))*ETDS + EPT(I-1)
      DIFF1 = ST(I) - ST(I-1)
      DIFF2 = EPT(I) - EPT(I-1)
      DELPEP(I) = DIFF2 - DIFF1*EI
      DIFF = PM*(EPT(I) - EPL)
      IF (DIFF)  310,335,315
  315 DELEP = EPL - EPT(I-1)
      ST(I) = DELEP/ETDS + ST(I- 1)
      EPT(I) = EPL
      DIFF1 = ST(I) - ST(I-1)
      DIFF2 = EPT(I) - EPT(I-1)
      DELPEP(I) = DIFF2 - DIFF1*EI
C*** RESET ALL RESIDUAL STRESSES ***
  335 DO 340  J = 3,I
  340 S(J) = -ST(I) - SB(J)
C*** RESET FRICTIONAL STRESSES IF NECESSARY ***
  344 DO 345  J = 3,N
  345 SB(J) = -SB(J)
  400 CONTINUE
C*******************
C***  PRINTOUT  ***
C*******************
```

```
      PRINT 65
      STM = (ST(1) + ST(I))/2.0
      PSSUM = 0.0
      DELPEP(1) = 0.0
      PRINT 67,  M,  EPT(1),ST(1),DELPEP(1),PSSUM,STM
      DO 420  J = 2,I
      PSSUM = PSSUM + DELPEP(J)
  420 PRINT 69, J,EPT(J),ST(J),DELPEP(J),PSSUM
  500 PRINT 2
      PRINT 1
 1000 CALL EXIT
      STOP
      END
      SUBROUTINE FORMSS
C*****************************************************
C*** CALC. FRICTIONAL STRESS & SPRING STIFFNESSES ***
C*****************************************************
      REAL  KS
C     CALCULATION OF MODULI
      COMMON  EPT,ST,EI,YPS,DELS,KH,H,SHEI,SHEC,RC,
     1 EPP,STM,EDR,EPPS,AK,A1,SB,PM,
     2       N,NSKIP,MSKIP,NREV,      I,NSKIP1
      DIMENSION ST(300),EPT(300),EDR(300),SB(300)
      AKI = 1.0/AK
C*** SET FRICTIONAL STRESSES ***
      SBI = AK*A1
      SB(3) = PM*SBI
      DELS1 = PM*DELS
      DO  110   J = 4,N
  110 SB(J) = SB(J-1) + DELS1
C*** SET SPRING STIFFNESSES ***
      DELEP = DELS*EI + ((SBI+DELS)*AKI)**SHEI
      ETI = DELEP/DELS
      EDR(3) = (ETI - EI)
      DO 100  J = 4,N
      SBI = SBI + DELS
      DELEP = DELS*EI + ((SBI+DELS)*AKI)**SHEI - (SBI*AKI)**SHEI
      ETI = DELEP/DELS
  100 EDR(J) = (ETI - EI)
  120 RETURN
      END
$ENTRY
  2.0000E+05  2.0000E+03  3.0000E+07  2.0000E-05
  1.7800E-01  1,2380E+05
         2
  2.0000E-02
 -2.0000E-02
```

PARALLEL MODEL

```
C
C*****************************************************
C   STRAIN CONTROL - PARALLEL MODEL (1)
C   SIMPLIFIED INPUT-OUTPUT
C*****************************************************
C
      REAL KS
    1 FORMAT ('1')
    2 FORMAT (//////)
    5 FORMAT (4E12.4)
    8 FORMAT  (E12.4)
   10 FORMAT (2E12.4)
   19 FORMAT  (I10)
   31 FORMAT (T55,' INPUT INFORMATION'///T3,' CONSTANTS FORMING STRESS-S
     1TRAIN RELATION'//T24,'STRENGTH COEFFICIENT =',
     1 F11.1,T84,'STRAIN HARDENING EXPONENT =',F14.4/
     2 T23,'MODULUS OF ELASTICITY =',F11.1/)
   36 FORMAT (T30,'YIELD STRENGTH =',F11.1,T88,'PLASTIC',
     1 ' STRAIN OFFSET =',F17.7/)
   37 FORMAT (T20,' MAXIMUM STRESS REQUIRED =',F11.1,T92,' STRESS INCREM
     1ENT =',F11.1/T25,' NUMBER OF ELEMENTS =',I9////)
   55 FORMAT (////' PROGRAM HAS EXCEEDED THE ALLOTTED',I5,'  ELEMENTS ON
     1THE',I5,'  REVERSAL')
   58 FORMAT (T5,'STRAIN PEAKS:'/T05,'ORDER',T20,'STRAIN')
   60 FORMAT (I10,1PE16.5)
   65 FORMAT  (T11,'REV.',T25,'POINT',T39,'STRAIN',T55,'STRESS',
     1 T66,'DEL. P. STRAIN',T84,'P. STRAIN',T098,
     2 'MEAN STRESS')
   67 FORMAT (I13,T29,'1',1PE16.4,2PE16.4,1P2E16.4,
     1 2PE16.4)
   69 FORMAT (I29,1PE16.4,2PE16.4,1PE16.4,1PE16.4)
      DIMENSION SB(300),ST(300),S(300),EPT(300),EPB(300),
     1 EPLL(300),DELPEP(300),ESUM(300),EPPL(300)
      COMMON  EPT,ST,EI,YPS,DELS,KH,H,SHEI,SHEC,RC,
     1 EPP,STM,EPB,EPPS,AK,A1,SB,PM,E,ESUM,
     2       N,NSKIP,MSKIP,NREV,      I,NSKIP1
      PRINT 1
C******************
C*** INPUT DATA ***
C******************
C     DATA INPUT
  100 READ 5,  SULT,DELS,E,YPPS
      READ 10, SHES,KS
      READ 19,  NREV
      READ 8,   (EPLL(J),  J=1,NREV)
      YPSM = KS*YPPS**SHES
      N    = (SULT - YPSM)/DELS
      PRINT 31,  KS,SHES,E
      PRINT 36,  YPSM,YPPS
      PRINT 37,  SULT,DELS,N
      PRINT 58
      PRINT 60,  (J,EPLL(J),  J=1,NREV)
C**********************
C*** INITIAL VALUES ***
C**********************
      DO  200   J = 2,N
  200 EPPL(J) = 0.0
      AK = KS
      SHEI = 1.0/SHES
      EI = 1.0/E
```

```
      A1 = YPPS**SHES
      I = 1
      PRINT 2
      PM = -1.0
      EPL = 0.0
      ST(I) = 0.0
C****************************************
C*** CONSTRUCT STRESS-STRAIN CURVE ***
C****************************************
C*** SET SLIDER STRESSES & SPRING STIFFNESSES ***
      CALL FORMSS

C*** START CYCLING ***
      DO 500  M = 1,NREV
      EPT(1) = EPL
      EPL = EPLL(M)
C*** FOR FIRST SEGMANT ***
  240 ST(1) = ST(I)
      PM = -PM
      I = 2
      EPT(2) = EPPL(2) + EPB(2)
      ST(2) = ST(1) + (EPT(2) - EPT(1))*E
      DIFF = PM*(EPT(2) - EPL)
      DELPEP(2) = 0.0
      IF (DIFF)  310,344,305
  305 EPT(2) = EPL
      ST(2) = ST(1) + (EPT(2)-EPT(1))*E
      GO TO  344
C*** FOR REMAINING SEGMENTS ***
  310 I = I + 1
      IF (I .LE. N)  GO TO 312
      PRINT 55,  N,NREV
      PRINT 1
      GO TO  1000
  312 EPT(I) = EPPL(I) + EPB(I)
      ET = E - ESUM(I-1)
      ST(I) = ST(I-1) + (EPT(I) - EPT(I-1))*ET
      DIFF1 = ST(I) - ST(I-1)
      DIFF2 = EPT(I) - EPT(I-1)
      DELPEP(I) = DIFF2 - DIFF1*EI
      DIFF = PM*(EPT(I) - EPL)
      IF (DIFF)  310,335,315
  315 EPT(I) = EPL
      ST(I) = ST(I-1) + (EPT(I) - EPT(I-1))*ET
      DIFF1 = ST(I) - ST(I-1)
      DIFF2 = EPT(I) - EPT(I-1)
      DELPEP(I) = DIFF2 - DIFF1*EI
C*** RESET ALL PLASTIC STRAINS ***
  335 I1 = I - 1
      DO 340  J = 2,I1
  340 EPPL(J) = EPT(I) - EPB(J)
C*** RESET YIELD STRAINS   ***
  344 DO 345  J = 2,N
  345 EPB(J) = -EPB(J)
  400 CONTINUE
C******************
C***  PRINTOUT  ***
C******************
      PRINT 65
      STM = (ST(1) + ST(I))/2.0
      PSSUM = 0.0
      DELPEP(1) = 0.0
      PRINT 67,  M,  EPT(1),ST(1),DELPEP(1),PSSUM,STM
      DO 420  J = 2,I
```

```
      PSSUM = PSSUM + DELPEP(J)
  420 PRINT 69, J,EPT(J),ST(J),DELPEP(J),PSSUM
  500 PRINT 2
      PRINT 1
 1000 CALL EXIT
      STOP
      END
      SUBROUTINE FORMSS
C****************************************************
C*** CALC. FRICTIONAL STRESS & SPRING STIFFNESSES ***
C****************************************************
      REAL  KS
C     CALCULATION OF MODULI
      COMMON  EPT,ST,EI,YPS,DELS,KH,H,SHEI,SHEC,RC,
     1 EPP,STM,EPB,EPPS,AK,A1,SB,PM,F,ESUM,
     2       N,NSKIP,MSKIP,NREV,      I,NSKIP1
      DIMENSION ST(300),EPT(300),EPB(300),SB(300),ESUM(300)
      AKI = 1.0/AK
C*** SET FRICTIONAL STRESSES ***
      SBI = AK*A1
      EPB(2) = SBI*EI
C*** SET SPRING STIFFNESSES ***
      DELEP = DELS*EI + ((SBI+DELS)*AKI)**SHEI
      EPB(3) = EPB(2) + DELEP
      ET = DELS/DELEP
      ESUM(2) = E - ET
      DO 100  J = 3,N
      SBI = SBI + DELS
      DELEP = DELS*EI + ((SBI+DELS)*AKI)**SHEI - (SBI*AKI)**SHEI
      EPB(J+1) = EPB(J) + DELEP
      ET = DELS/DELEP
  100 ESUM(J) = E - ET
  120 RETURN
      END
$ENTRY
  2.0000E+05  2.0000E+03  3.0000E+07  2.0000E-05
  1.7800E-01  1.2380E+05
       2
  2.0000E-02
 -2.0000E-02
```

SERIES MODEL WITH CYCLIC HARDENING OR SOFTENING AND RELAXATION

```
C
C**************************************************
C  STRAIN CONTROL - SERIES MODEL (2)
C    SIMPLIFIED INPUT-OUTPUT
C    CYCLIC HARDENING OR SOFTENING AND RELAXATION
C**************************************************
C
      REAL KS,KC,KH
    1 FORMAT ('1')
    2 FORMAT  (///////)
    5 FORMAT (4E12.4)
    8 FORMAT  (E12.4)
   10 FORMAT (2E12.4)
   17 FORMAT (5E12.4)
   19 FORMAT  (I10)
   31 FORMAT (T55,' INPUT INFORMATION'///T3,' CONSTANTS FORMING STRESS-S
     1TRAIN RELATION'//T16,' STATIC STRENGTH COEFFICIENT =',F11.1,T76,'
     2STATIC STRAIN HARDENING EXPONENT =',F14.4/T16,' CYCLIC STRENGTH CO
     3EFFICIENT =',F11.1,T76,' CYCLIC STRAIN HARDENING EXPONENT =',F14.4
     4/T22,' MODULUS OF ELASTICITY =',F11.1/)
   32 FORMAT (T3,' RELAXING FUNCTION CONSTANTS'//T26,' RELAXING CONSTANT
     1 =',F14.4///)
   34 FORMAT (T3,' HARDENING/SOFTENING CONSTANTS'//T31,' H/S EXPONENT ='
     1,F14.4,T93,' H/S COEFFICIENT =',F11.1/T27,' MAXIMUM HARDNESS =',F1
     24.4,T92,' MIMIMUM HARDNESS =',F18.8/T26,' HARDNESS EXPONENT =',F14
     3.4////)
   36 FORMAT (T13,' MONOTONIC YIELD STRENGTH =',F11.1,T87,' CYCLIC YIELD
     1 STRENGTH =',F11.1/T22,' PLASTIC STRAIN OFFSET =',F17.7/)
   37 FORMAT (T20,' MAXIMUM STRESS REQUIRED =',F11.1,T92,' STRESS INCREM
     1ENT =',F11.1/T25,' NUMBER OF ELEMENTS =',I9////)
   55 FORMAT (////' PROGRAM HAS EXCEEDED THE ALLOTTED',I5,'  ELEMENTS ON
     1THE',I5,'   REVERSAL')
   58 FORMAT (T5,'STRAIN PEAKS:'/T05,'ORDER',T20,'STRAIN')
   60 FORMAT (I10,1PE16.6)
   65 FORMAT  (T11,'REV.',T25,'POINT',T39,'STRAIN',T55,'STRESS',
     1 T66,'DEL. P. STRAIN',T84,'P. STRAIN',T098,
     2 'MEAN STRESS')
   67 FORMAT (I13,T29,'1',1PE16.4,2PE16.4,1P2E16.4,
     1 2PE16.4)
   69 FORMAT (I29,1PE16.4,2PE16.4,1PE16.4,1PE16.4)
      DIMENSION SB(300),ST(300),S(300),EPT(300),EDR(300),
     1 EPLL(300),DELPEP(300)
      COMMON  EPT,ST,EI,YPS,DELS,KH,H,SHEI,SHEC,RC,
     1 EPP,STM,EDR,EPPS,AK,A1,SB,PM,
     2       N,NSKIP,MSKIP,NREV,      I,NSKIP1
      PRINT 1
C******************
C*** INPUT DATA ***
C******************
C     DATA INPUT
  100 READ 5,   SULT,DELS,E,YPPS
      READ 10, SHES,SHEC
      READ 17,  H,KH,HMAX,HMIN,SH
  120 READ 10,  RC
      READ 19,  NREV
      READ 8,  (EPLL(J),  J=1,NREV)
      KS=KH*HMIN**H
      KC = KH*HMAX**H
      YPSM = KS*YPPS**SHES
      YPSC = KC*YPPS**SHEC
```

```
      N   = (SULT - YPSM)/DELS
      PRINT 31,  KS,SHES,KC,SHEC,E
      PRINT 36,  YPSM,YPSC,YPPS
      PRINT 37,  SULT,DELS,N
      PRINT 33, RC
      PRINT 34,  H,KH,HMAX,HMIN,SH
      PRINT 58
      PRINT 60,  (J,EPLL(J),  J=1,NREV)
C***********************
C*** INITIAL VALUES ***
C***********************
C STRESS-STRAIN
      NSKIP2 = 1
      DO  200   J = 3,N
  200 S(J) = 0.0
      AK = KS
      SHEI = 1.0/SHES
      EI = 1.0/E
      A1 = YPPS**SHES
      I = 1
      PRINT 2
      PM = -1.0
      EPL = 0.0
      ST(I) = 0.0
C HARDENING
      NSKIP = 1
      MSKIP = 1
      SI = -1.0/SH
      EPPS = 1.0E-07
C***************************************
C*** CONSTRUCT STRESS-STRAIN CURVE ***
C***************************************
C*** SET SLIDER STRESSES & SPRING STIFFNESSES ***
      CALL FORMSS
C*** START CYCLING ***
      DO 500  M = 1,NREV
      NSKIP3 = 1
      EPT(1) = EPL
      EPL = EPLL(M)
C*** FOR FIRST SEGMANT ***
  240 ST(1) = ST(I)
      PM = -PM
      I = 2
      ST(2) = -S(3) - SB(3)
      EPT(2) = (ST(2) - ST(1))*EI + EPT(1)
      DIFF = PM*(EPT(2) - EPL)
      DELPEP(2) = 0.0
      IF (DIFF)  310,344,305
  305 DELEP = EPL - EPT(1)
      ST(2) = DELEP*E + ST(1)
      EPT(2) = EPL
      GO TO  344
C*** FOR REMAINING SEGMENTS ***
  310 I = I + 1
      IF (I .LE. N)  GO TO 312
      PRINT 55,  N,NREV
      PRINT 1
      GO TO  1000
  312 ST(I) = -S(I+1) - SB(I+1)
      STR =  ABS(ST(I-1))
      ETDS = EI + EDR(I)/(1.0 - STR/RC)
      EPT(I) = (ST(I) - ST(I-1))*ETDS + EPT(I-1)
      DIFFI = ST(I) - ST(I-1)
```

```
      DIFF2 = EPT(I) - EPT(I-1)
      DELPEP(I) = DIFF2 - DIFF1*EI
      DIFF = PM*(EPT(I) - EPL)
      IF (DIFF)  310,335,315
  315 DELEP = EPL - EPT(I-1)
      ST(I) = DELEP/ETDS + ST(I- 1)
      EPT(I) = EPL
      DIFF1 = ST(I) - ST(I-1)
      DIFF2 = EPT(I) - EPT(I-1)
      DELPEP(I) = DIFF2 - DIFF1*EI
C*** RESET ALL RESIDUAL STRESSES ***
  335 DO 340  J = 3,I
  340 S(J) = -ST(I) - SB(J)
C******************************
C*** HARDENING OR SOFTENING ***
C******************************
  344 GO TO (349,347), NSKIP
  349 EPP = EPT(I) - (EPT(1) + (ST(I)-ST(1))*EI)
      EPPA =  ABS(EPP)/2.0
  346 IF (EPPA.LT. 1.0E-07)  GO TO  347
  505 EPPA = EPPA**SI
      EPPS = EPPS + EPPA
      IF (EPPS .GT. HMAX)  NSKIP = 2
      GO TO  (510,515),  MSKIP
  510 IF (EPPS .LT. HMIN)  GO TO 520
      MSKIP = 2
      A1 = YPPS**SHEC
      SHEI = 1.000/SHEC
  515 AK = KH*EPPS**H
  520 CALL FORMSS
C*** RESET FRICTIONAL STRESSES IF NECESSARY ***
  347 GO TO (343,400),  NSKIP1
  343 DO 345  J = 3,N
  345 SB(J) = -SB(J)
  400 CONTINUE
C*****************
C***  PRINTOUT  ***
C*****************
      PRINT 65
      STM = (ST(1) + ST(I))/2.0
      PSSUM = 0.0
      DELPEP(1) = 0.0
      PRINT 67,  M,  EPT(1),ST(1),DELPEP(1),PSSUM,STM
      DO 420  J = 2,I
      PSSUM = PSSUM + DELPEP(J)
  420 PRINT 69, J,EPT(J),ST(J),DELPEP(J),PSSUM
  500 PRINT 2
      PRINT 1
 1000 CALL EXIT
      STOP
      END
      SUBROUTINE FORMSS
C*********************************************************
C*** CALC. FRICTIONAL STRESS & SPRING STIFFNESSES ***
C*********************************************************
      REAL  KS,KC,KH
C     CALCULATION OF MODULI
      COMMON  EPT,ST,EI,YPS,DELS,KH,H,SHEI,SHEC,RC,
     1 EPP,STM,EDR,EPPS,AK,A1,SB,PM,
     2       N,NSKIP,MSKIP,NREV,      I,NSKIP1
      DIMENSION ST(300),EPT(300),EDR(300),SB(300)
      AKI = 1.0/AK
      NSKIP1 = 2
```

```
C*** SET FRICTIONAL STRESSES ***
      SBI = AK*A1
      SB(3) = PM*SBI
      DELS1 = PM*DELS
      DO  110   J = 4,N
  110 SB(J) = SB(J-1) + DELS1
C*** SET SPRING STIFFNESSSES ***
      DELEP = DELS*EI + ((SBI+DELS)*AKI)**SHEI
      ETI = DELEP/DELS
      SDR(3) = (ETI - EI)*(1.0 - SBI/RC)
      DO 100  J = 4,N
      SBI = SBI + DELS
      DELEP = DELS*EI + ((SBI+DELS)*AKI)**SHEI - (SBI*AKI)**SHEI
      ETI = DELEP/DELS
  100 SDR(J) = (ETI - EI)*(1.0 - SBI/RC)
  120 RETURN
      END
$ENTRY
  2.0000E+05  2.0000E+03  1.1600E+07  2.0000E-05
  6.6000E-02  6.6000E-02
  1.0230E-01  1.5000E+05  1.9500E-02  3.0300E-04 -6.1480E-01
  2.0000E+20
        2
  2.0000E-02
 -2.0000E-02
```

PARALLEL MODEL WITH CYCLIC HARDENING OR SOFTENING AND RELAXATION

```
C
C*****************************************************
C  STRAIN CONTROL - PARALLEL MODEL (2)
C   SIMPLIFIED INPUT-OUTPUT
C   CYCLIC HARDENING OR SOFTENING AND RELAXATION
C*****************************************************
C
      REAL KS,KC,KH
    1 FORMAT ('1')
    2 FORMAT  (///////)
    5 FORMAT (4E12.4)
    8 FORMAT  (E12.4)
   10 FORMAT (2E12.4)
   17 FORMAT (5E12.4)
   19 FORMAT  (I10)
   31 FORMAT (T55,' INPUT INFORMATION'///T3,' CONSTANTS FORMING STRESS-S
     1TRAIN RELATION'//T16,' STATIC STRENGTH COEFFICIENT =',F11.1,T76,'
     2STATIC STRAIN HARDENING EXPONENT =',F14.4/T16,' CYCLIC STRENGTH CO
     3EFFICIENT =',F11.1,T76,' CYCLIC STRAIN HARDENING EXPONENT =',F14.4
     4/T22,' MODULUS OF ELASTICITY =',F11.1/)
   32 FORMAT (T3,' RELAXING FUNCTION CONSTANTS'//T26,' RELAXING CONSTANT
     1 =',F14.4///)
   34 FORMAT (T3,' HARDENING/SOFTENING CONSTANTS'//T31,' H/S EXPONENT ='
     1,F14.4,T93,' H/S COEFFICIENT =',F11.1/T27,' MAXIMUM HARDNESS =',F1
     24.4,T92,' MINIMUM HARDNESS =',F18.8/T26,' HARDNESS EXPONENT =',F14
     3.4/////)
   36 FORMAT (T19,' MONOTONIC YIELD STRENGTH =',F11.1,T87,' CYCLIC YIELD
     1 STRENGTH =',F11.1/T22,' PLASTIC STRAIN OFFSET =',F17.7/)
   37 FORMAT (T20,' MAXIMUM STRESS REQUIRED =',F11.1,T92,' STRESS INCREM
     1ENT =',F11.1/T25,' NUMBER OF ELEMENTS =',I9////)
   55 FORMAT (////' PROGRAM HAS EXCEEDED THE ALLOTTED',I5,'  ELEMENTS ON
     1THE',I5,'   REVERSAL')
   58 FORMAT (T5,'STRAIN PEAKS:'/T05,'ORDER',T20,'STRAIN')
   60 FORMAT (I10,1PE16.6)
   65 FORMAT  (T11,'REV.',T25,'POINT',T39,'STRAIN',T55,'STRESS',
     1 T66,'DEL. P. STRAIN',T84,'P. STRAIN',T098,
     2 'MEAN STRESS')
   67 FORMAT (I13,T29,'1',1PE16.4,2PE16.4,1P2E16.4,
     1 2PE16.4)
   69 FORMAT (I29,1PE16.4,2PE16.4,1PE16.4,1PE16.4)
      DIMENSION SB(300),ST(300),S(300),EPT(300),EPB(300),
     1 EPLL(300),DELPEP(300),ESUM(300),EPPL(300)
      COMMON  EPT,ST,EI,YPS,DELS,KH,H,SHEI,SHEC,RC,
     1 EPP,STM,EPB,EPPS,AK,AI,SB,PM,E,ESUM,
     2      N,NSKIP,MSKIP,NREV,      I,NSKIP1
      PRINT 1
C******************
C*** INPUT DATA ***
C******************
C     DATA INPUT
  100 READ 5,  SULT,DELS,E,YPPS
      READ 10, SHES,SHEC
      READ 17,  H,KH,HMAX,HMIN,SH
  120 READ 10,  RC
      READ 19,  NREV
      READ 8,  (EPLL(J),  J=1,NREV)
      KS=KH*HMIN**H
      KC = KH*HMAX**H
      YPSM = KS*YPPS**SHES
      YPSC = KC*YPPS**SHEC
      N   = (SULT - YPSM)/DELS
```

```
      PRINT 31,  KS,SHES,KC,SHEC,E
      PRINT 36,  YPSM,YPSC,YPPS
      PRINT 37,  SULT,DELS,N
      PRINT 32, RC
      PRINT 34,  H,KH,HMAX,HMIN,SH
      PRINT 58
      PRINT 60,  (J,EPLL(J),  J=1,NREV)
C*********************
C*** INITIAL VALUES ***
C*********************
C STRESS-STRAIN
      NSKIP2 = 1
      DO  200   J = 2,N
  200 EPPL(J) = 0.0
      AK = KS
      SHEI = 1.0/SHES
      EI = 1.0/E
      A1 = YPPS**SHES
      I = 1
      PRINT 2
      PM = -1.0
      EPL = 0.0
      ST(I) = 0.0
C HARDENING
      NSKIP = 1
      MSKIP = 1
      SI = -1.0/SH
      EPPS = 1.0E-07
C*************************************
C*** CONSTRUCT STRESS-STRAIN CURVE ***
C*************************************
C*** SET SLIDER STRESSES & SPRING STIFFNESSES ***
      CALL FORMSS
C*** START CYCLING ***
      DO 500  M = 1,NREV
      NSKIP3 = 1
      EPT(1) = EPL
      EPL = EPLL(M)
C*** FOR FIRST SEGMANT ***
  240 ST(1) = ST(I)
      PM = -PM
      I = 2
      EPT(2) = EPPL(2) + EPB(2)
      ST(2) = ST(1) + (EPT(2) - EPT(1))*E
      DIFF = PM*(EPT(2) - EPL)
      DELPEP(2) = 0.0
      IF (DIFF)  310,344,305
  305 EPT(2) = EPL
      ST(2) = ST(1) + (EPT(2)-EPT(1))*E
      GO TO  344
C*** FOR REMAINING SEGMENTS ***
  310 I = I + 1
      IF (I .LE. N)  GO TO 312
      PRINT 55,  N,NREV
      PRINT 1
      GO TO  1000
  312 EPT(I) = EPPL(I) + EPB(I)
      STP = ABS (ST(I-1))
      ET = (E - ESUM(I-1))*(1.0 - STR/RC)
      ST(I) = ST(I-1) + (EPT(I) - EPT(I-1))*ET
      DIFF1 = ST(I) - ST(I-1)
      DIFF2 = EPT(I) - EPT(I-1)
      DELPEP(I) = DIFF2 - DIFF1*EI
```

```
      DIFF = PM*(EPT(I) - EPL)
      IF (DIFF)  310,335,315
  315 EPT(I) = EPL
      ST(I) = ST(I-1) + (EPT(I) - EPT(I-1))*ET
      DIFF1 = ST(I) - ST(I-1)
      DIFF2 = EPT(I) - EPT(I-1)
      DELPEP(I) = DIFF2 - DIFF1*EI
C*** RESET ALL PLASTIC STRAINS ***
  335 I1 = I - 1
      DO 340  J = 2,I1
  340 EPPL(J) = EPT(I) - EPB(J)
C*******************************
C*** HARDENING OR SOFTENING ***
C*******************************
  344 GO TO (349,347), NSKIP
  349 EPP = EPT(I) - (EPT(1) + (ST(I)-ST(1))*EI)
      EPPA =  ABS(EPP)/2.0
  346 IF (EPPA.LT. 1.0E-07)  GO TO  347
  505 EPPA = EPPA**SI
      EPPS = EPPS + EPPA
      IF (EPPS .GT. HMAX)  NSKIP = 2
      GO TO  (510,515),  MSKIP
  510 IF (EPPS .LT. HMIN)  GO TO 520
      MSKIP = 2
      A1 = YPPS**SHEC
      SHEI = 1.0D0/SHEC
  515 AK = KH*EPPS**H
  520 CALL FORMSS
C*** RESET YIELD STRAINS   ***
  347 GO TO (343,400),  NSKIP1
  343 DO 345  J = 2,N
  345 EPB(J) = -EPB(J)
  400 CONTINUE
C*****************
C***  PRINTOUT  ***
C*****************
      PRINT 65
      STM = (ST(1) + ST(I))/2.0
      PSSUM = 0.0
      DELPEP(1) = 0.0
      PRINT 67,  M,  EPT(1),ST(1),DELPEP(1),PSSUM,STM
      DO 420  J = 2,I
      PSSUM = PSSUM + DELPEP(J)
  420 PRINT 69, J,EPT(J),ST(J),DELPEP(J),PSSUM
  500 PRINT 2
      PRINT 1
 1000 CALL EXIT
      STOP
      END
      SUBROUTINE FORMSS
C*************************************************
C*** CALC. FRICTIONAL STRESS & SPRING STIFFNESSES ***
C*************************************************
      REAL  KS,KC,KH
C     CALCULATICN OF MODULI
      COMMON  EPT,ST,EI,YPS,DELS,KH,H,SHEI,SHEC,RC,
     1 EPP,STM,EPB,EPPS,AK,A1,SB,PM,E,ESUM,
     2      N,NSKIP,MSKIP,NPEV,      I,NSKIP1
      DIMENSION ST(300),EPT(300),EPB(300),SB(300),ESUM(300)
      AKI = 1.0/AK
      NSKIP1 = 2
C*** SET FRICTIONAL STRESSES ***
      SBI = AK*A1
```

```
      EPB(2) = -PM*SBI*EI
C*** SET SPRING STIFFNESSES ***
      DELEP = DELS*EI + ((SBI+DELS)*AKI)**SHEI
      EPB(3) = EPB(2) - PM*DELEP
      ET = DELS/DELEP
      ESUM(2) = E -ET/(1.0 - SBI/RC)
      DO 100  J = 3,N
      SBI = SBI + DELS
      DELEP = DELS*EI + ((SBI+DELS)*AKI)**SHEI - (SBI*AKI)**SHEI
      EPB(J+1) = EPB(J) - PM*DELEP
      ET = DELS/DELEP
  100 ESUM(J) = E - ET/(1.0 - SBI/RC)
  120 RETURN
      END
$ENTRY
  2.0000E+05  2.0000E+03  1.1600E+07  2.0000E-05
  6.6000E-02  6.6000E-02
  1.0230E-01  1.5000E+05  1.9500E-02  3.0900E-04 -6.1480E-01
  2.0000E+20
          2
  2.0000E-02
 -2.0000E-02
```

SERIES MODEL CHARACTERISTIC OF A36 STEEL

```
C
C*****************************************************
C   STRAIN CONTROL - SERIES MODEL (A36)
C    SIMPLIFIED INPUT-OUTPUT
C    CYCLIC HARDENING FOR LARGE STRAINS CHARACTERISTIC
C     OF A36 STEEL AND CYCLIC RELAXATION
C*****************************************************
C
      REAL KS,KC,K2
    1 FORMAT ('1')
    2 FORMAT  (//////)
    5 FORMAT (3E12.4)
    8 FORMAT  (E12.4)
   10 FORMAT (2E12.4)
   19 FORMAT  (I10)
   31 FORMAT (T55,' INPUT INFORMATION'///T3,' CONSTANTS FORMING STRESS-S
     1TRAIN RELATION'//T16,' STATIC STRENGTH COEFFICIENT =',F11.1,T76,'
     2STATIC STRAIN HARDENING EXPONENT =',F14.4/T16,' CYCLIC STRENGTH CO
     3EFFICIENT =',F11.1,T76,' CYCLIC STRAIN HARDENING EXPONENT =',F14.4
     4/T13,'INTERMEDIATE STRENGTH COEFFICIENT =',F11.1,
     5 T70,'INTERMEDIATE STRAIN HARDENING EXPONENT =',F14.4
     6/T22,' MODULUS OF ELASTICITY =',F11.1/)
   32 FORMAT (T3,' RELAXING FUNCTION CONSTANTS'//T26,' RELAXING CONSTANT
     1 =',F14.4///)
   36 FORMAT (T19,' MONOTONIC YIELD STRENGTH =',F11.1,
     1 T087,'PLASTIC STRAIN OFFSET =',F17.7/
     2 T19,'CYCLIC YIELD STRENGTH =',F11.1/
     3 T12,'INTERMEDIATE YIELD STRENGTH =',F11.1/)
   37 FORMAT (T12,'STRESS INCREMENT =',F11.1,
     1 T080,'MONOTONIC NO. OF ELEMENTS =',I9/
     2 T080,'CYCLIC NO. OF ELEMENTS =',I9/
     3 T080,'INTERMEDIATE NO. OF ELEMENTS =',I9/////)
   55 FORMAT (////' PROGRAM HAS EXCEEDED THE ALLOTTED',I5,'  ELEMENTS ON
     1THE',I5,'  REVERSAL')
   58 FORMAT (T5,'STRAIN PEAKS:'/T05,'ORDER',T20,'STRAIN')
   60 FORMAT (I10,1PE16.6)
   65 FORMAT  (T11,'REV.',T25,'POINT',T39,'STRAIN',T55,'STRESS',
     1 T66,'DEL. P. STRAIN',T84,'P. STRAIN',T098,
     2 'MEAN STRESS')
   67 FORMAT (I13,T29,'1',1PE16.4,2PE16.4,1P2E16.4,
     1 2PE16.4)
   69 FORMAT (I29,1PE16.4,2PE16.4,1PE16.4,1PE16.4)
      DIMENSION SB(300),ST(300),S(300),EPT(300),EDR(300),
     1 EPLL(300),DELPEP(300)
      COMMON  EPT,ST,EI,YPS,DELS,KH,H,SHEI,SHEC,RC,
     1 EPP,STM,EDR,EPPS,AK,A1,SB,PM,
     2       N,NSKIP,MSKIP,NREV,      I,NSKIP1
      PRINT 1
C******************
C*** INPUT DATA ***
C******************
C     DATA INPUT
  100 READ 5,  DELS,E,YPPS
      READ 5,  SHES,SHEC,SHE2
      READ 5,  KS,KC,K2
  120 READ 10,  RC
      READ 19,  NREV
      READ 8,  (EPLL(J),  J=1,NREV)
      YPSM = KS*YPPS**SHES
```

```
      YPSC = KC*YPPS**SHEC
      YPS2 = K2*YPPS**SHE2
      NS = (KS - YPSM)/DELS + 1
      NC = (KC - YPSC)/DELS + 1
      N2 = (K2 - YPS2)/DELS + 1
      PRINT 31,  KS,SHES,KC,SHEC,K2,SHE2,E
      PRINT 36,  YPSM,YPPS,YPSC,YPS2
      PRINT 37,  DELS,NS,NC,N2
      PRINT 32, PC
      PRINT 59
      PRINT 60,  (J,EPLL(J),  J=1,NREV)
C**********************
C*** INITIAL VALUES ***
C**********************
C STRESS-STRAIN
      NSKIP2 = 1
      DO  200   J = 3,300
  200 S(J) = 0.0
      AK = KS
      SHEI = 1.0/SHES
      EI = 1.0/E
      A1 = YPPS**SHES
      I = 1
      PRINT 2
      PM = -1.0
      EPL = 0.0
      ST(I) = 0.0
C HARDENING
      NSKIP = 1
      MSKIP = 1
      NH = 1
      N = NS + 4
C**************************************
C*** CONSTRUCT STRESS-STRAIN CURVE ***
C**************************************
C*** SET SLIDER STRESSSES & SPRING STIFFNESSES ***
      CALL FURMSS
C*** START CYCLING ***
      DO 500  M = 1,NREV
      NSKIP3 = 1
      EPT(1) = EPL
      EPL = EPLL(M)
C*** FOR FIRST SEGMANT ***
  240 ST(1) = ST(I)
      PM = -PM
      I = 2
      ST(2) = -S(3) - SB(3)
      EPT(2) = (ST(2) - ST(1))*EI + EPT(1)
      DIFF = PM*(EPT(2) - EPL)
      DELPEP(2) = 0.0
      IF (DIFF)  310,344,305
  305 DELEP = EPL - EPT(1)
      ST(2) = DELEP*E + ST(1)
      EPT(2) = EPL
      GO TO  344
C*** FOR REMAINING SEGMENTS ***
  310 I = I + 1
      IF (I .LE. N)  GO TO 312
      PRINT 55,  N,M
      PRINT 1
      GO TO  1000
  312 ST(I) = -S(I+1) - SB(I+1)
      STR =  ABS(ST(I-1))
```

```
      ETDS = EI + EDR(I)/(1.0 - STR/RC)
      EPT(I) = (ST(I) - ST(I-1))*ETDS + EPT(I-1)
      DIFF1 = ST(I) - ST(I-1)
      DIFF2 = EPT(I) - EPT(I-1)
      DELPEP(I) = DIFF2 - DIFF1*EI
      DIFF = PM*(EPT(I) - EPL)
      IF (DIFF)  310,335,315
  315 DELEP = EPL - EPT(I-1)
      ST(I) = DELEP/ETDS + ST(I- 1)
      EPT(I) = EPL
      DIFF1 = ST(I) - ST(I-1)
      DIFF2 = EPT(I) - EPT(I-1)
      DELPEP(I) = DIFF2 - DIFF1*EI
C*** RESET ALL RESIDUAL STRESSES ***
  335 DO 340  J = 3,I
  340 S(J) = -ST(I) - SB(J)
C*********************************
C*** HARDENING OR SOFTENING ***
C*********************************
  344 GO TO (349,347), NSKIP
  349 EPP = EPT(I) - (EPT(1) + (ST(I)-ST(1))*EI)
      EPPA =  ABS(EPP)/2.0
  346 IF (EPPA.LT. 1.0E-07)  GO TO  347
      IF (NH .EQ. 2)   GO TO 505
      A1 = YPPS**SHE2
      SHEI = 1.0/SHE2
      AK = K2
      N = N2 + 4
      NH = 2
      GO TO   520
  505 A1 = YPPS**SHEC
      SHEI = 1.0/SHEC
      AK = KC
      N = NC + 4
      NSKIP = 2
  520 CALL FORMSS
C*** RESET FRICTIONAL STRESSES IF NECESSARY ***
  347 GO TO (343,400),  NSKIP1
  343 DO 345  J = 3,N
  345 SB(J) = -SB(J)
  400 CONTINUE
C*******************
C***  PRINTOUT  ***
C*******************
      PRINT 65
      STM = (ST(1) + ST(I))/2.0
      PSSUM = 0.0
      DELPEP(1) = 0.0
      PRINT 67,  M,  EPT(1),ST(1),DELPEP(1),PSSUM,STM
      DO 420  J = 2,I
      PSSUM = PSSUM + DELPEP(J)
  420 PRINT 69, J,EPT(J),ST(J),DELPEP(J),PSSUM
  500 PRINT 2
      PRINT 1
 1000 CALL EXIT
      STOP
      END
      SUBROUTINE FORMSS
```

```
C****************************************************
C*** CALC. FRICTIONAL STRESS & SPRING STIFFNESSES ***
C****************************************************
      REAL  KS,KC,K2
C     CALCULATION OF MODULI
      COMMON  EPT,ST,EI,YPS,DELS,KH,H,SHEI,SHEC,RC,
     1 EPP,STM,EDR,EPPS,AK,A1,SB,PM,
     2      N,NSKIP,MSKIP,NREV,     I,NSKIP1
      DIMENSION ST(300),EPT(300),EDR(300),SB(300)
      AKI = 1.0/AK
      NSKIP1 = 2
C*** SET FRICTIONAL STRESSES ***
      SBI = AK*A1
      SB(3) = PM*SBI
      DELS1 = PM*DELS
      DO  110   J = 4,N
  110 SB(J) = SB(J-1) + DELS1
C*** SET SPRING STIFFNESSES ***
      DELEP = DELS*EI + ((SBI+DELS)*AKI)**SHEI
      ETI = DELEP/DELS
      EDR(3) = (ETI - EI)*(1.0 - SBI/RC)
      DO 100  J = 4,N
      SBI = SBI + DELS
      DELEP = DELS*EI + ((SBI+DELS)*AKI)**SHEI - (SBI*AKI)**SHEI
      ETI = DELEP/DELS
  100 EDR(J) = (ETI - EI)*(1.0 - SBI/RC)
  120 RETURN
      END
$ENTRY
  1.0000E+03  3.0000E+07  2.0000E-04
  1.0000E-03  1.7900E-01  1.4300E-01
  4.0000E+04  1.2400E+05  8.7700E+04
  2.0000E+06
       3
  2.0000E-02
 -2.0000E-02
  2.0000E-02
```

PARALLEL MODEL CHARACTERISTIC OF A36 STEEL

```
C
C*****************************************************
C   STRAIN CONTROL - PARALLEL MODEL (A36)
C    SIMPLIFIED INPUT-OUTPUT
C    CYCLIC HARDENING FOR LARGE STRAINS CHARACTERISTIC
C     OF A36 STEEL AND CYCLIC RELAXATION
C*****************************************************
C
      REAL KS,KC,K2
    1 FORMAT ('1')
    2 FORMAT  (///////)
    5 FORMAT (3E12.4)
    8 FORMAT  (E12.4)
   10 FORMAT (2E12.4)
   19 FORMAT  (I10)
   31 FORMAT (T55,' INPUT INFORMATION'///T3,' CONSTANTS FORMING STRESS-S
     1TRAIN RELATION'//T16,' STATIC STRENGTH COEFFICIENT =',F11.1,T76,'
     2STATIC STRAIN HARDENING EXPONENT =',F14.4/T16,' CYCLIC STRENGTH CO
     3EFFICIENT =',F11.1,T76,' CYCLIC STRAIN HARDENING EXPONENT =',F14.4
     4/T13,'INTERMEDIATE STRENGTH COEFFICIENT =',F11.1,
     5 T70,'INTERMEDIATE STRAIN HARDENING EXPONENT =',F14.4
     6/T22,' MODULUS OF ELASTICITY =',F11.1/)
   32 FORMAT (T3,' RELAXING FUNCTION CONSTANTS'//T26,' RELAXING CONSTANT
     1 =',F14.4///)
   36 FORMAT (T19,' MONOTONIC YIELD STRENGTH =',F11.1,
     1 T087,'PLASTIC STRAIN OFFSET =',F17.7/
     2 T19,'CYCLIC YIELD STRENGTH =',F11.1/
     3 T12,'INTERMEDIATE YIELD STRENGTH =',F11.1/)
   37 FORMAT (T12,'STRESS INCREMENT =',F11.1,
     1 T080,'MONOTONIC NO. OF ELEMENTS =',I3/
     2 T080,'CYCLIC NO. OF ELEMENTS =',I3/
     3 T080,'INTERMEDIATE NO. OF ELEMENTS =',I3/////)
   55 FORMAT (////' PROGRAM HAS EXCEEDED THE ALLOTTED',I5,'  ELEMENTS ON
     1THE',I5,'  REVERSAL')
   58 FORMAT (T5,'STRAIN PEAKS:'/T05,'ORDER',T20,'STRAIN')
   60 FORMAT (I10,1PE16.6)
   65 FORMAT  (T11,'REV.',T25,'POINT',T39,'STRAIN',T55,'STRESS',
     1 T66,'DEL. P. STRAIN',T84,'P. STRAIN',T098,
     2 'MEAN STRESS')
   67 FORMAT (I13,T29,'1',1PE16.4,2PE16.4,1P2E16.4,
     1 2PE16.4)
   69 FORMAT (I29,1PE16.4,2PE16.4,1PE16.4,1PE15.4)
      DIMENSION SB(300),ST(300),S(300),EPT(300),EPB(300),
     1 EPLL(300),DELPEP(300),ESUM(300),EPPL(300)
      COMMON  EPT,ST,FI,YPS,DELS,KH,H,SHEI,SHEC,RC,
     1 EPP,STM,EPB,EPPS,AK,A1,SB,PM,E,ESUM,
     2       N,NSKIP,MSKIP,NREV,      I,NSKIP1
      PRINT 1
C******************
C*** INPUT DATA ***
C******************
C     DATA INPUT
  100 READ 5,  DELS,E,YPPS
      READ 5,  SHES,SHEC,SHE2
      READ 5,  KS,KC,K2
  120 READ 10,  RC
      READ 19,  NREV
      READ 8,  (EPLL(J),  J=1,NREV)
      YPSM = KS*YPPS**SHES
      YPSC = KC*YPPS**SHEC
```

```
      YPS2 = K2*YPPS**SHE2
      NS = (KS - YPSM)/DELS + 1
      NC = (KC - YPSC)/DELS + 1
      N2 = (K2 - YPS2)/DELS + 1
      PRINT 31,  KS,SHES,KC,SHFC,K2,SHE2,E
      PRINT 36,  YPSM,YPPS,YPSC,YPS2
      PRINT 37,  DELS,NS,NC,N2
      PRINT 32, RC
      PRINT 58
      PRINT 60,  (J,EPLL(J),  J=1,NREV)
C**********************
C*** INITIAL VALUES ***
C**********************
C STRESS-STRAIN
      NSKIP2 = 1
      DO  200   J = 1,300
  200 EPPL(J) = 0.0
      AK = KS
      SHEI = 1.0/SHES
      EI = 1.0/E
      A1 = YPPS**SHES
      I = 1
      PRINT 2
      PM = -1.0
      EPL = 0.0
      ST(I) = 0.0
C HARDENING
      NSKIP = 1
      MSKIP = 1
      NH = 1
      N = NS + 4
C**************************************
C*** CONSTRUCT STRESS-STRAIN CURVE ***
C**************************************
C*** SET SLIDER STRESSES & SPRING STIFFNESSES ***
      CALL FORMSS
C*** START CYCLING ***
      DO 500  M = 1,NREV
      NSKIP3 = 1
      EPT(1) = EPL
      EPL = EPLL(M)
C*** FOR FIRST SEGMANT ***
  240 ST(1) = ST(I)
      PM = -PM
      I = 2
      EPT(2) = EPPL(2) + EPB(2)
      ST(2) = ST(1) + (EPT(2) - EPT(1))*E
      DIFF = PM*(EPT(2) - EPL)
      DELPEP(2) = 0.0
      IF (DIFF)  310,344,305
  305 EPT(2) = EPL
      ST(2) = ST(1) + (EPT(2)-EPT(1))*E
      GO TO  344
C*** FOR REMAINING SEGMENTS ***
  310 I = I + 1
      IF (I .LE. N)  GO TO 312
      PRINT 55,  N,NREV
      PRINT 1
      GO TO  1000
  312 EPT(I) = EPPL(I) + EPH(I)
      STR = ABS (ST(I-1))
      ET = (E - ESUM(I-1))*(1.0 - STR/RC)
      ST(I) = ST(I-1) + (EPT(I) - EPT(I-1))*ET
```

```
      DIFF1 = ST(I) - ST(I-1)
      DIFF2 = EPT(I) - EPT(I-1)
      DELPEP(I) = DIFF2 - DIFF1*EI
      DIFF = PM*(EPT(I) - EPL)
      IF (DIFF)  310,335,315
  315 EPT(I) = EPL
      ST(I) = ST(I-1) + (EPT(I) - EPT(I-1))*ET
      DIFF1 = ST(I) - ST(I-1)
      DIFF2 = EPT(I) - EPT(I-1)
      DELPEP(I) = DIFF2 - DIFF1*EI
C*** RESET ALL PLASTIC STRAINS ***
  335 I1 = I - 1
      DO 340  J = 2,I1
  340 EPPL(J) = EPT(I) - EPB(J)
C*********************************
C*** HARDENING OR SOFTENING ***
C*********************************
  344 GO TO (349,347), NSKIP
  349 EPP = EPT(I) - (EPT(1) + (ST(I)-ST(1))*EI)
      EPPA =  ABS(EPP)/2.0
  346 IF (EPPA.LT. 1.0E-07)  GO TO  347
      IF (NH .EQ. 2)   GO TO 505
      A1 = YPPS**SHE2
      SHEI = 1.0/SHE2
      AK = K2
      N = N2 + 4
      NH = 2
      GO TO   520
  505 A1 = YPPS**SHEC
      SHEI = 1.0/SHEC
      AK = KC
      N = NC + 4
      NSKIP = 2
  520 CALL FORMSS
C*** RESET YIELD STRAINS   ***
  347 GO TO (343,400),  NSKIP1
  343 DO 345  J = 2,N
  345 EPB(J) = -EPB(J)
  400 CONTINUE
C******************
C***  PRINTOUT  ***
C******************
      PRINT 65
      STM = (ST(1) + ST(I))/2.0
      PSSUM = 0.0
      DELPEP(1) = 0.0
      PRINT 67,  M,  EPT(1),ST(1),DELPEP(1),PSSUM,STM
      DO 420  J = 2,I
      PSSUM = PSSUM + DELPEP(J)
  420 PRINT 69, J,EPT(J),ST(J),DELPEP(J),PSSUM
  500 PRINT 2
      PRINT 1
 1000 CALL EXIT
      STOP
      END
      SUBROUTINE FORMSS
```

```
C*****************************************************
C*** CALC. FRICTIONAL STRESS & SPRING STIFFNESSES ***
C*****************************************************
      REAL  KS,KC,K2
C*** CALCULATION OF MODULI  ***
      COMMON  EPT,ST,EI,YPS,DELS,KH,H,SHEI,SHEC,RC,
     1 EPP,STM,EPB,EPPS,AK,A1,SB,PM,E,ESUM,
     2       N,NSKIP,MSKIP,NREV,      I,NSKIP1
      DIMENSION ST(300),EPT(300),EPB(300),SB(300),ESUM(300)
      AKI = 1.0/AK
      NSKIP1 = 2
C*** SET FRICTIONAL STRESSES ***
      SBI = AK*A1
      EPB(2) = -PM*SBI*EI
C*** SET SPRING STIFFNESSES ***
      DELEP = DELS*EI + ((SBI+DELS)*AKI)**SHEI
      EPB(3) = EPB(2) - PM*DELEP
      ET = DELS/DELEP
      ESUM(2) = E -ET/(1.0 - SBI/RC)
      DO 100  J = 3,N
      SBI = SBI + DELS
      DELEP = DELS*EI + ((SBI+DELS)*AKI)**SHEI - (SBI*AKI)**SHEI
      EPB(J+1) = EPB(J) - PM*DELEP
      ET = DELS/DELEP
  100 ESUM(J) = E - ET/(1.0 - SBI/RC)
  120 RETURN
      END
$ENTRY
  1.0000E+03  3.0000E+07  2.0000E-04
  1.0000E-03  1.7900E-01  1.4300E-01
  4.0000E+04  1.2400E+05  8.7700E+04
  2.0000E+06
         3
  1.5000E-02
 -1.5000E-02
  1.5000E-02

********* B0001210 ***** 742 ************** JUMO                    **************
```