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Evaluation and Verification of Advanced Methods to Assess Multiple-Site Damage of Aircraft Structure

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Final Report

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16. Abstract

Widespread fatigue damage (WFD) is a complex phenomenon that is extremely difficult to analyze with standard methods developed from first principles of linear elastic fracture mechanics (LEFM). Because of the limited applications of LEFM, more advanced methods have been explored and developed over the past decade. These include analytical tools to determine parameters governing the onset and growth of cracks and elastic-plastic fracture criterion for residual strength determinations. The tools also include the finite element alternating method (FEAM); a computationally efficient yet rigorous approach to calculate two- and three-dimensional stress-intensity factor solutions governing crack growth; FASTRAN, a fatigue crack growth analysis program using a crack-closure model; and STAGS, an advanced finite element program implemented with fracture mechanics and stable-tearing analysis capabilities for generalized shell structures. The elastic-plastic failure criterion includes the plastic zone touch, crack tip opening angle (CTOA), and the T*-integral. These computational tools must be verified and validated using experimental data to ensure successful transfer of useable and accurate technology to the industry.

The objectives of this study were to (1) take existing analysis tools and establish the processes required of using them as engineering tools to determine the effects of multiple-site damage (MSD) on the residual strength of representative aircraft structures and (2) investigate small crack behavior to better understand the formation of MSD in structures. These tools and criteria were used and verified in this study to analyze portions of the multiple-site crack initiation, growth, linkup, and catastrophic fracture process. For the development of MSD, the fundamental phenomenon of fatigue crack initiation in material and the rate of growth were addressed experimentally at the coupon level and analytically using FASTRAN. The initiation of MSD was addressed at the component level on flat panels that were representative of typical fuselage lap splices. Experimentally generated data and a closure-based crack growth code were used to develop equivalent initial flaw sizes. Residual strength analysis used the application of the T*-integral, CTOA, and plastic zone linkup criteria to predict the linkup and fast fracture of MSD in curved panels and aft pressure bulkhead. A procedure was developed that used elastic-plastic finite element analyses with STAGS and CTOA to perform the stable tearing and unstable fracture of MSD in aircraft structures.

From extensive experimental work, test data was generated and used for correlation and validation and verification of the various methodologies and criteria.

17. Key Words	18. Distribution Statement
Widespread fatigue damage; Multiple site damage; Stress-intensity factor, (SIF); Crack tip opening angle, Plastic zone linkup, (PZL); Plastic zone touch, (PZT); T*-Integral; Crack initiation; Crack growth rate; Equivalent initial flaw size, (EIFS); Residual strength; Fracture mechanics	This document is available to the public through the National Technical Information Service (NTIS) Springfield, Virginia 22161.

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LIST OF ACRONYMS AND SYMBOLS

AAWG	Airworthiness Assurance Working Group
AFRL	Air Force Research Laboratory
AGARD	Aerospace Research and Development
BES	Boundary element system
BIAM	Beijing Institute of Aeronautical Materials
CAAC	Civil Aviation Authority of China
CTOA	Crack tip opening angle
C(T)	Compact Tension
DOF	Degree of Freedom
EIFS	Equivalent initial flaw size
EO	Engineering order
EPFEAM	Elastic-plastic finite element alternating method
FAA	Federal Aviation Administration
FASTER	Full-Scale Aircraft Structural Test Evaluation and Research
FEA	Finite element analysis
FEAM	Finite element alternating method
GUI	Graphical user interface
LaRC	Langley Research Center
LEFM	Linear elastic fracture mechanics
LVDT	Linear Variable Differential Transformer
MPC	Multiple-point constraint
MSD	Multiple-site damage
NAARP	National Aging Aircraft Research Program
NASA	National Aeronautics and Space Administration
NDI	Nondestructive inspection
NIST	National Institute of Standards and Technology
OEM	Original equipment manufacturer
POD	Probability of detection
PZL	Plastic zone linkup
SCG	Small crack growth
SEM	Scanning Electronic Microscope
SENT	Single-edge notch under tension
SIF	Stress-intensity factor
TCL	Tool command language
USAF	United States Air Force
WFD	Widespread fatigue damage
WPAFB	Wright-Patterson Air Force Base

α	Constraint factor
K	Stress-intensity factor
a_1/L	Dimensionless parameter
a_{eff}	Effective crack length
β_1	Total geometry correction factor for the lead crack
β_2	Total geometry correction factor for the MSD crack
β_u	Correction factors
c/a	Crack depth to crack length
da/dN	Crack growth rate
ΔK	Crack tip stress-intensity factor range
ΔK	Stress-intensity factor range
ΔK_{eff}	Effective stress-intensity factor range
F_{TU}	The material allowable
F_{TY}	Yield strength
F_{TY}	Material yield strength
Γ_ε	Crack tip contour
$M(T)$	Middle-crack tension
R-ratio	Stress ratio (minimum stress/maximum stress)
T^*_R	T*-integral resistance
Ψ_c	Critical COTA
$\Psi_{c,}$	Critical tearing angle

EXECUTIVE SUMMARY

This report summarizes the results from a study performed by The Boeing Company, Huntington Beach, CA, during August 1996 to February 2003. This study was undertaken to achieve two goals: (1) take existing analysis tools developed under government-funded research and establish the processes required to use them as engineering tools to determine the effects of multiple-site damage (MSD) on the residual strength in the representative aircraft structures and (2) investigate small crack behavior to better understand the formation of MSD in a structure.

WFD is a complex phenomenon that is extremely difficult to analyze with standard methods developed from first principles of linear elastic fracture mechanics (LEFM). Because of the limited applications of LEFM, more advanced methods have been explored and developed over the past decade with the support and sponsorship of the Federal Aviation Administration (FAA) and the National Aeronautics and Space Administration. This includes analytical tools to determine parameters governing the onset and growth of cracks and elastic-plastic fracture criterion for residual strength determinations. The tools include the finite element alternating method (FEAM); a computationally efficient yet rigorous approach to calculate two- and three-dimensional stress-intensity factor (SIF) solutions governing crack growth; FASTRAN, a fatigue crack growth analysis program using a crack-closure model; and STAGS, an advanced finite element program implemented with fracture mechanics and stable-tearing analysis capabilities for generalized shell structures. The elastic-plastic failure criterion include the plastic zone touch (PZT), crack tip opening angle (CTOA), and the T*-integral.

These tools and criteria were used and verified in this program to analyze portions of the multiple-site crack initiation, growth, linkup, and catastrophic fracture process. For the development of MSD, the fundamental phenomenon of fatigue crack initiation in material and the rate of growth were addressed at the coupon level experimentally and analytically using FASTRAN. The initiation of MSD was dealt with at the component level on flat panels that were representative of typical fuselage lap splices. Experimentally generated data and a closure-based crack growth code were used to develop equivalent initial flaw sizes (EIFS). For residual strength analysis, the approach taken was to apply the T*-integral, CTOA, and plastic zone linkup (PZL) criteria to predict the linkup and fast fracture of MSD. A procedure was developed that used elastic-plastic finite element analyses using STAGS and CTOA to perform the stable tearing and unstable fracture of MSD in aircraft structures.

Computational tools must be verified and validated using experimental data to ensure successful transfer of useable and accurate technology to industry. Extensive experimental work was carried out to generate test data for correlation and validation of the various methodologies and criteria. Testing was conducted collaboratively by five organizations: (1) The Boeing Company, Long Beach, CA; (2) United States Air Force (USAF), Air Force Research Laboratory (AFRL) at Wright-Patterson Air Force Base; (3) Beijing Institute of Aeronautical Materials (BIAM); (4) Civil Aviation Authority of China (CAAC); and (5) the FAA William J. Hughes Technical Center.

This project was divided into six major tasks to analyze portions of the multiple-site crack initiation, growth, linkup, and catastrophic fracture process.

1. Crack Initiation. Cracks were initiated and developed from edge-notched coupons and analyzed using FASTRAN. Testing was conducted by BIAM and CAAC under several fatigue loading conditions, including constant-amplitude and spectrum loading. Good correlation between analysis and experimental data was demonstrated under constant-amplitude loading for crack sizes larger than 0.005 inch. However, under spectrum loading, there was poor correlation.

2. Equivalent Initial Flaw Size. A semiempirical procedure was developed for the determination of EIFS using FASTRAN. Tests were conducted by AFRL using large flat panels with four joint configurations representative of aircraft joint construction. The attempts to develop comprehensive SIF solutions by compounding or superpositioning for the individual effects derived from first principles were not effective. An iterative method was developed to empirically account for these factors for the prediction to match the experimental results. In this way, the EIFS was determined to fall between 0.0001 to 0.0015 inch for the four types of splice joints. However, whether the results can be applied to other structures under different loading conditions or using different crack growth models requires additional study.

3. Small Crack Growth. Small crack growth data was generated in pin-loaded specimens and analyzed using FASTRAN. Testing was conducted by AFRL under various load transfer conditions. In general, good correlation was obtained between test and analysis for open-hole specimens under constant-amplitude loads. However, analysis predicted 20 to 30 percent faster crack growth rate for the pin-loaded specimens.

4. MSD in Flat Panels. The CTOA, T*-integral, and PZL criteria were used to analyze flat panels with MSD. Tests were conducted by AFRL using large flat panels with four joint configurations representative of aircraft joint construction. The PZL criterion provides a quick and simple way for residual strength estimations. T*-integral, together with FEAM, was able to predict the stable tearing of MSD cracks in a flat spliced panel. Using STAGS code, the CTOA criterion was able to predict the residual strengths of MSD in splice joints. Using these criteria, predictions of the residual strength were within 8 percent.

5. MSD in Curved Panels. The CTOA criterion was used to analyze curved panels with MSD. Tests were conducted by the FAA William J. Hughes Technical Center using the Full-Scale Aircraft Structural Test Evaluation and Research facility. CTOA predictions agree well with the curved panel test results, within 5 percent.

6. MSD in Aft Pressure Bulkhead. The CTOA criterion was used to analyze an aft pressure bulkhead with MSD. Tests were conducted by the AFRL. CTOA predictions agree well with the curved panel test results, within 5 percent.

In summary, this project demonstrated a successful transfer of technology developed from basic research to real-work applications. Using this technology, a methodology to assess the development of MSD and its effect on the residual strength of aircraft structure was developed. The three major components of the methodology are crack initiation, crack growth and linkup,

and residual strength. The crack initiation methodology used experimentally generated EIFS data and an analytical closure model to determine initial flaw sizes and distribution for multiple-site cracking. The CTOA, T*-integral, and PZT criteria were used to predict crack growth and linkup. Elastic-plastic finite element analyses were used with the CTOA to determine the residual strength of an aircraft structure containing a long lead crack in the presence of MSD. The methodologies were verified through a comprehensive test program.

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APPENDIX B—METHODS

This appendix contains the procedures, descriptions of computer codes, and input/output files used for the widespread fatigue damage (WFD) analyses as discussed in section 5. The complete UNIX shell scripts, FORTRAN source codes, and the data used for the current WFD programs are provided on a separate CD.

Page No.	Description
B-2	Equivalent initial flaw size analysis procedures and shell script file
B-7	Computer code get_eifs.f for collapsing measured EIFS
B-13	Computer code betauk.f for determining analytical-experimental correction factor
B-16	Computer code efsize.f for determining EIFS sizes
B-20	Finite element global-local mapping procedures
B-23	Computer code fmstrs_nl.f for extracting global NASTRAN nonlinear solutions
B-26	Computer code genfeam_nl.f for mapping global solutions to the local model
B-31	Computer code meshfem.f for converting ABAQUS files to TKALT for the local model
B-34	Program input instruction for running EPFEAM code TKALT
B-59	Computer program for running NASTRAN-to-STAGS conversion
B-71	A brief description of some of the files for 2DFEAM code

B.1 COMPUTATION OF AVERAGE EIFS SIZES.

The equivalent initial flaw size (EIFS) analysis steps are coded in the UNIX ksh script betau for each crack location of all EIFS test panels that were examined using scanning electronic microscope. The analysis steps are outlined as follows:

- Prepare the experimentally measured crack growth data and store them in a directory, denoted as 1 in the figure B-1. The format of the data sets is shown in table B-3.

- Running computer code get_eifs to synchronize the measured data into a small band and to fit a polynomial curve through the synchronized crack growth history, denoted as 2 in figure B-1.

- Using the baseline FASTRAN-II input file, denoted as 4 in figure B-1, and the modified crack growth history, denoted as 3 in figure B-1, to determine the correction factor (β_u) using the computer code betauk, denoted as 5 in figure B-1. The processes are iterated six times to obtain good convergence of β_u factors.

- Once the final β_u is determined, the baseline FSTRAN input file is modified with the β_u factor, denoted as 6 in figure B-1.

- The next step is to run FASTRAN-II code using modified FASTRAN-II input files. The FASTRAN-II analyses are performed using 16 various EIFS sizes. Store crack growth history to the crack growth matrices, denoted as 7 in figure B-1.

- The EIFS sizes can be interpolated for each measured data point from the crack growth matrices. The average EIFS sizes are calculated using the computer code efsizes, denoted as 8 in figure B-1. The outputs are stored in a file eifise.out, denoted as 9 in figure B-1.

The script file and the source codes for get_eifs, betauk, efsizes are discussed in the following appendices. The input and output data for all EIFS data points are provided on the CD.

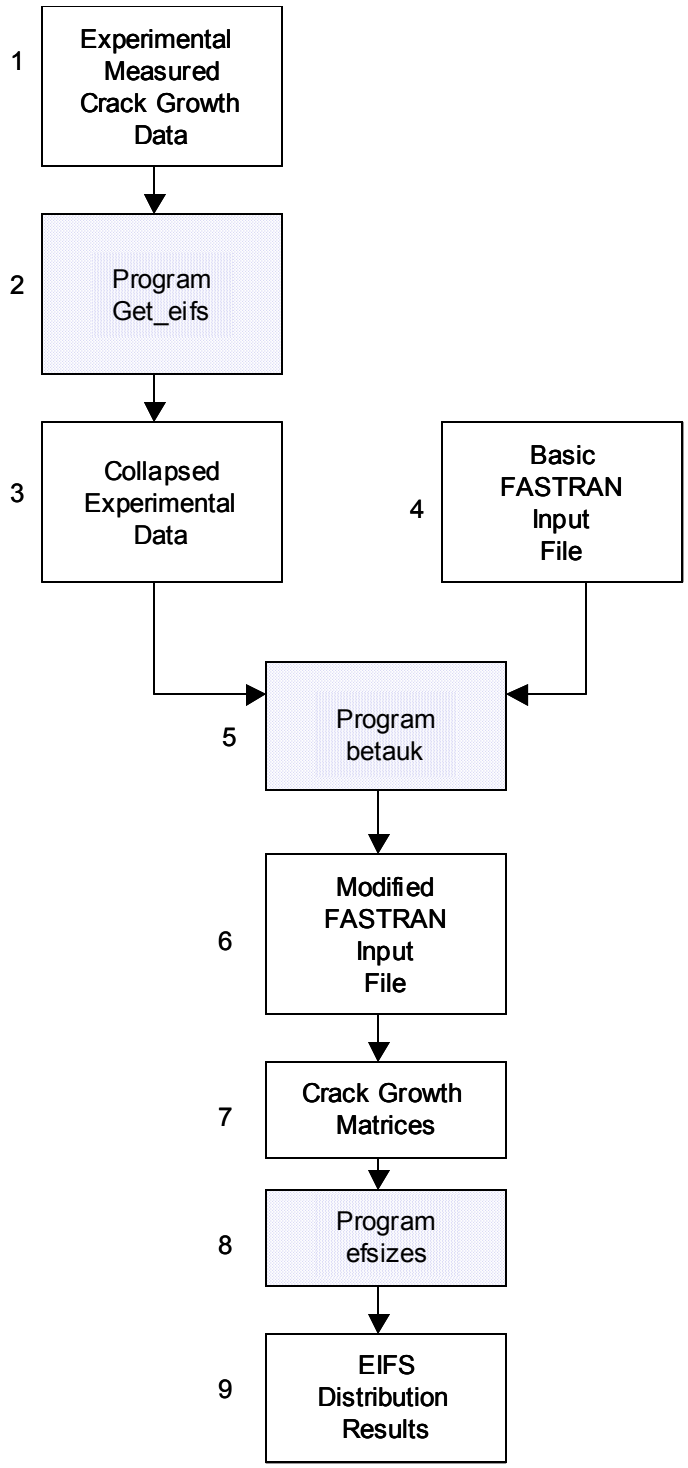


FIGURE B-1. FLOWCHART OF EIFS ANALYSIS, CODED IN THE SHELL SCRIPT

TABLE B-1. ksh SCRIPT betau FOR RUNNING EIFS ANALYSIS

```
#
==============================================================================
#       "E I F S  Analysis"
#    Ching Hsu  Boeing, Long Beach
#
==============================================================================
clear
banner "EIFS"
#   use dof=2 for all except panel no. 7 (use 4)
echo " Enter degree of polynominal equation \n    (use 4 for EIFS-7 and 2 for
others) ..\c"; read dof
echo "$dof">ndeg.dat
#ls -1 get_eifs.in_*
echo " Enter ID ...\c";read id
runid=$id
echo "$runid">efs.cntl
count=1;last=6

# --- change to EIFS directory
      cd ~/WFD/EIFS/Fatigue/Type_2/Beta45

# --- get crack growth test data and collapse the experimental data
      ln -sf get_eifs.in_$runid get_eifs.in
      get_eifs<get_eifs.in
      ln -sf mod_cyc.dat_$runid mod_cyc.dat

# --- setup FASTRAN input files
      cp fast2.in_betau_$runid fast2.betau.in
      echo "fast2.betau.in" > tempfile_fast

# --- change initial crack sizes in the input file
      chngac < chngac.in

# --- reset beta factor modification file
      rm mod1.dat

# --- begin of iteration
      while [ "$count" -le $last ]
        do
        fast2.2.exe < tempfile_fast
        echo " read fastrans2 ...";run read_fast2 x
        echo " runnig betauk ...$count "; betauk<betauk.in

# --- change the initial flaw
        if [ "$count" -eq "1" ]
           then
           echo " running chngac ...";chngac<chngac.in_betauk
        fi
        let count=$count+1
      done

      cp fast2.betau.in fast2.in_betau_"$runid"_fnl
      cp get_eifs.out_ftd get_eifs.out_ftd_$runid
```

```
#
==============================================================================
#   computes EIFS
#
==============================================================================
clear
# get id of the crack growth database
  ver='1'
  ver=''
   ls -1 *fnl$ver
 while read x;do runid=$x;done<efs.cntl
# echo " enter run id ...\c";read runid
  echo " run id =$runid "


count=1;last=16


# --- clean up files
      rm fast2_crkgro.dat_$runid


# --- set up input file for fastran
      echo "fast2.betau.in " > tempfile_fast


# --- set up initial crack sizes
      genefs <genefs.in


# --- create generic fastan input file
      cp fast2.in_betau_"$runid"_fnl$ver fast2.betau.in


# --- execute fastran
      while [ "$count" -le $last ]
        do

# --- update fastran input file: fast2.$runid.in
      chnefs <chnefs.in


# --- run fastran
      echo " running fast2 "
      fast2.2.exe < tempfile_fast


# --- extracting crack growth history
      read_fast2 < read_fast2.in

# --- save analytical growth history to a file
      cat fast2_crkgro.dat >> fast2_crkgro.dat_$runid


# --- repeat
      let count=$count+1
      done
```

```
# --- copy all prediction to a generic file for plotting
      cp fast2_crkgro.dat_$runid fast2_crkgro.dat
      cp fast2_crkgro.dat_$runid fast2_crkgro.dat_$runid$ver
      efsize < efsize.in

      cp crack_vs_cyc.dat crack_vs_cyc.dat_$runid$ver
      cp  efsize.out  efsize.out_$runid$ver
      cp  efsize.log  efsize.log_$runid$ver

echo " =============== E N D ============================================  "
```

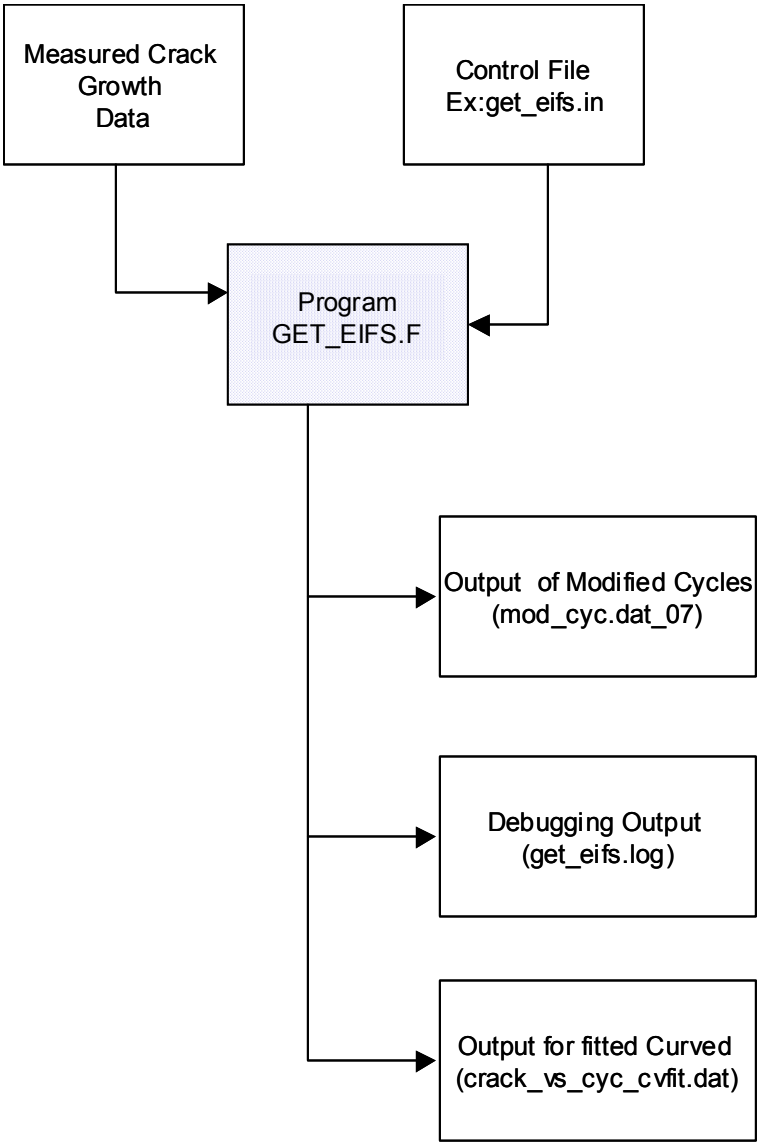


FIGURE B-2. INPUT AND OUTPUT FILES FOR PROGRAM get_eifs.f

TABLE B-2. TYPICAL INPUT FILE FOR PROGRAM get_eifs.f

FILENAME get_eifs.in

```
/uhs1112013/d1xr/c045270/WFD/EIFS/Fatigue/Type_2/Beta45/SEM/
mod_cyc.dat_07
sem_07A06L.dat
sem_07A06R.dat
sem_07A07L.dat
sem_07A07R.dat
sem_07A08L.dat
sem_07A12R.dat
sem_07A13R.dat
sem_07A14L.dat
sem_07A14R.dat
sem_07A15R.dat
sem_07A16L.dat
sem_07A16R.dat
sem_07A17L.dat
sem_07A17R.dat
```

Directory for the measured crack growth datasets

Filename of the modified crack growth history

Filenames of measured crack growth history

TABLE B-3. TYPICAL INPUT FILE FOR PROGRAM get_eifs.f—MEASURED CRACK GROWTH HISTORY

FILENAME sem_07a07l.dat

```
# /uhs1112013/d1xr/c045270/WFD/EIFS/Test_data/SEM/sem_07A07L.dat
#   28   07A07L
      1   93840    .042    .011
      2   95710    .043    .009
      3   99010    .046    .007
      4  100880    .048    .003
      5  104180    .052    .011
      6  106050    .054    .014
      7  107810    .056    .015
      8  111220    .059    .016
      9  112980    .060    .019
     10  114520    .062    .020
     11  116390    .063    .019
     12  119690    .065    .020
     13  121560    .067    .012
     14  123320    .067    .015
     15  124860    .069    .015
     16  126730    .070    .017
     17  128490    .072    .018
     18  130030    .072    .015
     19  131900    .073    .016
     20  133660    .075    .015
     21  135200    .077    .011
     22  137070    .079    .013
     23  138830    .081    .013
     24  140370    .083    .015
     25  142240    .085    .015
     26  144000    .087    .016
     27  145540    .089    .015
     28  147410    .092    .015
```

Filename

Crack ID

Number of data points

Crack length and depth

Number of cycles

Data point number

TABLE B-4. TYPICAL OUTPUT FILE FOR PROGRAM get_eifs.f

FILENAME mod_cyc.dat_07

```
#   Date: 22-Oct-01   Time: 11:28:44

#  sem_07A06L.dat       Mod Cyc=  26438
#     38
     80200     53668   .0260
     82070     55538   .0290
     85370     58838   .0330
     87240     60708   .0340
     89000     62468   .0350
     90540     64008   .0360
     92410     65878   .0370
     95710     69178   .0390
     97580     71048   .0400
     99340     72808   .0430
    100880     74348   .0460
    102750     76218   .0480
    104510     77978   .0510
    106050     79518   .0540
    107920     81388   .0570
. . . . . . . . . . . . . . . . . .
. . . . . . . . . . . . . . . . . .
. . . . . . . . . . . . . . . . . .
    131900    105368   .0880
    133770    107238   .0910
    135530    108998   .0940
    137070    110538   .0970
    138940    112408   .1010
    140700    114168   .1040
    142240    115708   .1080
    144110    117578   .1150
    145870    119338   .1180
    147410    120878   .1230

#  sem_07A06R.dat       Mod Cyc=  19200
#     60
     28500      9206   .0040
     30260     10966   .0060
. . . . . . . . . . . . . . . . . .
. . . . . . . . . . . . . . . . . .
. . . . . . . . . . . . . . . . . .
```

Modification cycles for the crack

Crack length

Modified number of cycles

Original number of cycles

TABLE B-5. TYPICAL OUTPUT FILE FOR PROGRAM get_eifs.f

FILENAME get_eifs.log

```
  1   .000332     26438   38   sem_07A06L.dat
  2   .000505     19200   60   sem_07A06R.dat
  3   .000000     30412   28   sem_07A07L.dat
  4   .000000     54134   36   sem_07A07R.dat
  5   .000000     96503   10   sem_07A08L.dat
  6   .000040     33201   50   sem_07A12R.dat
  7   .000006     46681   42   sem_07A13R.dat
  8   .000772     12576   38   sem_07A14L.dat
  9   .000052     26338   55   sem_07A14R.dat
 10   .000288     35948   46   sem_07A15R.dat
 11   .014971     26730   31   sem_07A16L.dat
```

File name for the original Crack growth history

Number of data points

Modification cycles

Fitted initial crack length

crack number

TABLE B-6. TYPICAL OUTPUT FILE FOR PROGRAM get_eifs.f—FITTED CURVE

FILENAME crack_vs_cyc_cvfit.dat

```
#  Initial crack length= .0038380

#no       Cycle           Length        Da/Dn            a/R
  1    1.00000E+00    3.83799E-03    2.43867E-07    4.09386E-02
  2    3.70635E+03    4.82088E-03    2.87223E-07    5.14227E-02
  3    7.41170E+03    5.96914E-03    3.33011E-07    6.36709E-02
  4    1.11171E+04    7.29016E-03    3.80321E-07    7.77617E-02
  5    1.48224E+04    8.78771E-03    4.28139E-07    9.37356E-02
  6    1.85278E+04    1.04617E-02    4.75402E-07    1.11592E-01
  7    2.22331E+04    1.23082E-02    5.21061E-07    1.31287E-01
  8    2.59384E+04    1.43193E-02    5.64149E-07    1.52739E-01
  9    2.96438E+04    1.64839E-02    6.03838E-07    1.75829E-01
 10    3.33491E+04    1.87883E-02    6.39492E-07    2.00409E-01
 11    3.70545E+04    2.12167E-02    6.70704E-07    2.26311E-01
 12    4.07599E+04    2.37521E-02    6.97322E-07    2.53356E-01
 13    4.44652E+04    2.63778E-02    7.19461E-07    2.81364E-01
 14    4.81706E+04    2.90778E-02    7.37496E-07    3.10163E-01
 15    5.18759E+04    3.18379E-02    7.52050E-07    3.39604E-01
 16    5.55813E+04    3.46468E-02    7.63972E-07    3.69565E-01
 17    5.92866E+04    3.74965E-02    7.74307E-07    3.99963E-01
 18    6.29920E+04    4.03834E-02    7.84272E-07    4.30756E-01
 19    6.66973E+04    4.33087E-02    7.95230E-07    4.61959E-01
 20    7.04027E+04    4.62786E-02    8.08668E-07    4.93639E-01
 21    7.41080E+04    4.93054E-02    8.26192E-07    5.25925E-01
 22    7.78134E+04    5.24074E-02    8.49525E-07    5.59012E-01
. . . . . .
. . . . . .
. . . . . .
. . . . . .
 37    1.33394E+05    1.51926E-01    4.32967E-06    1.62055E+00
 38    1.37099E+05    1.69519E-01    5.20145E-06    1.80821E+00
 39    1.40804E+05    1.90747E-01    6.30216E-06    2.03464E+00
 40    1.44510E+05    2.16584E-01    7.70296E-06    2.31023E+00
```

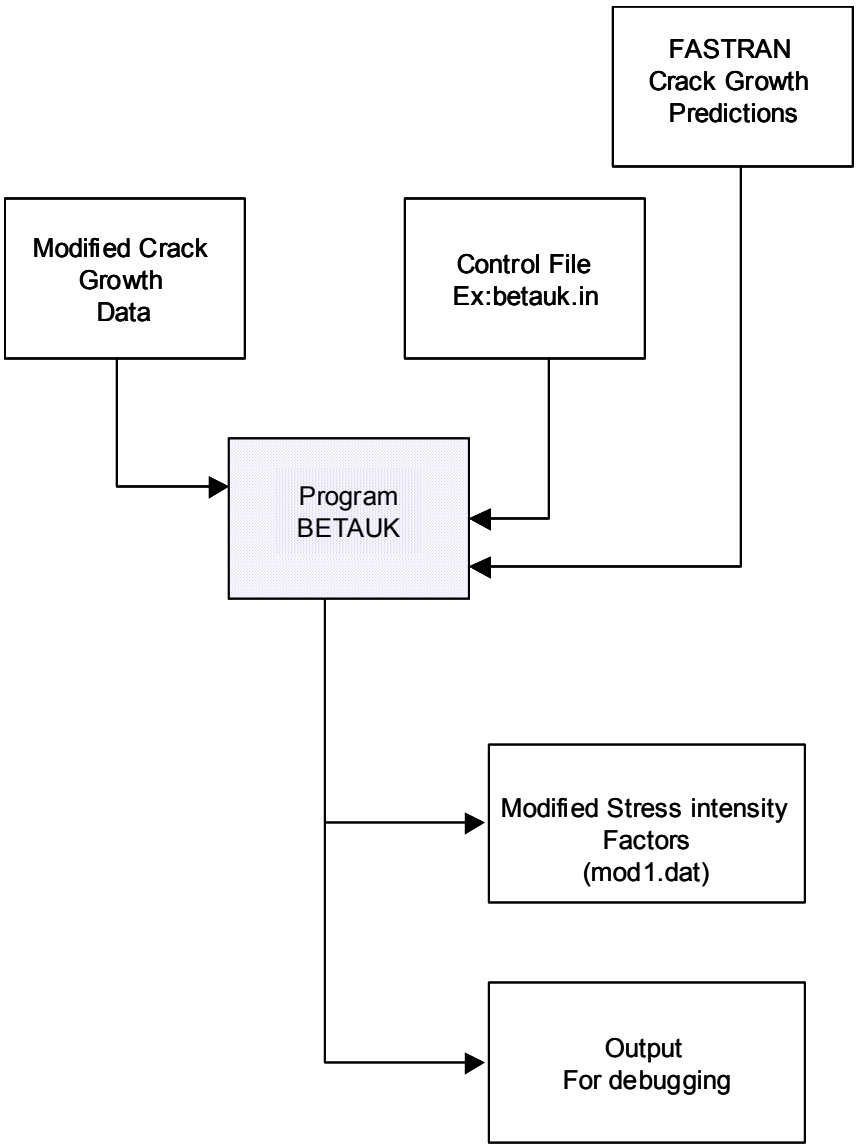


FIGURE B-3. INPUT AND OUTPUT FILES FOR PROGRAM betauk.f

TABLE B-7. TYPICAL INPUT FILE FOR PROGRAM betauk.f

FILENAME betauk.in

```
/uhs1112013/d1xr/c045270/WFD/EIFS/Fatigue/Type_2/Beta45/
fast2.betau.in
fast2_crkgro.dat
mod_cyc.dat
4.08  1.0
0 0
mod1.dat
```

File Directory

Filename for FASTRAN input data

FASTRAN prediction

Modified Crack growth History (see table B-4)

Paris' coefficients 'n' in the equation of $da/dN = c\Delta K^n$

Modification cycles

TABLE B-8. TYPICAL OUTPUT FILE FOR PROGRAM betauk.f

FILENAME mod1.dat

#no	Length	T-Beta	N-beta	Last B	Next Ho	a/R
1	4.79677E-03	8.11503E-01	9.20139E-01	8.81936E-01	1.00000E+00	5.11656E-02
2	5.29677E-03	8.00263E-01	9.18846E-01	8.70943E-01	1.00000E+00	5.64989E-02
3	6.79677E-03	7.71304E-01	9.18094E-01	8.40114E-01	1.00000E+00	7.24989E-02
4	9.29677E-03	7.31076E-01	9.16667E-01	7.97537E-01	1.00000E+00	9.91656E-02
5	1.27968E-02	6.85757E-01	9.15623E-01	7.48951E-01	1.00000E+00	1.36499E-01
6	1.72968E-02	6.37677E-01	9.14933E-01	6.96966E-01	1.00000E+00	1.84499E-01
7	2.27968E-02	5.88560E-01	9.15956E-01	6.42564E-01	1.00000E+00	2.43166E-01
8	2.92968E-02	5.40852E-01	9.20472E-01	5.87581E-01	1.00000E+00	3.12499E-01
9	3.67968E-02	4.98927E-01	9.33133E-01	5.34680E-01	1.00000E+00	3.92499E-01
10	4.52968E-02	4.72682E-01	9.63695E-01	4.90489E-01	1.00000E+00	4.83166E-01
11	5.47968E-02	4.76013E-01	1.02632E+00	4.63808E-01	1.00000E+00	[illegible]
12	6.52968E-02	5.06424E-01	1.09595E+00	4.62088E-01	1.00[illegible]	[illegible]
13	7.67968E-02	5.18149E-01	1.07277E+00	4.83000E-01	1.00[illegible]	[illegible]
14	8.92968E-02	5.26947E-01	1.02154E+00	5.15835E-01	1.00[illegible]	[illegible]
15	1.02797E-01	5.45785E-01	9.88681E-01	5.52033E-01	1.00000E+00	1.09650E+00
16	1.17297E-01	5.68731E-01	9.69307E-01	5.86739E-01	1.00000E+00	1.25117E+00
17	1.32797E-01	5.93937E-01	9.58274E-01	6.19799E-01	1.00000E+00	1.41650E+00
18	1.49297E-01	6.18804E-01	9.51107E-01	6.50615E-01	1.00000E+00	1.59250E+00
19	1.66797E-01	6.41300E-01	9.45127E-01	6.78533E-01	[illegible]	[illegible]17E+00
20	1.85297E-01	6.61099E-01	9.42794E-01	7.01213E-01	[illegible]	[illegible]50E+00
21	2.04797E-01	6.80951E-01	9.38806E-01	7.25337E-01	[illegible]	[illegible]50E+00
22	2.25297E-01	6.99142E-01	9.38567E-01	7.44903E-01	1.00000E+00	2.40317E+00
23	2.46797E-01	7.16276E-01	9.3[illegible]	[illegible]	1.00000E+00	2.63250E+00
24	2.69297E-01	7.30951E-01	9.34[illegible]	[illegible]	1.00000E+00	2.87250E+00
25	2.92797E[illegible]	[illegible]	9.35[illegible]	[illegible]	1.00000E+00	3.12317E+00
26	3.17297E[illegible]	[illegible]	9.34268E-01	8.13689E-01	1.00000E+00	3.38450E+00
27	3.42797E[illegible]	[illegible]	9.32967E-01	8.28186E-01	1.00000E+00	3.65650E+00
28	3.69297E-01	7.84510E-01	9.33142E-01	8.40719E-01	1.00000E+00	3.93917E+00
29	3.96797E-01	7.95798E-01	9.33117E-01	8.52838E-01	1.00000E+00	4.23250E+00
30	4.25297E-01	8.07641E-01	9.33092E-01	8.65553E-01	1.00000E+00	4.53650E+00

Correction Factor for the previous iteration

Correction Factor for current iteration

Total Correction Factor

Crack Length

Ratio of crack length to the hole radius

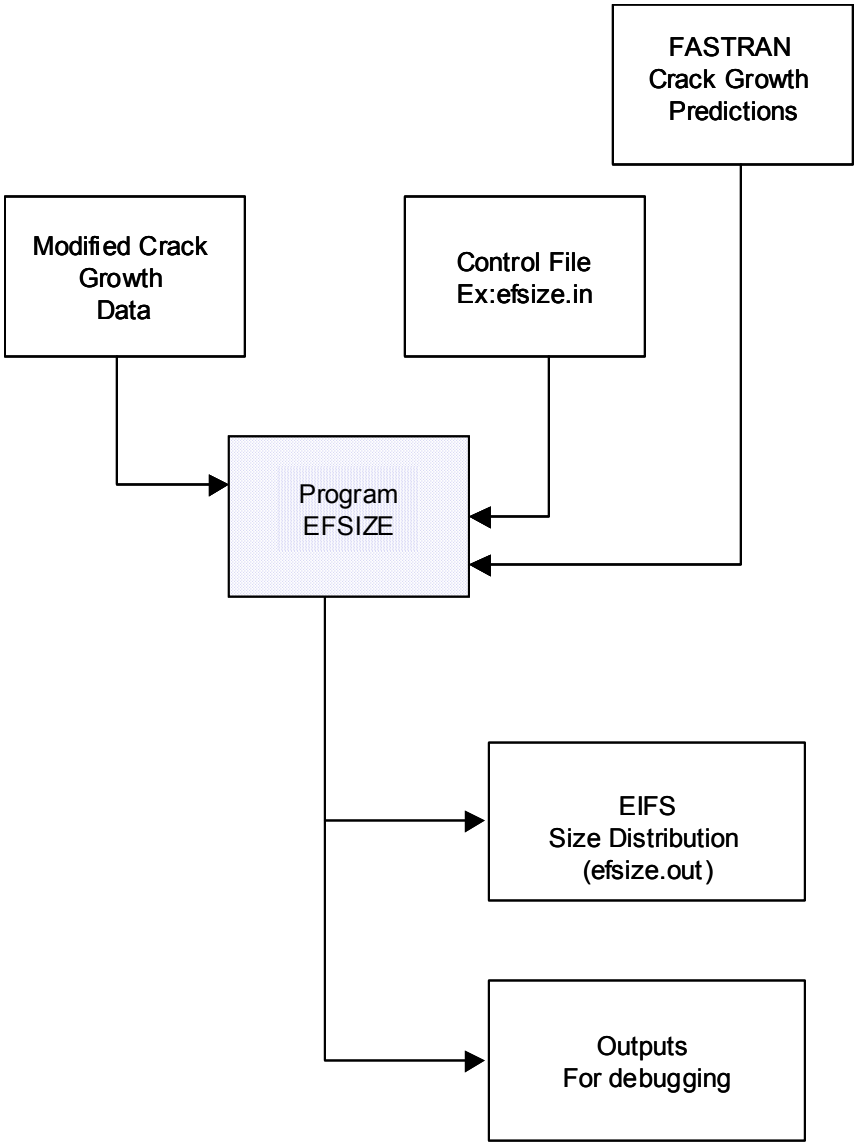


FIGURE B-4. INPUT AND OUTPUT FILES FOR PROGRAM efsize.f

TABLE B-9. TYPICAL INPUT FILE FOR PROGRAM efsize.f

FILENAME efsize.in

```
fast2_crkgro.dat
mod_cyc.dat
```

Predicted Crack growth history for various EIFS

Modified Crack growth History

TABLE B-10. TYPICAL OUTPUT FILE FOR PROGRAM efsize.f

FILENAME efsize.out

```
#    seq     NPT     EIFS      Crack

       1      38   6.696E-04    07A06L
       2      60   8.902E-04    07A06R
       3      28   5.676E-04    07A07L
       4      36   3.056E-04    07A07R
       5      10   1.598E-04    07A08L
       6      50   5.331E-04    07A12R
       7      42   3.663E-04    07A13R
       8      38   1.174E-03    07A14L
       9      55   6.669E-04    07A14R
      10      46   5.034E-04    07A15R
      11      31   6.422E-04    07A16L
      12      19   1.386E-04    07A16R
      13      39   4.079E-04    07A17L
      14      57   9.992E-04    07A17R

#    Number of crack= 14  Point=549  Average EIFS=  .00057
```

Average EIFS size for the specimen

Crack ID

Average EIFS for the crack

Number of data points

TABLE B-11. TYPICAL DEBUGGING FILE FOR PROGRAM efsize.f

FILENAME efsize.log

```
#   1   No. of pts=   38    File ->>sem_07A06L.dat

#    Seq  Cycles     Length        EIFS
       1   80200    .02600   5.00194E-04
       2   82070    .02900   5.23457E-04
       3   85370    .03300   5.36944E-04
       4   87240    .03400   5.23677E-04
       5   89000    .03500   5.09950E-04
. . . . . . . . . . . . . . . . . . . . .
. . . . . . . . . . . . . . . . . . . . .
. . . . . . . . . . . . . . . . . . . . .
. . . . . . . . . . . . . . . . . . . . .

      36  144110    .11500   8.97948E-04
      37  145870    .11800   8.72921E-04
      38  147410    .12300   8.77907E-04

#   2   No. of pts=   60    File ->>sem_07A06R.dat

#    Seq  Cycles     Length        EIFS
       1   28500    .00400   4.98639E-04
       2   30260    .00600   6.69808E-04
       3   31800    .00600   6.35195E-04
. . . . . . . . . . . . . . . . . . . . .
. . . . . . . . . . . . . . . . . . . . .
. . . . . . . . . . . . . . . . . . . . .
. . . . . . . . . . . . . . . . . . . . .
. . . . . . . . . . . . . . . . . . . . .
. . . . . . . . . . . . . . . . . . . . .
```

Crack ID

Corresponding EIFS for the measured data point

B.2 FINITE ELEMENT MODEL GLOBAL-LOCAL MAPPING.

The analysis steps are coded in the UNIX ksh script file, mapp, for mapping the boundary conditions from global NASTRAN model to local EPFEAM model. The analysis steps are outlined as follows:

- Prepare the global models with lead cracks, denoted 1 in figure B-5. Set the maximum load to 20 ksi for MSD flat panel models and the analytical load increment at 10% of the maximum load.

- Submit the global models to NASTRAN using nonlinear solution, sol 106. Save the ASCII outputs which contain the displacements of grid points, stress of quad4 and tria3, and forces of bar elements, denoted as 2 in figure B-5.

- Running the computer program fmstrs_nl to extract the pertinent displacements, stresses and loads, denoted as 4 in figure B-5. The extracted boundary conditions will be used for the local model, denoted as 3 in figure B-5. The main purpose of this intermediate step is to provide the listed outputs for error checking.

- The outputs of the fmstrs_nl, denoted as 5 in figure B-5, are used as the inputs for the mapping program genfeam_nl, denoted as 6 in figure B-5. The program will create complete input decks for the EPFEAM code tkalt, denoted as 7 in figure B-5.

The script file, mapp are listed as table B-12. The input and output data for all MSD flat panels are provided in the electronic media.

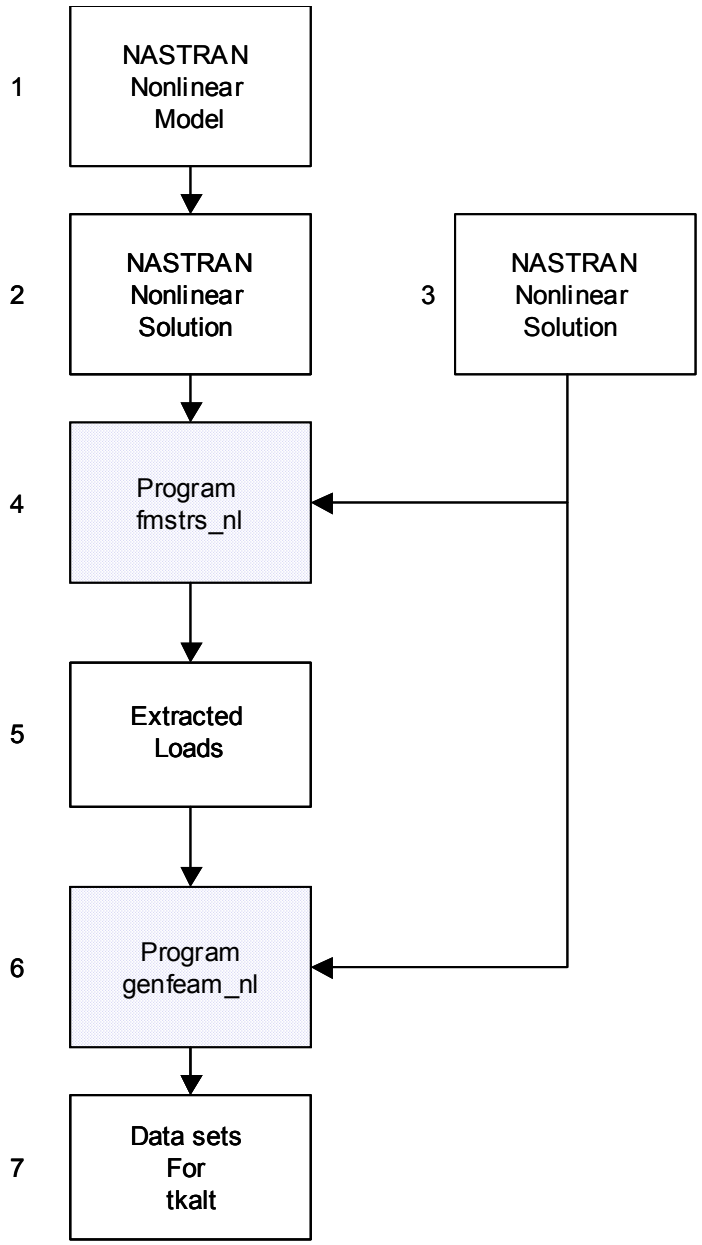


FIGURE B-5. FLOWCHART OF MAPPING GLOBAL-LOCAL BOUNDARY CONDITIONS

TABLE B-12. ksh SCRIPT FOR RUNNING GLOBAL-LOCAL MAPPING ANALYSIS

```
# ========================================================================
#  generate local boundary conditions
#  Ching Hsu
# ========================================================================
clear
banner " MAPPING"
echo " Enter first and last run number ....\c" ; read run_1 run_2

##cp /uhs1112013/d1xr/c045270/WFD/MSD/Type_2/fmstrs_step.dat load_step.in
count=$run_1;last=$run_2

while [ "$count" -le "$last" ]
  do
    echo " Running load extraction for" $count
    cp fmstrs.in_$count fmstrs.in
    fmstrs_nl <fmstrs.in

    echo " Running mapping for" $count
    run_gen=1
    while [ "$run_gen" -le 20 ]
      do
        ss="$count"_"$run_gen"
        echo " cp genfeam.in_$ss genfeam.in_$run_gen"
        genfeam_nl < genfeam.in_$run_gen
        let run_gen=$run_gen+1
      done
    let count=$count+1
  done

# ----------------------------   E N D -------------------------------------
```

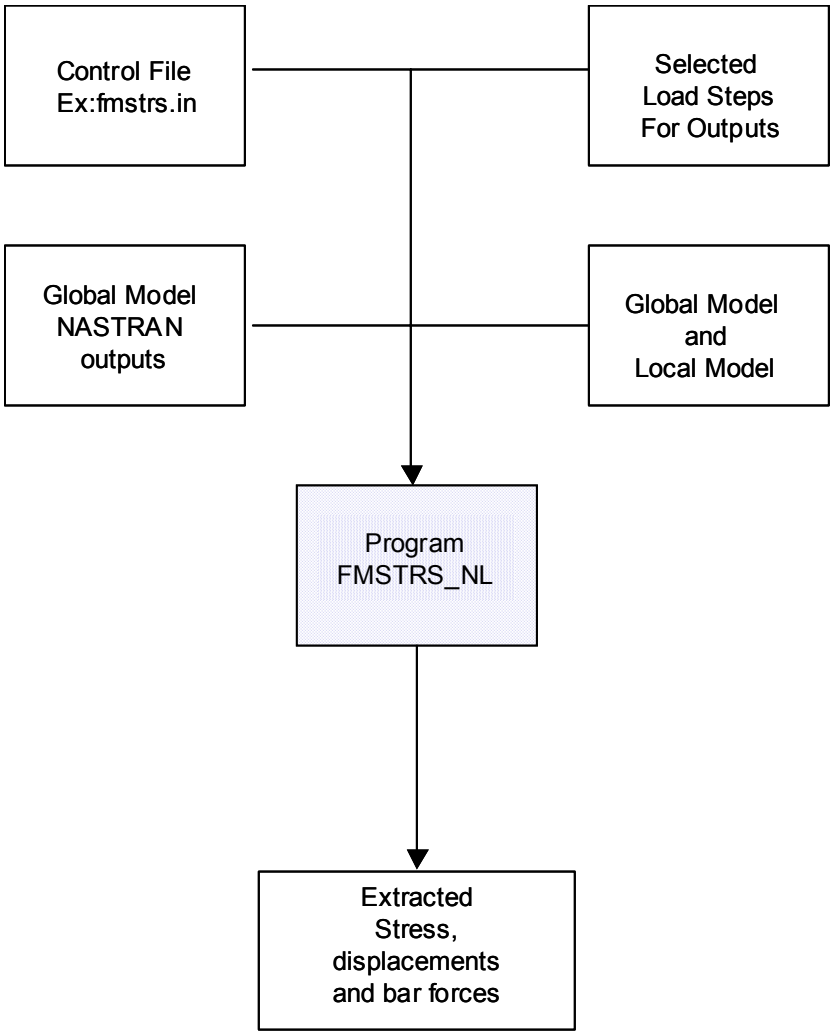


FIGURE B-6. INPUT AND OUTPUT FILES FOR PROGRAM fmstrs_nl.f

TABLE B-13. TYPICAL DEBUGGING FILE FOR PROGRAM efsize.f

FILENAME efsize.log

```
crack_run38.bdf
   7.50000  -2.62500    .00000
feam_mdl.fem
crack_run38.f06

.063
-1.  -1.
1
```

NASTRAN global Model

Origin of the local model

Filename of the local model

Filename of the NASTRAN solution

Thickness of the skin

Directional vectors of the bar elements

TABLE B-14. TYPICAL OUTPUT FILE FOR PROGRAM fmstrs_nl.f

FILENAME crack_run72.bds

```
crack_run72.f06
 No. elm =   46
 Sizes   =    -1.406     1.406    -1.406     1.406
 Cenetr  =  13.50000  -2.62500    .00000
 Point 1 =  12.09375  -4.03125    .00000
 Point 2 =  14.90625  -4.03125    .00000
 Point 3 =  14.90625  -1.21875    .00000
 Point 4 =  12.09375  -1.21875    .00000

STRESS AT THE NODAL POINTS
   36527       4
    -1.50000     -.18750        .000   -5.15457E+03    1.04874E+03    2.52277E+02
    -1.31250     -.18750        .000   -5.21425E+03    8.67914E+02    2.52277E+02
    -1.31250     -.00500        .000   -1.05827E+04   -9.03662E+02    2.52277E+02
. . . . . . . . . .
. . . . . . . . . .

    -1.50000     -.00500        .000   -1.05230E+04   -7.22836E+02    2.52277E+02
   36877       4
    -1.31250     1.52500        .000   -1.65174E+03    1.97516E+03   -6.09562E+03
    -1.50000     1.52500        .000   -1.78161E+03    1.58163E+03   -6.09562E+03

DISPLACEMENTS AT THE NODAL POINTS
   36527       4
    -1.50000     -.18750        .000   -1.18186E-02    2.66353E-02     .00000E+00
    -1.31250     -.18750        .000   -1.19187E-02    2.76344E-02     .00000E+00
    -1.31250     -.00500        .000     .00000E+00     .00000E+00     .00000E+00
    -1.50000     -.00500        .000     .00000E+00     .00000E+00     .00000E+00
. . . . . . . . . .
. . . . . . . . . .
         4
    Bar ID       X         Y         Z             Vx             Vy
      5129      .000      .000      .000   3.49524E+02   9.85853E+03
      5253     -.750      .875      .000  -1.42359E+03   3.86091E+03
```

Size of the local model

Coordinates of the four corners

Extracted stress (σx, σy and τxy)

Extracted displacements (Dx, Dy, DZ)

Extracted bar forces per unit thickness

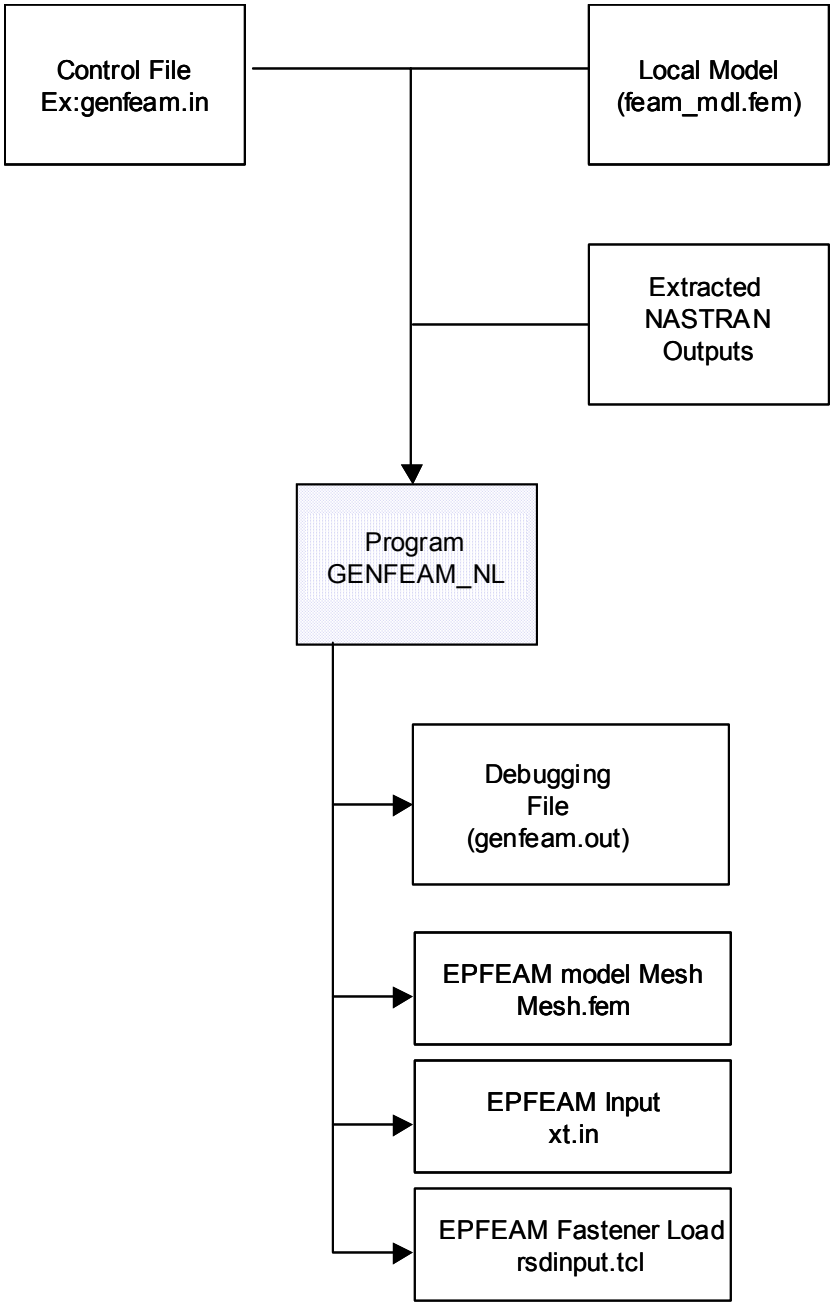


FIGURE B-7. INPUT AND OUTPUT FILES FOR PROGRAM genfeam_nl.f

TABLE B-15. TYPICAL INPUT FILE FOR PROGRAM genfeam_nl.f

FILENAME genfeam.in

```
feam_mdl.fem
crack_run38.bds
mesh.fem_run38
xt.in_run38
rsdinput.tcl_run38
  -3.50012   -.56250   -.10875    .10875
.1875
```

Filename of local model

Extracted NASTRAN Solution

Filenames of outputs

Fastener diameter

Location of crack tips, (left and right tip, two per crack)

TABLE B-16. TYPICAL OUTPUT FILE FOR PROGRAM genfeam_nl.f

FILENAME xt.in

```
 2
 -5.50012  -1.31250
  -.10875    .10875
 -2.50012   1.00000    .00000
 -2.50012   1.00000    .00000
```

Number of crack tips

Crack tip coordinates

Coordinates of the lower left corner

TABLE B-17. TYPICAL OUTPUT FILE FOR PROGRAM genfeam_nl.f—DISPLACEMENTS AND TRACTIONS

FILENAME mesh.fem

```
    1770       3  -5.31957E-03   1.98729E-02
    1776       3  -5.29550E-03   1.93863E-02
    1782       3  -5.25118E-03   1.89643E-02
    1791       3  -5.20322E-03   1.85403E-02
    . . . . . . . . . . . .
    . . . . . . . . . . . .
    . . . . . . . . . . . .

    7439       3  -6.94166E-03   3.17184E-02
    7441       3  -6.89691E-03   3.16332E-02
    7443       3  -6.83920E-03   3.15371E-02
    7445       3  -6.75199E-03   3.13667E-02
    7447       3  -6.67594E-03   3.12107E-02
      -1       0    .00000E+00    .00000E+00

    1457     1     8.38867E+00   2.75741E+00   8.40341E+00   3.00610E+00   7.79839E+00   2.96120E+00
    1458     1     7.79839E+00   2.96120E+00   7.60347E+00   3.60240E+00   6.82904E+00   3.56476E+00
    1459     1     6.82904E+00   3.56476E+00   5.72939E+00   3.51623E+00   4.72577E+00   3.48842E+00
    . . . . . . . . . . . .
    . . . . . . . . . . . .
    . . . . . . . . . . . .
      15     2    -1.71660E+00   4.67634E-01  -1.63890E+00   1.74921E-01  -1.56361E+00   1.10418E-01
      21     2    -1.56361E+00   1.10418E-01  -1.47278E+00   9.26390E-02  -1.37884E+00   1.17400E-01
      28     2    -1.37884E+00   1.17400E-01  -1.42187E+00   3.14294E-01  -1.25610E+00   3.78748E-01
      36     2    -1.25610E+00   3.78748E-01  -1.17223E+00   4.05781E-01  -9.29448E-01   3.39564E-01
      -1     0      .00000E+00    .00000E+00    .00000E+00    .00000E+00    .00000E+00    .00000E+00
```

Definition of forced displacements at the lower edge

Definition of tractions at the other three edges (Tx and Ty, three per element)

TABLE B-18. TYPICAL OUTPUT FILE FOR PROGRAM genfeam_nl.f

FILENAME mesh.fem

```
set crks {
{  -5.50012  -1.12500 }
{   -.10875    .10875 }
               }
set mainCrk 2;
set ALTCrkBodySize {  -3.20016   5.76000 };
set pressure 1;
set KIC  120.0;
set ALTPointLoad {
{  -3.00000    .09375  -2.04721E-02  -7.72216E-03  }
{  -1.50000    .09375  -2.86042E-02   1.89726E-03  }
{    .00000    .09375  -2.84288E-02   5.54438E-02  }
{  -3.00000    .87500  -9.35144E-02  -4.89712E-02  }
{   5.25000    .87500   2.40198E-01   5.21580E+00  }
               }
```

Coordinates of the crack tips

X coordinates of the left and right edges

Location and magnitudes of the concentrated loads (X, Y, Px, Py)

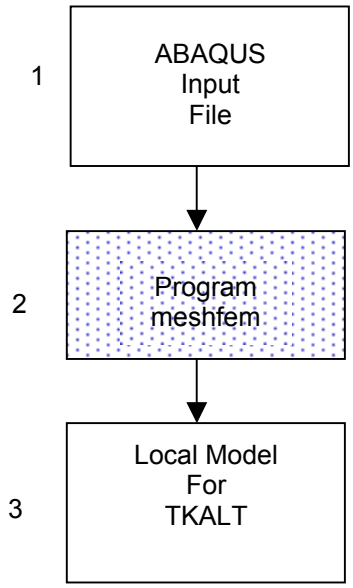


FIGURE B-8. INPUT AND OUTPUT FILES FOR PROGRAM meshfem.f

TABLE B-19. TYPICAL ABAQUS FILE FOR THE LOCAL MODEL

```
*HEADING
ABAQUS job created on 23-Mar-98 at 15:21:57
**
*NODE
     1,   0.512501,   0.0249999
     2,   0.511724,   0.0374302
     3,   0.498601,   0.0373719
     4,   0.499376,   0.0249688
     5,   0.525001,   0.0499999
     6,   0.497519,    0.049752
     7,   0.525001,   0.0249999
     8,    0.51822,   0.101406
     9,   0.489483,     0.10201
……..
……..

**
**
** fem
**
*ELSET, ELSET=FEM
     1,     2,     3,     4,     5,     6,     7,     8,
     9,    10,    11,    12,    13,    14,    15,    16,
    17,    18,    19,    20,    21,    22,    23,    24,
    25,    26,    27,    28,    29,    30,    31,    32,
    33,    34,    35,    36,    37,    38,    39,    40,
    41,    42,    43,    44,    45,    46,    47,    48,
……..
……..
……..
……..
```

Definition for the grid points

Definition for the elements

TABLE B-20. TYPICAL TKALT FILE FOR THE LOCAL MODEL

```
 1    -.98438    .02197
 2    -.97552    .02904
 3    -.98438    .02930
 4    -.98438    .03662
 5    -.09237    .01603
 6    -.09577    .01652
 7    -.10600    .01834
 8    -.97556    .01452
 9    -.98438    .01465
10    -.98438    .00732
11    -.97549    .04357
12    -.98438    .04395
13    -.96655    .05758
14    -.98438    .05859
15    -.98438    .05127
16    -.98438    .07324
17    -.96676    .00720
18    -.96674    .01440
……..
……..
-1    .00000    .00000
  12    3    21    22    4    2    25    11
  18    21    3    9    20    2    1    8
  86    18    9    83    17    8    10    82
  28    14    92    32    16    13    34    27
  14    12    22    92    15    11    23    13
……..
……..

 2863   2915   2866   2857   2865   2867   2859   2858
 2914   2918   2915   2863   2920   2921   2865   2864
  -1     0     0     0     0     0     0     0
-1   0    .00000    .00000
 0   -4    .000    .000    .000    .000    .000    .000
-1   0    .000    .000    .000    .000    .000    .000
```

Definition for the grid points

Termination for the nodes

Definition for the elements

Termination for the elements

Termination for the displacements and tractions

B.3 PROGRAM INSTRUCTION FOR tkalt.

This section lists the basic assumptions used in the tkalt code, the input parameters, examples of the tool command language (TCL) control files, and the executable TCL file for program flow control.

B.3.1 ASSUMPTIONS THAT ARE HARD CODED IN tkalt.

1. The lead crack tip is on the left-hand side of the local region, modeled as an edge crack.

2. There is only one lead crack.

3. runID increases as the coordinate of the lead crack tip increases

4. Boundary conditions (BC) are stored in the files $bcFileRoot$runID

5. rsdinput's are $rsdinputRoot$runID

6. Point loads are specified in $rsdinputRoot$runID

7. Input files are in the directory $inputDir

8. BC are given at unit load level

9. xmin > -999 for the local model

10. Lead crack is extended by a fixed increment when the runID is increased by 1

11. The following parameters are hard code in the procedure addTstar in the executable module.

    contour size: epsion = 0.087″
    crack growth step: crkIncr = 0.04″
    load increment step: loadIncr = 3%

12. The strain-stress curve is hard coded in the procedure addFlowCurve in the executable module, if the TCL variable myPlasticity is set to yes.

B.3.2 GLOBAL TCL VARIABLES.

1. Specify the paths and names for the input files. The input files include the following:

    a. A finite element method (FEM) model file

       This specifies the FEM mesh used by the EPFEAM. It contains the coordinate of nodes and nodes of elements.

    b. A number of boundary condition (BC) files

This specifies the prescribed nodal displacements and traction boundary conditions.

c. TCL command file—This specifies the TCL variables, such as:

ALTCrkBodySize <the max. and min. x-coord. of the local model>
ALTPointLoad <point loads>, etc.

Examples for other pamameters:

```
set bcFileRoot      mesh.fem_run
set rsdinputRoot    rsdinput.tcl_run
set femModel        feam_mdl.fem
set inputDir        .
set curRunID        75
set lastRunID       113
```

Here,

The input files are located in the current directory feam_mdl.fem is the name of the FEM model file. mesh.fem_run is the root name of BC files. So, the boundary conditions are stored in

mesh.fem_run75,
mesh.fem_run76,
...,
mesh.fem_run113.

Associated files for TCL commands are

rsdinput.tcl_run75,
rsdinput.tcl_run76,
rsdinput.tcl_run113.

2. The size of multiple-site damage (MSD) cracks.

Two equal length MSD cracks are assumed to be emanating from the edge of a rivet hole. All the MSD cracks are assumed to have the same initial crack length. This variable will be used, together with others, to construct the list of crack positions. The following command specifies that MSD cracks have an initial crack length of 0.05″.

```
set MSDsize  0.05
```

3. T*-integral resistance curve

The TCL command that will give the T*-integral value on the resistance curve for a given amount of crack growth da.

Example 1:

```
set myTStar {1.1*<0.7063-0.03982*$da-0.06973/<0.1746+$da>>}
```

In the above example, the T*-integral resistance curve is evaluated using a TCL expression.

Example 2:

```
set myTStar { [tStarProc $da] }
proc tStarProc { da } {
        if { $da < 0.09 } {
                return 0.53
        } else {
return [expr 1.35*<0.7063-0.03982*$da-0.06973/<0.1746+$da>>]
        }
}
```

In example 2, the T*-integral resistance curve is evaluated by calling a TCL procedure, tStarProc. When the amount of crack growth is smaller than 0.09″, the T*-integral on the resistance curve is 0.53 <ksi in>; otherwise, it is given as 1.35*<0.7063-0.03982*$da-0.06973/<0.1746+$da>>.

4. Position of the lead crack tip

Example:

```
set curLeadTip        -0.563
set curRunLimit       -0.563
set runLimitIncr      0.09375
```

Here, it specifies that the initial position of the tip of the lead crack is at -0.563. The boundary condition for the first run case, given in the files $inputDir/$bcFileRoot$curRunID, and $inputDir/$rsdinputRoot$curRunID, are valid until the lead crack tip passed -0.563. The boundary condition in the next run case will be valid until the lead crack passes -0.563+0.09375.

5. The x coordinates of the rivet holes with MSD crack

Lead cracks must be on the x axis. Equal length MSD cracks can be specified on the rivet holes ahead of the tip of the lead crack.

Example:

```
set holePosition     {0 1.5 3.0}
```

Here, three rivet holes, centered at x=0″, x=1.5″, x=3.0″ have MSD cracks, with an initial crack length = $MSDsize. Note, the x coordinates must be presented in the ascent order in the list.

6. The size of rivet holes

The radius of the rivet holes.

Example:

```
set holeRadius            0.082
```

Two MSD emanating from a rivet hole are modeled as a single small crack from

x= $holePosition-<$holeRadius+$MSDsize>

to

x= $holePosition+<$holeRadius+$MSDsize>.

7. Optional Inputs: no rivet force on the crack surface on

Example:

```
set noInitCrackSurfaceRivet  yes
set pinY                     0.082
```

In this case, the program will try to remove the point loads applied at y=0.082 and x< $curLeadTip, specified in the input files rsdinput.tcl_run*. When noInitCrackSurfaceRivet and pinY are not specified, no point load will be removed.

8. Input/output files and directories

Example:

```
set caseID 1
set no 2
set case case$caseID
set homeDir  [file join $env<HOME> caseEp/$case/res/$no]
source [file join $env<HOME> caseEp/$case/x.conf]
```

In the above example, the results <out.dat, tear.dat> will be saved in the directory $homeDir, i.e.,

~/caseEp/case1/res/2/.;

some of the TCL commands are in ~/caseEp/case1/x.conf. Note, it may be convienent to save some of the common TCL commands in one file, say,

~/caseEp/case1/x.conf,

so that it can be reused by different runs of tearing analysis.

Note: $caseID will be used by $getBCCmd

9. Using BC at specific load level—Nonlinear global Analysis.

When the lead crack tip reaches a crack length that requires BC update, it will invoke $getBCCmd to get BC at current load level. $getBCCmd is excecuted with three arguments:

$getBCCmd caseID currentRunID currentLoadLevel

caseID is the identification number of the case

currentRunID is the run ID for which the BC is requested. currentLoadLevel is the predicted load level at current crack length. The boundary condition for the local region at this level is requested. However, the boundary condition must be linearly scale to that for the unit level in the input files $bcFileRoot$runID and $rsdinputRoot$runID.

If getBCCmd is not specified, it is assumed that the BC is precalculated and stored in the directory for input files, i.e.,

<$inputDir>

When getBCCmd is specified, it will be invoked with the three arguments to get BC at run time. $getBCCmd must generate the BC and save the input files in $inputDir.

Example:

set getBCCmd /uhs1112013/d1xr/c045270/Bin/getbndy

Note: The environment variable PATH must be set correctly, if $getBCCmd invokes other unix commands.

10. Specify strain-stress curve

This command specifies the strain-stress curve in the files $rsdinputRoot$runID.

Example:

```
ALTResource matID CurveFitted
ALTResource flowCurve {
0.0043  45
0.01    51.5
0.02    56
0.04    61
0.07    65.5
0.10    68
0.16    70
        }
```

In this case, Young's modulus will be determined from the first pair of strain-stress data.

11. Advanced Features

The user may use the file xt.tcl at the current directory to dynamically control the execution of tkalt. The executable module will execute the commands in xt.tcl after each step of stable tearing analysis, if xt.tcl exists at the current directory. See the executable module for details.

TABLE B-21. TCL EXAPMLE FOR RUNNING MSD FLAT PANEL WITH 0.100″ MSD CRACKS

Filename.run.tcl

```
 define the location for the input files

set inputDir .
set bcFileRoot   mesh.fem_run
set rsdinputRoot rsdinput.tcl_run
set femModel     feam_mdl.fem

# the T* curve is saved in tStar.tcl

source [file join $env<HOME> T_star_Rst/tStar.tcl]

# define the BC set.

set curRunID                  44
set lastRunID                 67
set curRunLimit            -0.7125
set runLimitIncr            0.1425
set curLeadTip             -0.40975


# define rivet hole and MSD

set holeRadius              0.09375
set holePosition       {0 1.14 2.28}
set pinY                    0.09375
set MSDsize                 0.100

# where to put the output file

#global caseID
set    caseID 2
set    no   3
set    case case$caseID
set    homeDir  [file join $env<HOME> test]
set    homeDir  [file join $env<HOME> Trun/Run_203 ]

set nonlinerInit yes

# how to get BC

set getBCCmd ~/Bin/getbndy


#run executable module  ( see Appendix XX for complete listing)

source $AltLibDir/tearApp.tcl
```

TABLE B-22. TCL EXAPMLE FOR T*-INTEGRAL RESISTANCE CURVE

Fine name : T_star_Rst/tStar.tcl

```
set myTStar { [tStarProc $da] }
proc tStarProc { da } {
    if { $da < 0.09 } {
      return 0.53
    } else {
      return [expr 1.35*<0.7063-0.03982*$da-0.06973/<0.1746+$da>>]
    }
}
```

TABLE B-23. FORMAT OF TCL COMMAND IN THE run.tcl FILE

```
begin run.tcl
        set inputDir     <variable>
        set curRunID     <variable>
        set lastRunID    <variable>
        bcFileRoot           <variable>
        rsdinputRoot         <variable>
        femModel             <variable>
        inputDir             <variable>
        curRunID             <variable>
        lastRunID            <variable>
        MSDsize              <variable>
        MyTStar              <variable>
        curLeadTip           <variable>
        curRunLimit          <variable>
        runLimitIncr         <variable>
        holePosition         <variable>
        holeRadius           <variable>
        noInitCrackSurfaceRivet      <variable>
        pinY                 <variable>
        homeDir              <variable>
        getBCCmd             <variable>
        source $AltLibDir/tearApp.tcl
end of run.tcl
```

TABLE B-24. EXECUTABLE TCL COMMAND FOR THE EPFEAM ANALYSYS

FILENAME tearapp.tcl

```
catch { unset runIDDef }
set i $curRunID
set x $curRunLimit
while { $i <= $lastRunID } {
    set runIDDef<$i> $x
    incr i
    set x [expr $x+$runLimitIncr]
}
catch { unset i; unset x }


 check the proc's
     addMSD
     addTstar
 for hard coded parameters



 if stiffness matrix can be reused,

    set reuse 1

 otherwise

    set reuse 0


 some unix system commands

set catCmd /usr/bin/cat
set mvCmd  /usr/bin/mv
set cpCmd  /usr/bin/cp



   procedures



 append two more MSD cracks

proc addMSD { } {

     hard coded

    global curLeadTip holePosition holeRadius MSDsize
    global jumpDef
    set jumpDef {}


     set the left crack tip at -999 so that it is out side the
     local model
```

```
    set out "\nset crks {\n{-999 $curLeadTip}\n"
    if { $MSDsize >= 0 } {
      set radius [expr $holeRadius + $MSDsize]
      foreach center $holePosition {
          set leftTip  [expr $center - $radius]
          set rightTip [expr $center + $radius]
          lappend out  " $leftTip $rightTip "
          append out "\n"
      }
    } else {
      set radius [expr <$holeRadius < 0.095> ? 0.095 : $holeRadius]
      foreach center $holePosition {
          set leftTip  [expr $center - $radius - 0.1]
          set rightTip [expr $center + $radius]
          append jumpDef  " $leftTip $rightTip "
      }
    }
    append out "}\n"
    return $out
}


 specify T* resistence curve

proc addTstar { } {

     hard coded

    set out {
      set daLimit             1.30
      crack::config -epsilon  .087
      crack::config -crkIncr  .040
      crack::config -loadIncr    3
      set pressure 1
         set plotInterval 1
    }

    global myTStar
    if { [info exists myTStar] } {
      append out "crack::config -tStar [list $myTStar]\n"
    }
    return $out
}


 flow curve for plasticity.  Young's modulus will be determined from
 the first pair of strain stress data.

proc addFlowCurve { } {

     hard coded

    set out {
        ALTResource matID CurveFitted
        ALTResource flowCurve {
                0.0043  45
```

```
                0.01    51.5
                0.02    56
                0.04    61
                0.07    65.5
                0.10    68
                0.16    70
        }
        ALTResource
    }
    return $out

}


 create mesh.fem in the current directory

proc genMeshFem { runID } {
    global inputDir bcFileRoot femModel
    global catCmd

    set model [file join $inputDir $femModel]
    set bc    [file join $inputDir $bcFileRoot$runID]
    exec $catCmd $model $bc > mesh.fem
}


 create mesh.pt in the current directory

proc genMeshPt { runID } {
    global inputDir rsdinputRoot noInitCrackSurfaceRivet
    global pinY

    set noRivet 0
    if { [info exists noInitCrackSurfaceRivet ] } {
      if { $noInitCrackSurfaceRivet } {
          set noRivet 1
      }
    }

    set ALTPointLoad {}
    source [file join $inputDir $rsdinputRoot$runID]
    set fileID [open "mesh.pt" w ]
    puts $fileID "set ALTPointLoad {"
    if { $noRivet } {
      foreach pinLoad $ALTPointLoad {
          foreach {x y px py} $pinLoad {}
          if { ! <$x < 0 && $y == $pinY> } {
            puts $fileID "{ $pinLoad }"
          }
      }
    } else {
      foreach pinLoad $ALTPointLoad {
          puts $fileID "{ $pinLoad }"
      }
    }
    puts $fileID "}"
    close $fileID
```

```
}


 create rsdinput.tcl in the current directory

proc genRsdinputTcl { runID } {
    global inputDir bcFileRoot rsdinputRoot femModel myPlasticity
    global catCmd

    append content "source [file join $inputDir $rsdinputRoot$runID]"
    append content "\n"
    append content [addMSD]
    append content [addTstar]
    if { [info exists myPlasticity] } {
      if { $myPlasticity } {
          append content [addFlowCurve]
      }
    }
    append content "source mesh.pt"
    exec $catCmd > rsdinput.tcl << $content
}


 convert mesh.fem into a binrary file: xt.config

proc genBinInput { } {
    global AltBinDir
    global mvCmd
    exec $AltBinDir/genConf > local.mesh
    exec $mvCmd mesh.config xt.config
}


 check if the lead crack is reaching the edge of rivet hole
 Assume, there is only one lead crack at left hand side of the panel

proc crack::checkJump {} {
    global jumpDef
    set crks $crack<list>

    set id [lindex $crks 0]
    set b $crack<$id,b>
    foreach {l r} $jumpDef {
      if { <$b > $l> && <$b < $r> } {
           set crack<$id,b> $r
           set crack<$id,b0> $r
           break
      }
    }
}


 customized routine to generate contours for grow cracks

proc crack::genContour { file } {
    global stopMSD
    set noMSD 0
```

```
if { [info exists stopMSD] } {
  if { $stopMSD } {
      set noMSD 1
  }
}

set crks $crack<list>

set leftEdge 0
set rightEdge 0
switch $crack<edgeCrk> {
    left { set leftEdge 1 }
    right { set rightEdge 1 }
}

set num [expr [llength $crks]*2]
if { $leftEdge || $rightEdge } {
    incr num -1
}

set fileID [open $file w]
puts $fileID $num
set i 0
set num [expr [llength $crks]-1]


 pick a good guess for numpt

set rad $crack<epsilon>
set step $crack<contourStep>
set halfnum   [expr int<$rad/$step>]
set halfnum2  [expr 2*$halfnum]
while { $i <= $num } {
    set id [lindex $crks $i]

    if { $i == 0 } {
      set left  [ expr $crack<$id,b0>-$rad ]
      set right [ expr $crack<$id,b>+$rad ]
      set numpt [ expr int<<$right-$left>/$step>]
      global curLeadTip
      set curLeadTip [ expr $crack<$id,b>+0.0 ]
      puts $fileID "           $left    -0.0001"
      puts $fileID "$halfnum   $left    -$rad"
      puts $fileID "$numpt     $right   -$rad"
      puts $fileID "$halfnum2  $right   $rad "
      puts $fileID "$numpt     $left    $rad "
      puts $fileID "$halfnum   $left    0.0001"
      puts $fileID "0 0 0\n"

  } else {
      if { $noMSD } {
        set left  [ expr $crack<$id,a>-$rad ]
        set right [ expr $crack<$id,a0>+$rad ]
        set numpt [ expr int<<$right-$left>/$step>]
        puts $fileID "           $right   -0.4"
        puts $fileID "0 0 0\n"
```

```
            set left  [ expr $crack<$id,b0>-$rad ]
            set right [ expr $crack<$id,b>+$rad ]
            set numpt [ expr int<<$right-$left>/$step>]
            puts $fileID "           $left    -0.4"
            puts $fileID "0 0 0\n"

          } else {
            set left  [ expr $crack<$id,a>-$rad ]
            set right [ expr $crack<$id,a0>+$rad ]
            set numpt [ expr int<<$right-$left>/$step>]
            puts $fileID "           $right -0.0001"
            puts $fileID "$halfnum   $right -$rad "
            puts $fileID "$numpt     $left  -$rad "
            puts $fileID "$halfnum2  $left   $rad "
            puts $fileID "$numpt     $right  $rad "
            puts $fileID "$halfnum   $right  0.0001"
            puts $fileID "0 0 0\n"

            set left  [ expr $crack<$id,b0>-$rad ]
            set right [ expr $crack<$id,b>+$rad ]
            set numpt [ expr int<<$right-$left>/$step>]
            puts $fileID "           $left   -0.0001"
            puts $fileID "$halfnum   $left   -$rad "
            puts $fileID "$numpt     $right  -$rad "
            puts $fileID "$halfnum2  $right   $rad "
            puts $fileID "$numpt     $left    $rad "
            puts $fileID "$halfnum   $left    0.0001"
            puts $fileID "0 0 0\n"
          }
      }

        incr i
    }
    close $fileID

    checkBC
}

proc checkBC { } {
    global curRunID runIDDef curLeadTip


     Assume that runID increases as the coordinate of the
     lead crack tip increases

    global BCChanged
    if { ! [info exists BCChanged] } {
      set BCChanged 0
    }

    while { 1 } {
      if { ! [info exists runIDDef<$curRunID>] } {

            runID not defined. No boundary condition
            exists for this case.  Quit.

          puts " *** stop tearing at runID = $curRunID ***"
```

```
          set BCChanged 0
          quitTearing
          break
      } else {
          set limit $runIDDef<$curRunID>
          if { $curLeadTip > $limit } {
            incr curRunID
            set BCChanged 1
          } else {
            break
          }
      }
    }

    if { $BCChanged } {
      InterBC
    }
}

proc InterBC {} {
    global getBCCmd

    if { [info exists getBCCmd] } {
       set cmd /uhs1112013/d1xr/c045270/Bin/getbndy
      set cmd $getBCCmd

      global curLoadLevel curRunID caseID
      exec $cmd $caseID $curRunID $curLoadLevel
    }

    genMeshFem $curRunID
    genMeshPt  $curRunID
}

proc getInitBC { } {
    checkBC
    global BCChanged
    if { ! $BCChanged } {
      InterBC
    } else {
      set BCChanged 0
    }
    catch {
      global daLimit
      if { $daLimit < 0 } {
          puts " *** stop: not init BC found"
          exit
      }
    }
}
```

```
 convert out.dat into tear.dat. tear.dat contains load level
 versus x-coordinates of the crack tips.
 The format of tear.dat is
```

```
 loadLevel1 crackTip1 crackTip2 crackTip3 ...
 loadLevel2 crackTip1 crackTip2 crackTip3 ...
 ...
 ..
 .

proc listLoadLevel { } {

    set fileID [open "out.dat" r]
    set tearID [open "tear.dat" w]
    set n 0
    while { ! [eof $fileID] } {
      gets $fileID line
      if { ! [regexp -- "load level: <<\[0-9.\]>*>" $line match load] } {
          continue;
      }

       read off the comment for offset

      gets $fileID line
      set tips $load
      set i 0
      while { 1 }  {
          gets $fileID line
          if { [regexp -- "" $line] } {
            while { $i < $n } {
                incr i
                lappend tips $ptip
            }
            set n $i
            break;
          }
          set tip [lindex $line 0]
          if { $tip != {} } {
            incr i
            set ptip $tip
            lappend tips $tip
          }
      }
      puts $tearID $tips
    }
    close $tearID
    close $fileID
}


 1. Result will be added to out.dat incrementally
 2. If daLimit is specify, the termination of the tearing simulation
    will be controled by daLimit only.  Otherwise,
    it terminates when all cracks are linked up.
 3. Add a run time control - a tcl script file: xt.tcl
    It will be sourced, if exists at the run time,
    1> after residual strength analysis for the initial cracks
       status = AfterRsd
    2> after each tearing step <increase the load or grow the crack>
       status = InTearing
```

```
proc ALTTear::App { {plotItems {}}  {anaReuse 0} {anaGenLoc 0} } {
        crack::GetTstar ALTCrkTstar ALTCrkEpsilon .getTstar
    global AltLibDir AltBinDir
    global plotInterval
    if { ! [info exists plotInterval] } {
      set plotInterval 0
    }

    global daLimit
    if { ! [info exists daLimit] } {
      set daLimit 1000000
    }
    set curGrowStep 0
    set plotID 0

    catch {global crack; unset crack}
    if { $anaGenLoc == 0 } {
      ALTRsd::makeMeshCtrl
      ALTRsd::preProc
    }


     must specify the body size first

    global ALTPointLoad; set ALTPointLoad {}
    source rsdinput.tcl
    ALTRsd::GenPtLoadFile
    crack::config -bodySize "$ALTCrkBodySize"

    foreach crk $crks {
      eval new crack $crk
    }

    set da 0
    global crack
    set Jo [expr $crack<tStar>]
    set KIC [expr sqrt<10500*$Jo>]

    puts "KICo= $KIC"
    puts "tStar=$crack<tStar>"
    puts "epsilon=$crack<epsilon>"
    puts "crkIncr=$crack<crkIncr>"
    puts "loadIncr=$crack<loadIncr>%"

    crack::genTipFile xt.in
    crack::genContour xt.J1
    set rsd [ new ALTRsd $KIC $pressure]
    set eload [ALTRsd::elastic $rsd $anaReuse]
    set pload [ALTRsd::plastic $rsd]

    if { [file exists "xt.tcl"] } {
      set status {AfterRsd}
      source "xt.tcl"
    }
```

```
set iniLdFactor [expr $pload/$pressure]
 ALTRsd::preProc $iniLdFactor

 note: replaced with scaling after ALT::Init


set ALTOrigLoad   $pressure
set ALTLoad       $pload
set ALTLoadFactor 1
set ALTLoadIncr   [expr 0.01*$crack<loadIncr>]
set ALTLoadPlotOffSet 0

crack::genTipFile xt.in
crack::genContour xt.J1

set fileID [open "out.dat" w]
puts $fileID "\ the history of crack growth"
puts $fileID "\$data=curve2D"
close $fileID

 === analyze ===
global curLoadLevel
set curLoadLevel [expr $iniLdFactor*$ALTLoadFactor*$ALTOrigLoad]
InterBC

ALT::Init
exec $AltBinDir/genBC [expr $iniLdFactor] xt.bnd
ALTRsd::GenPtLoadFile [expr $iniLdFactor]
ALT zeroEdgeLoads readNewBC saveBC;   new BC

delete [ ALT::SetUp -noAssembly]
delete [ ALT::Elastic -10 ]
set vT [ ALT::FullPlastic 15 ]
ALT::SaveState
eval ALT::Plot $plotItems

set analyzing 1
while { $analyzing } {
  puts "Load Level: [expr $iniLdFactor*$ALTLoadFactor*$ALTOrigLoad]\n"
  crack::printAll

  set vT [crack::fixValue $vT]
  puts "T*-integral:"
  set fileID [open "out.dat" a]
  ALTTear::printCrack $fileID \
      [expr $iniLdFactor*$ALTLoadFactor*$ALTOrigLoad] $ALTLoadPlotOffSet
  vec::print $vT
  close $fileID

  if { [file exists "xt.tcl"] } {
      set status {InTearing}
      source "xt.tcl"
  }

  if { [crack::grow [vec::value $vT]] } {
```

```
     a hack to jump the crack from left edge to right edge
     of a rivet hole

    crack::checkJump
    if { $curGrowStep < $plotInterval } {
        incr plotID
      exec cp xt.stat stat.$plotID
    }
    incr curGrowStep
    if { $curGrowStep >= $plotInterval } {
      set curGrowStep 0
    }

    set ALTLoadPlotOffSet [expr 0.0015+$ALTLoadPlotOffSet]
    crack::linkUp
    puts " *** MSG ***: crack grow"
    crack::genTipFile xt.in
    crack::genContour xt.J1
    ALT::EpCrackGrowInit

     a hack to allow change of BC in crack::genContour
     new BC will be in mesh.fem, mesh.pt and must set

           global BCChanged; set BCChanged 1

     to trig the update as the following.
    global BCChanged
    if { ! [info exists BCChanged] } {
      set BCChanged 0
    } elseif { $BCChanged == 1 } {
      set BCChanged 0
      exec $AltBinDir/genConf > local.mesh
      exec mv mesh.config xt.config
      source mesh.pt
      exec $AltBinDir/genBC [expr $ALTLoadFactor*$iniLdFactor] xt.inc
      ALTRsd::GenPtLoadFile [expr $ALTLoadFactor*$iniLdFactor]
      ALT::LoadGrowInit xt.inc
    }
} else {
    set ALTLoadPlotOffSet 0
    puts " *** MSG ***: more load"
    set ALTLoadFactor [expr $ALTLoadFactor+$ALTLoadIncr]

    set curLoadLevel [expr $iniLdFactor*$ALTLoadFactor*$ALTOrigLoad]
    InterBC

    exec $AltBinDir/genBC [expr $ALTLoadFactor*$iniLdFactor] xt.inc
    ALTRsd::GenPtLoadFile [expr $ALTLoadFactor*$iniLdFactor]
    ALT::LoadGrowInit xt.inc
}

set vT [ ALT::FullPlastic 15 ]
ALT::SaveState
eval ALT::Plot $plotItems

if { <[crack::num] < 2> && <$daLimit >= 100000> } {
    puts " *** stop tearing at all cracks are linked up ***"
```

```
          set analyzing 0
      }
      if { [crack::maxDa] > $daLimit } {
          if { $daLimit > 0 } {
            puts " *** stop tearing at da = [crack::maxDa] ***"
          }
          set analyzing 0
      }
    }
    set fileID [open "out.dat" a]
    ALTTear::printCrack                    $fileID                    [expr
$iniLdFactor*$ALTLoadFactor*$ALTOrigLoad]
    close $fileID
}



 support for run time control

 1. loadTk: load the top window . and
 2. showPlotMenu: show the menu for ploting
    Tearing simulation will be paused until exiting the menu
 3. quitTk: quit tk and resume tearing simulation
 4. quitTearing: quit tk and ready to stop tearing simulation



 An Example of xt.tcl.  It brings up the menu for plotting.  The
 tearing analysis is paused.  It will resume after the plotting
 session.

   loadTk
   showPlotMenu {Example}

 Another example.  It bring the tearing analysis to an end.

   break

 One more. The user can put in more commands in file
 yt.tcl to be executed after the plotting.  yt.tcl can
 be written just before the user quit the plotting menu.

   loadTk
   showPlotMenu {Wait and see}
   if { [file exists "yt.tcl"] } {
      source "yt.tcl"
   }

proc loadTk { } {
    global AltLibDir
    catch {
      StartTk $AltLibDir/ALTrc.tk
      destroy .h
      destroy .f
    }
    if { [info command exitAll] == {} } {
      rename exit exitAll
```

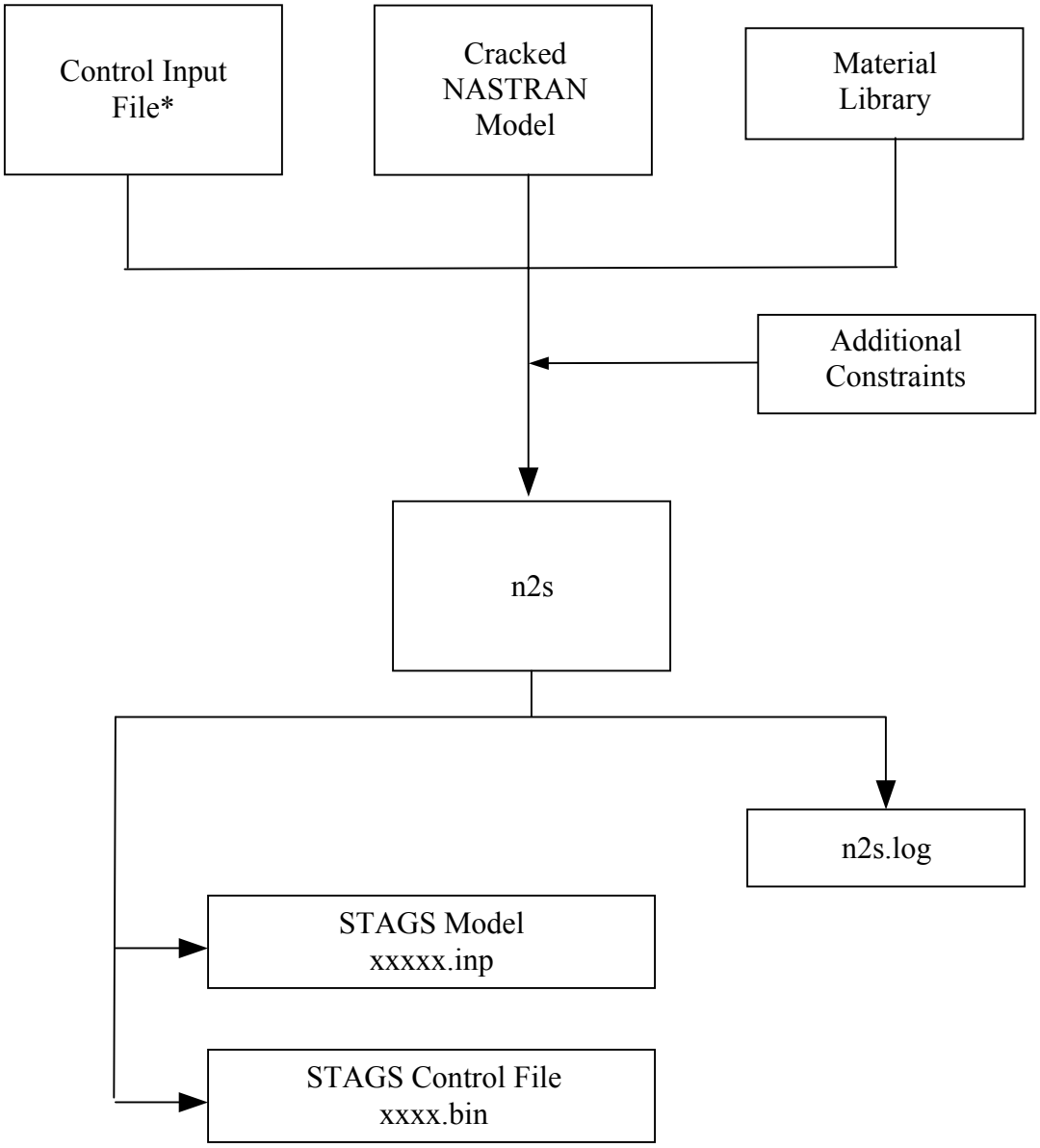
```
      proc exit { } {
          rename exit {}
          rename exitAll exit
          global runAfterTk
          set runAfterTk 1
          if { [info command .t] != {} } {
            destroy .t
          }
      }
    }
    if { [info command .l] == {} } {
      pack [label .l -width 0 -height 0 -text "tearing ..."]
    }
}

proc showPlotMenu { {status  {tearing ...}} } {
    if { [info command .l] != {} } {
      pack forget .l
    }

    catch {
      destroy .h
      destroy .f
    }
    global anaType anaTypeID
    set anaTypeID 6
    set anaType "Stable Tearing"
    pack [frame .t]
    pack [label .t.h -width 50] -fill x -expand true \
      -ipady 1 -ipadx 3 -side bottom
    getVisualOpt {.t} .t.h

        waitTk
        destroy .t
    tkwait window .t

    if { [info command .l] == {} } {
      pack [label .l -width 0 -height 0 -text $status]
    } else {
      .l configure -text $status
      pack .l
    }
    tkwait visibility .l
}


proc waitTk { } {
    global runAfterTk
    vwait runAfterTk
}

proc quitTk { } {
    if { [info command exitAll] != {} } {
      exit
    }
}
```

```
proc quitTearing { } {
    quitTk
    global daLimit
    set daLimit -1
}



   show progress in runID


proc showServerScript { } {
    global port scaleCmd
    set port 2021
    set scaleCmd  {.f.s}
    set out  {
      proc showLine  { channel } {
          gets $channel line
          if { [eof $channel] } {
            catch { close $channel }
            exit
          }

atch {eval $line}

          while { ! [fblocked $channel] } {
            gets $channel line
            if { [eof $channel] } {
                catch { close $channel }
                exit
            }
            catch {eval $line}
          }
          global sname
          set from [$sname cget -from]
          set to [$sname cget -to]
          set intv [expr "<$to-$from>/5"]
          $sname configure -tickinterval $intv
      }
      proc connect { channel addr port } {
          fconfigure $channel -blocking no
          fileevent $channel readable "showLine $channel"

          global serverID
          close $serverID
      }
    }
    append out "\
      if { \[ catch {\
          set serverID \[socket -server connect $port\] } \] } {\
          exit\
      }\
    "
    append out {
      pack [label .l -text "Stable Tearing"] -side top
      set f [frame .f -bd 2 -relief groove]
      global sname
```

```
    }
    append out "set sname $scaleCmd"
    append out {
      scale $sname -showvalue yes -width 5 -length 300 -variable status \
          -orient horizontal -from 0 -to 100 -resolution 1 -tickinterval 10 \
          -state disabled
      pack $sname -side left
      pack $f  -padx 7 -pady 2
      update
    }
    return $out
}

proc startStatusBar { } {
    global socketID
    if { ! [info exists socketID] } {
      set socketID {}
    }
    if { $socketID == {} } {
      exec wish << [showServerScript] &
    } else {
      return
    }
    after 100 { set socketID {} }
    vwait socketID

    global port
    set n 15
    while { $n > 0 } {
      if { [catch { set socketID [socket localhost $port] } ] } {
          after 100
          incr n -1
      } else {
          break
      }
    }
    if { $socketID == {} } {
      puts "fail to connect localhost $port"
      exit
    }
    initStatus
}

proc initStatus { } {
    global curRunID lastRunID socketID scaleCmd
    puts $socketID "$scaleCmd configure -from $curRunID -to $lastRunID"
    flush $socketID
    showStatus
}

proc showStatus { } {
    global curRunID scaleCmd socketID
    if { [catch {
      puts $socketID "global status; set status $curRunID";
      flush $socketID } ] } {
      catch {close $socketID}
      set socketID {}
```

```
    }
}

proc moveResults { } {
    global homeDir
    if { [info exists homeDir] } {
      file rename -force out.dat tear.dat $homeDir
    }
}



   run a problem



global curLoadLevel
set curLoadLevel 1
 set pressure in addTstar to the same

getInitBC
genBinInput
genRsdinputTcl $curRunID


 elastic case

 ALTALT::Run 1 1

if { [info exists xt.tcl] } {
    source "xt.tcl"
}

 tearing

puts "starting from runID: $curRunID"
puts "last runID: $lastRunID"


 show status

if { [info exists env<DISPLAY>] } {
    if { $env<DISPLAY> != {} } {
       startStatusBar
    }
}

ALTTear::App {} $reuse 1
listLoadLevel
moveResults
exit
```

B.4 COMPUTER CODE FOR NASTRAN-TO-STAGS CONVERSION.



*Note: See next page for input instruction

FIGURE B-9. FLOWCHART OF CONVERSION CODE n2s

TABLE B-25. INPUT FORMAT FOR n2s CODE

Line 1	$inda
Line 2	j_title='.....'
Line 3	mat_fn='.....'
Line 4	nas_fn='.....'
Line 5	stags_fn='.....'
Line 6	crack_fn='.....'
Line 7	quad5_fn='.....'
Line 8	baref='.....'
Line 9	spcref='.....'
Line 10	elasps='....'
Line 11	mat_lib='....'
Line 12	g2card='....'
Line 13	linear=I
Line 14	load_set=I1, I2
Line 15	grdset='111000'
Line 16	idisp=I
Line 17	ilin=I
Line 18	ipshl5=I1,I2,.....
Line 19	ctoa=R1,R2
last line	$end

j_title=	'Job Title max=80 characters' (optional)
mat_fn=	'material ID cross reference table, including definition of PSHELL for plane strain core' (optional)
nas_fn=	'filename of the NASTRAN bulk data'
stag_fn=	'filename of the output STAGS file'
crack_fn=	'filename of the file that defines the cracked nodes' (optional)
quad5_fn=	'filename of the file that defines the 5-node quad elements' (optional)
baref=	'filename of the file that defines the reference node of the bar elements' (optional)
elasps=	"filename that contains the property ID of the linear elastic shells (optional)
mat_lib=	'filename of the material property library' (optional)
g2_card=	'filename of the file defines rigid links'
linear	=1 for linear-elastic analysis =2 for nonlinear analysis

load_set=	Load case ID for case A and case B, respectively
grdset=	character string of 6 characters, consists of either '0' or '1', 0 = fixed and 1=freed, used for additional constraints applied to ALL grid points in DOF =1 through 6 (optional)
idisp=	either '1' or '0', '1' indicates the applied forces will be treated as applied forced displacement and the reaction forces of grids with forced displacements will be printed out in .out2 file (optional)
ilin=	if ilin=0, linear-elastic shell properties will be used otherwise elastic-plastic shell properties will be used (optional)
ipshel5	Up to 10 PSHELL ID, specifies which PSHELL that will be checked if the 5-node quads exist
CTOA=	Up to 2 critical CTOA angle, for fatigue crack and saw cut simulation, respectively (optional)

TABLE B-26. EXAMPLE OF INPUT FILE FOR n2s

Filename n2s.in

```
$inda
j_title='Longitudinal Splice, Half Model, Element Size=.0469"'
linear=2
mat_fn='mat_ref.dat'
nas_fn='last.bdf'
stags_fn='ctoa_flat.inp'
crack_fn='g5_crack.inp'
load_set=1054  0
quad5_fn='cq5_ref.dat'
$end
```

Starting Line

Job Title

2 for Non-linear

Material properties Library

Input NASTRA File

Output STAGS File

Crack Surface Definition

Case ID for Load case A and B

Filename of 5- node quads

Last Line

TABLE B-27. EXAMPLE OF INPUT FILE FOR n2s

Filename mat_ref.dat

```
2024   2002    0
20241  2002    1
7075   7075    0
```

1 - plane strain core
0 - plane stress

ID in the material Library

ID in the NASTRAN bulk data

TABLE B-28. INPUT FILE FOR n2s—MATERIAL PROPERTY LIBRARY

Filename for Material Library: mat_all.dat

```
=========================================================
Clad 2024-T3 LT Sheet (Coupon test)
3001  1.05e+07 .33 3.94e6 0. 0.
9
.00282 29614
.00420 39327
.00512 43592
.00580 45487
.00660 46671
.01144 49159
.05600 58043
.11120 62781
.50000 63966
=========================================================
Clad 2024-T3 TL Sheet (Coupon test)
3002  1.05e+07 .33 3.94e6 0. 0.
9
.00265 27875
.00400 37017
.00480 40139
.00580 42146
.00920 46049
.01720 49728
.03920 54634
.10000 61324
.20200 62997
==========================================================
Clad 2024-T3 LT Sheet
2001  1.03e+07 .33 3.94e6 0. 0.
10
.0044  45320
.0050  47000
.0060  48500
.010   50500
.015   51700
.030   54800
.05    58000
.08    61200
.12    63200
```

Description of material

G (psi)

Poission's ratio

Young's Modules (psi)

Material ID

Number of Strain-stress data point

Column 2 - Stress (psi)

Column 1 – Strain

TABLE B-28. INPUT FILE FOR n2s—MATERIAL PROPERTY LIBRARY
(Continued)

```
.184   63800
==============================================================
Clad 2024-T3 TL Sheet, MIL-5 Fig. 3.2.1.1.6(b)
2002 1.03e+07 .33 3.94e6  0. 0.
10
.0036 37080.
.0046 41000.
.006  43800.
.010  46500.
.015  48600.
.03   52600.
.05   56400.
.08   59500.
.12   61800.
.18   63000.
================================================================
Clad 2024-T3 LT Sheet NASA data
2003  1.03e+07 .33 3.94e6 0. 0.
7
4.368900146e-03 4.500000000e+04
9.999999776e-03 5.150000000e+04
1.999999955e-02 5.600000000e+04
3.999999911e-02 6.100000000e+04
7.000000030e-02 6.550000000e+04
1.000000015e-01 6.800000000e+04
1.599999964e-01 7.000000000e+04
===================================================================
Clad 2024-T3 TL Sheet, MIL-5 Fig. 3.2.1.1.6(b), Mod for large
disp
2004 1.03e+07 .33 3.94e6  0. 0.
10
.0036 37080.
.0046 41000.
.006  43800.
.010  46500.
.015  48600.
.03   52600.
.05   56400.
.08   59500.
.12   61800.
.50   65000.
```

TABLE B-28. INPUT FILE FOR n2s—MATERIAL PROPERTY LIBRARY
(Continued)

```
==============================================================
7075-T6 LT Sheet  - MIL-5 pg. 3-371
7075  1.03e+07 .33 3.94e6 0. 0.
8
.006505 67000.
.008    69000.
.0105   70000.
.026    72000
.060    75000.
.080    75800
.100    76000.
.200    76100.
=============================================================
7075-T6 LT Sheet  - MIL-5 pg. 3-371 , mod for large disp
7076  1.03e+07 .33 3.94e6 0. 0.
8
.006505 67000.
.008    69000.
.0105   70000.
.026    72000
.060    75000.
.080    75800
.100    76200.
.500    77000.
=============================================================
Clad 2024-T3 LT Sheet , mod. for large disp
2005  1.03e+07 .33 3.94e6 0. 0.
10
.0044  45320
.0050  47000
.0060  48500
.010   50500
.015   51700
.030   54800
.05    58000
.08    61200
.12    63200
.500   64800
```

TABLE B-28. INPUT FILE FOR n2s—MATERIAL PROPERTY LIBRARY
(Continued)

```
==============================================================
Clad 2014-T6 LT Sheet MIL-5 Fig. 3.2.1.1.6(b)
2014  1.02e+07 .33 3.94e6 0. 0.
8
.005 51000.
.006  58200.
.010 62800.
.020 67000.
.040 70000.
.060 71200.
.100 71300.
.200 71400.
==============================================================
Clad 2014-T6 LT Sheet MIL-5 Fig. 3.2.1.1.6(a) Longitudinal
2015  1.02e+07 .33 3.8356 0. 0.
9
0.00480392 49000.
.0053 52000.
.0060 54000.
.0070 56500.
.0100 58000.
.03   61000
.05   62000
.1000 63500
.2000 64000
==============================================================
Clad 2014-T6 LT Sheet MIL-5 Fig. 3.2.1.1.6(a) Longitidinal mod.
upper strain
2016  1.02e+07 .33 3.94e6 0. 0.
8
.005 51000.
.006 58200.
.010 62800.
.020 67000.
.040 70000.
.060 71500.
.100 73000.
.200 74500.
```

TABLE B-28. INPUT FILE FOR n2s—MATERIAL PROPERTY LIBRARY
(Continued)

```
==============================================================
Clad 2014-T6 LT Sheet MIL-5 Fig. 3.2.1.1.6(a) Longitidinal
2017  1.02e+07 .33 3.8356 0. 0.
9
0.00480392 49000.
.0053 52000.
.0060 54000.
.0070 56500.
.0100 58000.
.03   61000
.05   62000
.1000 64000
.2000 65500
==============================================================
Clad 2014-T6 LT Sheet MIL-5 Fig. 3.2.1.1.6(a) Longitudinal mod.
upper strain
2018  1.02e+07 .33 3.94e6 0. 0.
9
.005 51000.
.006 58200.
.010 62800.
.020 67000.
.040 70000.
.060 71500.
.100 73000.
.200 74500.
.500 77000.
================================================================
Titanium
4001  1.60e+07 .33 3.94e6 0. 0.
3
.005 80000.
.010 160000.
.100 161000.
```

TABLE B-29. TYPICAL INPUT FILE FOR n2s

Format for Cracked Nodes: g5_input.dat

G5 cards (see STAGS input format)

```
1   325 0 1   5.000    .040    .000  12.000    .000 100.000      $ G-5
 0 1 12431 12431 1 0 1   15041   15041 1 0                       $ G-6
 0 1 12430 12430 1 0 1   15040   15040 1 0                       $ G-
 0 1 12429 12429 1 0 1   15039   15039 1 0                       $ G-6
 0 1 12425 12425 1 0 1   15038   15038 1 0                       $ G-6
 0 1 12333 12333 1 0 1   15037   15037 1 0                       $ G-6
 0 1 12224 12224 1 0 1   15036   15036 1 0                       $ G-6
 0 1 12082 12082 1 0 1   15035   15035 1 0                       $ G-6
 0 1 12036 12036 1 0 1   15034   15034 1 0                       $ G-6
 0 1 12035 12035 1 0 1   15033   15033 1 0                       $ G-6
 0 1 12034 12034 1 0 1   15032   15032 1 0                       $ G-6
 0 1 12033 12033 1 0 1   15031   15031 1 0                       $ G-6
 0 1 11844 11844 1 0 1   15030   15030 1 0                       $ G-6
 0 1 11843 11843 1 0 1   15029   15029 1 0                       $ G-g
```

G6 cards (see STAGS input format)

TABLE B-30. EXAMPLE OF INPUT FILE FOR n2s—5-NODE QUAD REFERENCE DATA

Format for definition of the 5th node in the 5-node quad element (type 510): c5_ref.dat

3077	1571	1848	1908	1570	1484	2
3081	1569	1842	1907	1568	1482	2
3082	1560	1844	1904	1561	1476	2
3095	1566	1846	1906	1565	1480	2
3097	1564	1841	1905	1563	1478	2
3116	1592	1929	1878	1593	1927	1
3387			609	618	373	1
4151	2		3398	3401	2607	1
50787	5815	5814	6209	6210	14616	3
45904	8932	8931	9294	9295	13265	1
45991	6897	6896	7314	7315	13267	3
50546	6638	6243	6246	6641	13698	1
50549	5855	5854	5857	6240	13668	4
50551	5851	5484	5854	5855	13633	4
50588	6639	6638	6641	7036	13696	1

NASTRAN Element ID

Node ID (node 1-4)

Node ID of the 5th node

Edge number where the 5th node locates

```
All the commands used in the EPFEAM code are TCL commands.  Knowledge
about TCL is needed to take fully the advantage of the scripting
commands provided.

CMC has a book on Tk/Tcl.  There are also some tutorial material
available on the internet.   Dr. Kawai knows it.

-----------------------------------------------------------------
1) ALTALT::Run -- run elastic analysis

ALTALT::Run anaReuse anaGenLoc

where anaReuse = 0     stiffness matrix can not be reused
               = 1                      can be reused
      anaGenLoc = 0    use the local input file (local.out)
                = 1    use customized mesh
                       (mesh.fem, xt.in, xt.J1, rsdinput.tcl)
defauts:
      anaReuse = 0
      anaGenLoc = 0

-----------------------------------------------------------------
2) ALTEPALT::Run -- run elastic-plastic analysis

ALTEPALT::Run anaReuse anaGenLoc

where anaReuse = 0     stiffness matrix can not be reused
               = 1                      can be reused
      anaGenLoc = 0    use the local input file (local.out)
                = 1    use customized mesh
                       (mesh.fem, xt.in, xt.J1, rsdinput.tcl)
defauts:
      anaReuse = 0
      anaGenLoc = 0

-----------------------------------------------------------------
3) ALTRsd::Rsd -- run residual strength analysis

ALTRsd::Rsd anaType anaReuse anaGenLoc

where anaType = elastic      elastic analysis
              = plastic      elastic-plastic analysis
      anaReuse = 0     stiffness matrix can not be reused
               = 1                      can be reused
      anaGenLoc = 0    use the local input file (local.out)
                = 1    use customized mesh
                       (mesh.fem, xt.in, xt.J1, rsdinput.tcl)
defauts:
      anaType = elastic
      anaReuse = 0
      anaGenLoc = 0

-----------------------------------------------------------------
4) ALTTear::App -- run table tearing analysis (application phase)
Note: analysis stops when MSD cracks are linked up with the lead crack.
Therefore, this can not be used to analyze the tearing of a single
crack.


ALTTear::App plotItem anaReuse anaGenLoc
```

```
where plotItem = {}    nothing to be plotted
               =       (other options are used to generate snap-shot of
                         strain/stress contour when image-processing
                         packages are installed (ImagMagick and
                         ghostscript)
      anaReuse = 0     stiffness matrix can not be reused
               = 1                      can be reused
      anaGenLoc = 0    use the local input file (local.out)
                = 1    use customized mesh
                       (mesh.fem, xt.in, xt.J1, rsdinput.tcl)
defauts:
      plotItem = {}
      anaReuse = 0
      anaGenLoc = 0
```

---

5) Ploting commands (available in interactive mode. In scripting mode, some tricky is needed. The enviroment variable DISPLAY must set to direct the windows to an X-server. At the begin of the script, use the command "source ~/.tkaltrc" to initialize the graphics part. Then, these command becomes available.)

(a) To prepare a window for plot, use the following command

```
source $ALTLibDir/ALTplot; mtvInit mtv
```

(b) To plot stress/strain or mesh, use the following

```
ALTPlot opt; .mtv.mtv -readMesh

where opt = m    plot mesh
          = t1          sigma_{11}
          = t2          sigma_{12}
          = t3          sigma_{22}
          = e           equivalent plastic strain
          = w           stress work density
          = s1          epsilon_{11}
          = s2          epsilon_{12}
          = s3          epsilon_{22}
```

(c) To plot a data set in a file,, use the following

```
.mtv.mtv -read fileName
```

where fileName is the name of the file. For example, out.dat.

(d) use the key "PgUp" and "PgDn" to switch between different pages in the ploting window. (Note: direct the keystrike to that window, not at the command prompt.) The commands for this are

```
.mtv.mtv -prev
.mtv.mtv -next
```

(e) to generate a postscript copy of the plot

```
.mtv.mtv -print fileName
```

where fileName is the file where the postcript will be written.

(d) to close the window

```
destroy .mtv
```

A Brief description of some of the files for 2DFEAM code

Local analysis is a plane stress analysis of AL 2024T3. The input file can be a single file (local.out); or severel other files (mesh.fem, xt.in, xt.J1, rsdinput.tcl). When the single file (local.out) is used, the automatic mesh generate will create the other input files based on this file.

Analysis type includes
  a) elastic alternating analysis
  b) elastic-plastic alternating analysis
  c) elastic residual strength analysis
  d) elastic-plastic residual strength analysis
  e) stable tearing analysis
  f) command driven analysis

in a) elastic FEAM is used to compute the crack tip SIF
in b) EPFEAM is used to compute T* (J) at the specified crack tip contours
in c) the residual strength of the panel is computed, assuming that the load level is propotional to all the specified BC.
in d) residual strength based on EPFEAM and T* (J) (an equivalent KIC is specified)
in e) a stable tearing analysis. A lot more testing is needed. Special care is needed.
in f) the mesh and bounary condition is first read in. Then, drive the analysis using the TCL commands. Detailed knowledge is required. It stops when all the cracks are linked up, i.e. there is only one crack left.

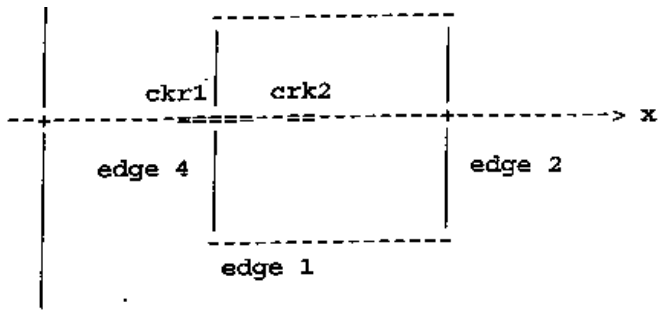
I. input file for local model (local.out)

The input file for local model contains the information for automatic generation of the mesh for the local model. The mesh generator considers only a rectangular local model, with/without rivet holes.

The first section of the input file specifies the informations about the cracks. First, no. of cracks and crack tip coordinates are specified. All cracks are on the x-axis. Therefore, only x-coordinates are specified. Then, a list ot crack tip coordinates is specified. An edge crack is specified by letting one of the crack tip locate outside the body. Cracks at left hand side must appear earlier than those at the right hand side.

The second section specifys the boundary conditions at each edge. Boundary conditions at each edge is represented by values of a list of nodes. The traction/displacement in between the points are obtained using linear interpolation. First the number of nodes on each edge is specified. Then, the boundary conditions at each edge is specified. The four edges are indicated as the following.

```
y
^
|                edge 3
```



The boundary condition type is

code	x-direction	y-direction
0	traction	traction
1	displacement	displacement
2	displacement	traction
3	traction	displacement

A typical line of boundary condition point is

x y fx fy

where (x,y) are the coordinates of the point. Fx, fy is the prescribed value. They may be traction or displacement, determined by the specified code (for the type of boundary condition) for the edge. For edge 1 and 3, the x-coordinates of the BC points must be in increasing order. For edge 2 and 4, the y-coordinates of the points must be in increasing order. These nodes may not be the same as nodes in the FEM mesh (created by the mesh generator).

The third section is about the rivet holes. It also contains the information for mesh generation. All the holes are of the same radius. A list of x-coordinates (in increasing order) is given as the possible x-cooridnates for the center of rivet holes. Similary, a list of y-coordinates is given for the possible locations for the rivet holes. These numbers can be introduced to the control the mesh generation. When there is no hole, the specified radius of the hole will control the mesh size. The center of holes is specified by the indices of the x/y coordinates in the list. A typical line for rivet hole is

nx ny Px Py

where (Px,Py) are the (x,y) components of the pin load. The nx'th coordinate in the list for the x-coordinates is the x-coordinate of the hole. Similarly, ny is the index for the y-coordinate of the hole. The line with non-positive indices marks the end of the list of holes. The unit for the displacement is inch; and Ksi for stress.

Finally, other informations are specified. Some parameters are listed below. They will be used to set the corresponding internal variable. There are essentially TCL commands.

---

1. the load level index for the currently specified B.C

set pressure x

where x is the load level index. Typically, it is the far field stress.

It is used in the residual strength/stable tearing analysis.

---

2. critical SIF

set KIC x

where x is the critial SIF in (Ksi in^0.5)

---

3. set T* resistance curve

crack::config -tStar {0.1+sqrt($da)}

The formula must be inside {}. $da is the key word. It stands for the amount of crack extension. If not specified, a defaut curve will be used.

---

4. set epsilon for the T* curve

crack::config -epsilon 0.05

If not specifed, a defaut value will be used.

---

5. set the amount of crack extension for each crack growth step in stable tea

crack::config -crkIncr 0.04

If not specified, a defaut value will be used.

Example (local.out):

```
==================================================================
4                 # number of cracks
-10 10            # (left, right) crack-tip cooridnates for the 1'th crack
10.5 11           # second crack
11.5 12           # third
12.5 13           # the last one
3 2 0 0           ### boundary conditon types for edge 1,2,3,4
2 2 2 2           ### no. of points used for specify BC for each edge
0  -20 0 0        # the first point on the first edge (x,y,fx,fy)
45 -20 0 0        # the second (last) point on the ~~second~~ first edge
45 -20 0 0        # BC for the second edge
45  20 0 0        #    for the second edge
0   20 0 1        # BC for the third
45  20 0 1        #    for the third edge
0  -20 0 0        # BC
0   20 0 0        #
1 1 3             # no. of (x,y) coordinates and the radius of the hole
20                # list of x-coordinates, seperated by space
0                 # list of y-coordiantes
-1 -1 0 0         # the end of list for rivet holes
set pressure 1; # other control parameters
set KIC 90;     # ...
crack::config -tStar {0.1+sqrt($da)}
crack::config -epsilon "0.05"
crack::config -crkIncr "0.04"
```

4 2 1.

0.1 0.2 0.

0.1 0.2

X=0.1 - - -

Y=0.2 0.5 0.6 0

Y=0.1 0 0 20

1 2 3

3 P_x P_y

==========

II. input file for the FEM mesh (mesh.fem)

The code accepts currently only 8-node elements. The load is specifed as distributed load at element edge. Current GUI does not take point loads.

The first section is the nodal list. A typcal line is

```
ID x y
```

where ID is the nodal number and (x,y) are coordinates. A negative ID marks the end of the nodal list

The second section is the element list. A typcal line is

```
n1 n2 n3 n4 n5 n6 n7 n8
```

where n1-n8 are node IDs as specified in the first section. Negative IDs marks the end of the element list. The numbering scheme is shown in the following. The edges are also numbered as the following.

```
                    edge 3

            n4        n7        n3
             o--------o--------o
             |                 |
             |                 |
edge 4; n8   o                 o  n6; edge 2
             |                 |
             |                 |
             o--------o--------o
            n1        n5        n2

                    edge 1
```

The third part is the nodal constraints. A typical line is

```
ID  code  fx  fy
```

where ID is the nodal ID as in the first section. The code is

code	constraint-type
1	u is specified, fx=u, fy has no meaning
2	v is specified, fy=v, fx has no meaning
3	both u,v are specified, fx=u, fy=v

A negative ID marks the end of the nodal constraints.

The last section is the edge loads. A typical line is

```
eleID edgeID fx1 fy1 fx2 fy2 fx3 fy3
```

where it indicates that the load is on the eleID'th element, the edgeID'th edge. fx1, fx2, fx3 are the values (Tx) at the three nodes of the edge. Tx is the x-component of the traction. Similarly, fy1, fy2, fy3 are the values of the y-component of the tractions. A negative eleID marks the end of the edge loads.

example (mesh.fem):

```
==================================================================
1 0 0     # the nodal list
2 2 0
3 2 2
4 0 2
5 1 0
6 2 1
7 1 2
8 0 1
-1 0 0   # end of nodal list (three numbers are needed at this line)
1 2 3 4 5 6 7 8     # the element list
-1 0 0 0 0 0 0 0    # end of element list
1 3 0 0             # the nodal constraints (both u,v are fixed at node 1)
5 2 0 0
2 2 0 0
-1 0 0 0            # end of the nodal constraint list
1 3 0.1 0 0.1 0.5 0.1 1.0  # edge load list
-1 0 0 0 0 0 0 0            # end
==================================================================
```

III. input file for the cracks (xt.in)

The first part is same as the first section in the input file for the local model (local.out)

Then, points where displacement in x/y direction is constrained for the analytical solution is specified. (Do not specify a point on the crack surface.) It requirs two lines. The first line specifys the x,y coodinates of the point and the prescribed u. The second line specifys the x,y coordinates of the second point and the prescribed v. The two points can be at the same location.

Example (xt.in):

```
==================================================================
4               # number of cracks
-10 10          # (left, right) crack-tip cooridnates for the 1'th crack
10.5 11         # second crack
11.5 12         # third
12.5 13         # the last one
20 0 0          # u is 0 for the analytical solution at (20,0)
```

```
20 0 0          # v is 0 for the analytical solution at (20,0)
==================================================================
```

IV. input file for the contours (xt.J1)

The first line ~~contours~~ contains the number of contours in the file. A contour is specified by a list of nodes. Contours are sepereated by single line. These nodes can not be located exactly on the crack surface.

Example (xt.J1):

```
==================================================================
2                   # two contours
   0.0 -0.0001      # the first node at (0,0)
15 0.0 -1.0         # the second node at (0,-1). use 15 points between the
25 1.0 -1.0         # the first and second node. use 25 points between the
30 1.0  1.0         # the second and third node.
25 0.0  1.0
15 0.0  0.0001
0  0    0           # this marks the end of the contour

   0.0 -0.0001      # the first node at (0,0)
15 0.0 -1.5         # the second node at (0,-1.5). use 15 points between the
25 1.5 -1.5         # the first and second node. use 25 points between the
30 1.5  1.5         # the second and third node.
25 0.0  1.5
15 0.0  0.0001
0  0    0           # this marks the end of the contour
```

V. file for other inputs (rsdinput.tcl)

This part is almost the same as the last section in local.out. The variable "crks" must be set explicitly in rsdinput.tcl when local.out is not used.

example (rsdinput.tcl)

```
==================================================================
set crks {
 {-10.000000 10.000000}
 {10.500000 11.000000}
 {11.500000 12.000000}
 {12.500000 13.000000}
 };                                          # the list of crack tips
set ALTCrkBodySize {0.000000 45.000000};     # the xmin and xmax
set pressure 1;                              # the load level index
set KIC 90;                                  # critical (equivalent) SIF
==================================================================
```

The variable crks contains the list of cracks.

The variable ALTCrkBodySize contains the min and max x-coordinates for the body at y=0 (where the crack line is). It is used to determined if there is an edge crack.

VI. output file 1 (out.dat)

Some major results are put in out.dat by the GUI.

VII. output file 2 (xt.mtv)

Right after a contour plot for the stress, or the plastic strain, xt.mtv contains corresponding nodal values. It is listed for each element at each node. The nodal coordinates followed by corresponding value. The stress is the total elasto-plastic stress. The plastic strain is the equivalent plastic strain.

APPENDIX C—MATERIAL PROPERTY TEST DATA

This appendix contains the *da/dN* data of Al 2024-T3 clad sheet in either the L-T or T-L directions, as discussed in section 4.

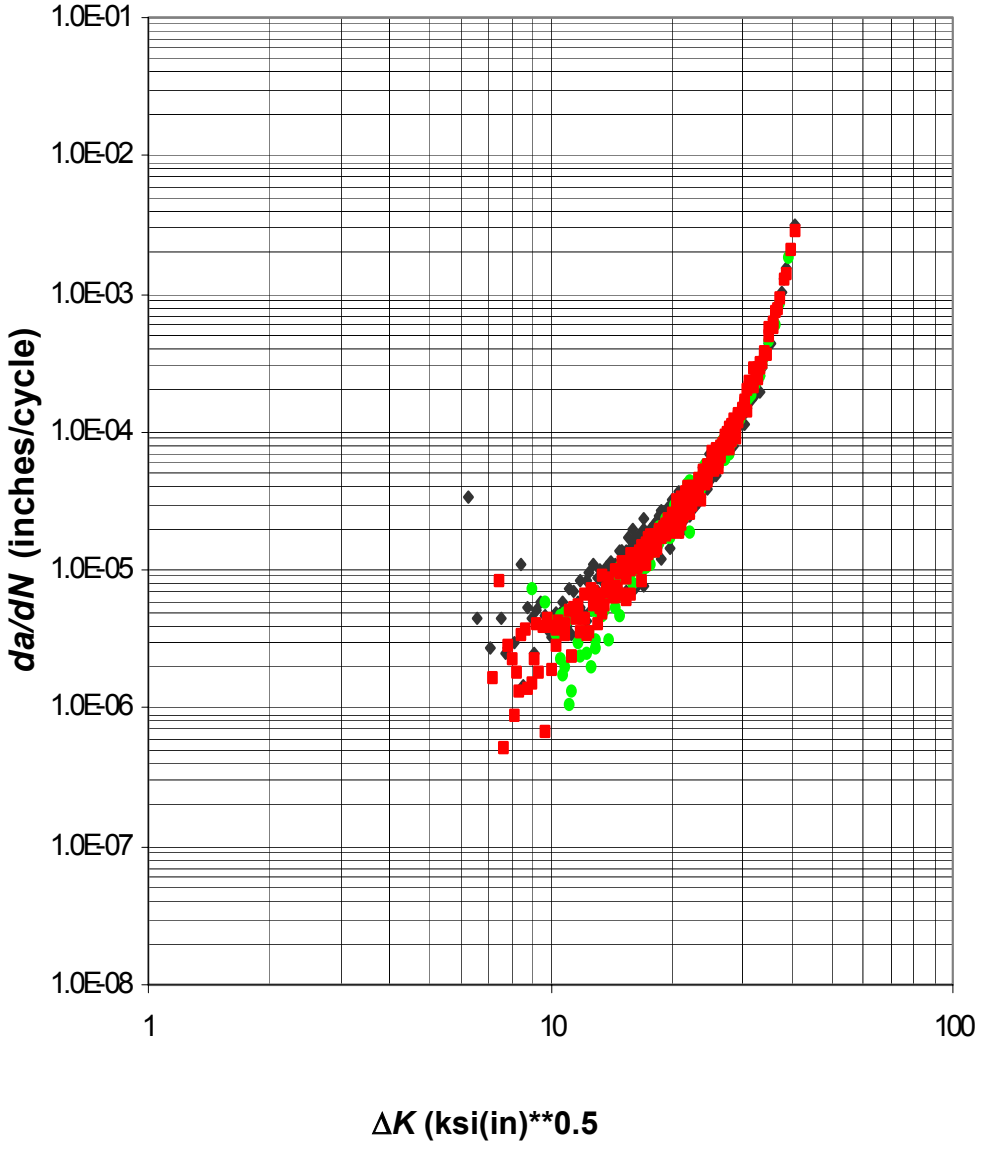


FIGURE C-1. *da/dN* FOR Al 2024-T3 CLAD L-T DIRECTION, R = 0.0, LAB AIR, ROOM TEMPERATURE, SPECIMEN NO. CR-3 (diamond symbols), CR-4 (circle symbols), AND CR-5 (square symbols)

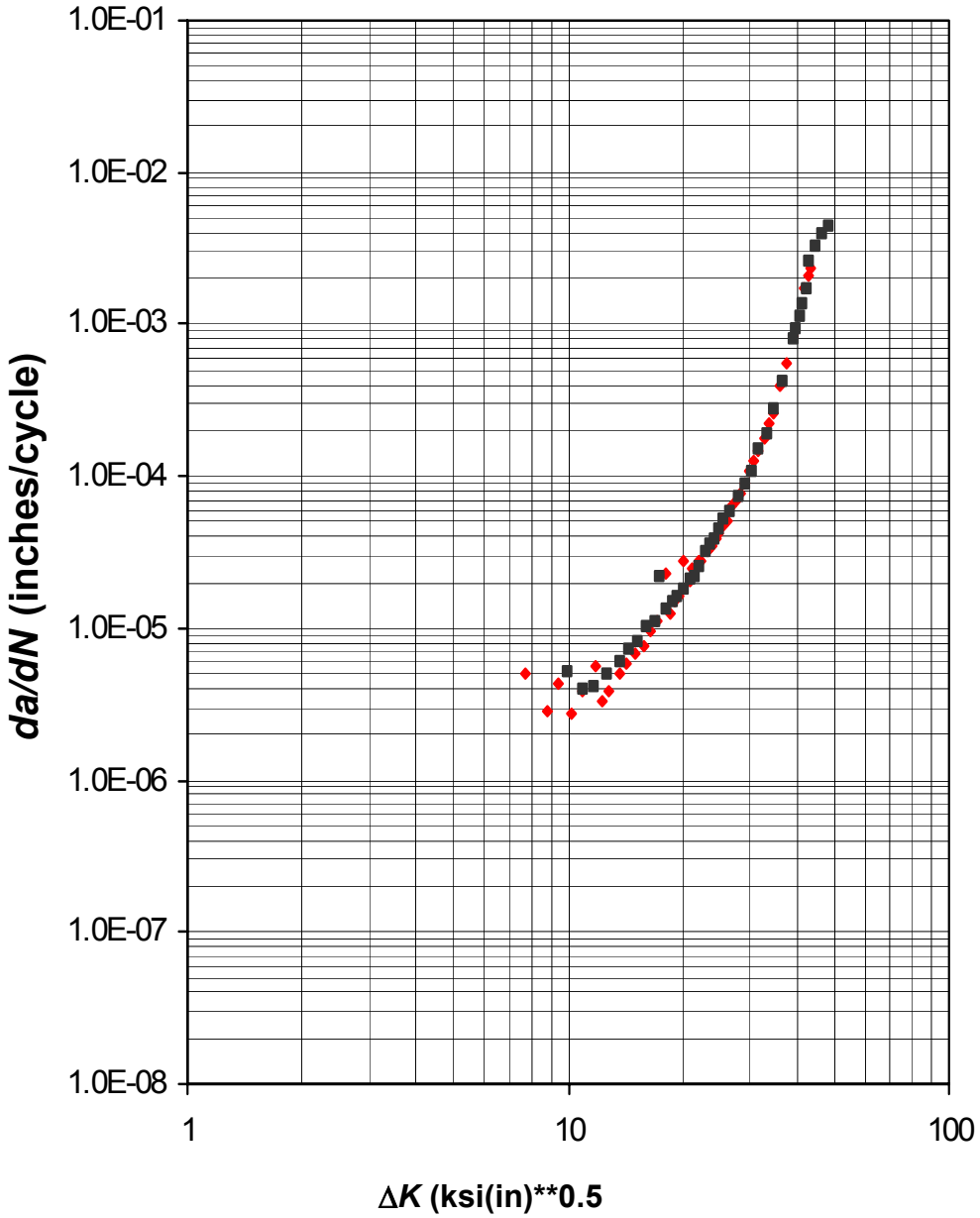


FIGURE C-2. *da/dN* FOR Al 2024-T3 CLAD L-T DIRECTION, R = -0.1, LAB AIR, ROOM TEMPERATURE, SPECIMEN NO. CR-6 (diamond symbols) AND CR-7 (square symbols)

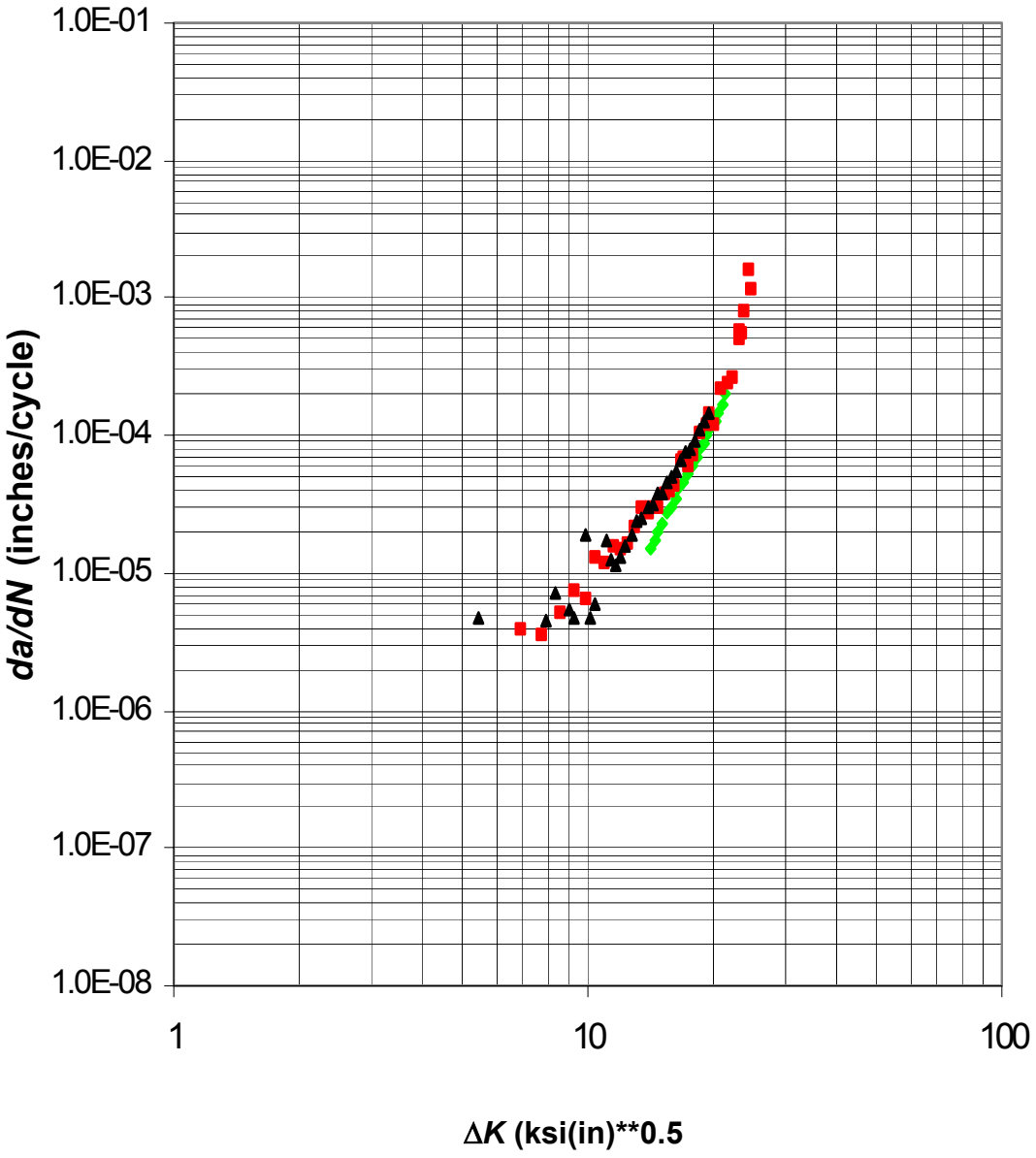


FIGURE C-3. *da/dN* FOR Al 2024-T3 CLAD T-L DIRECTION, R = 0.5, LAB AIR, ROOM TEMPERATURE, SPECIMEN NO. CR-8 (diamond symbols), CR-9 (square symbols), AND CR-10 (triangle symbols)

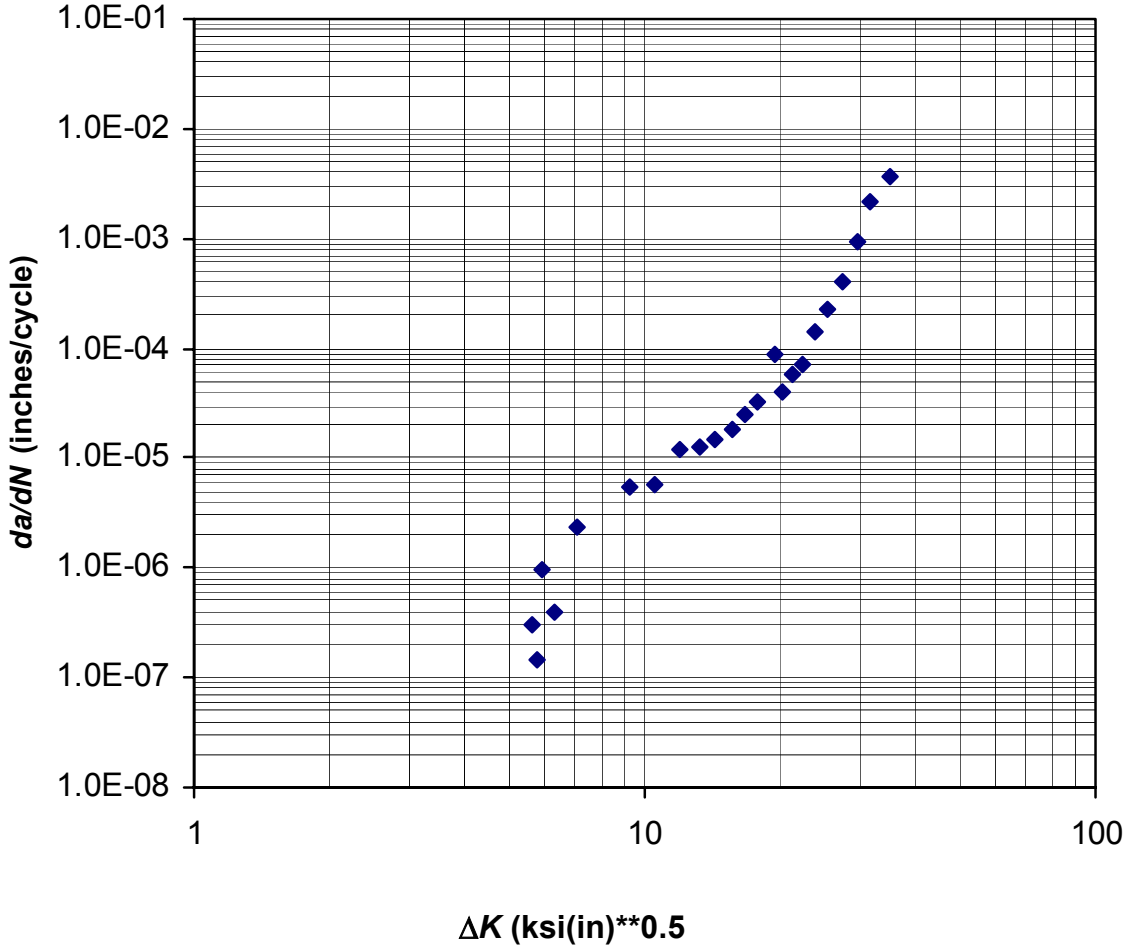


FIGURE C-4. *da/dN* FOR Al 2024-T3 CLAD T-L DIRECTION, R = 0.1, LAB AIR, ROOM TEMPERATURE, SPECIMEN NO. CR-11

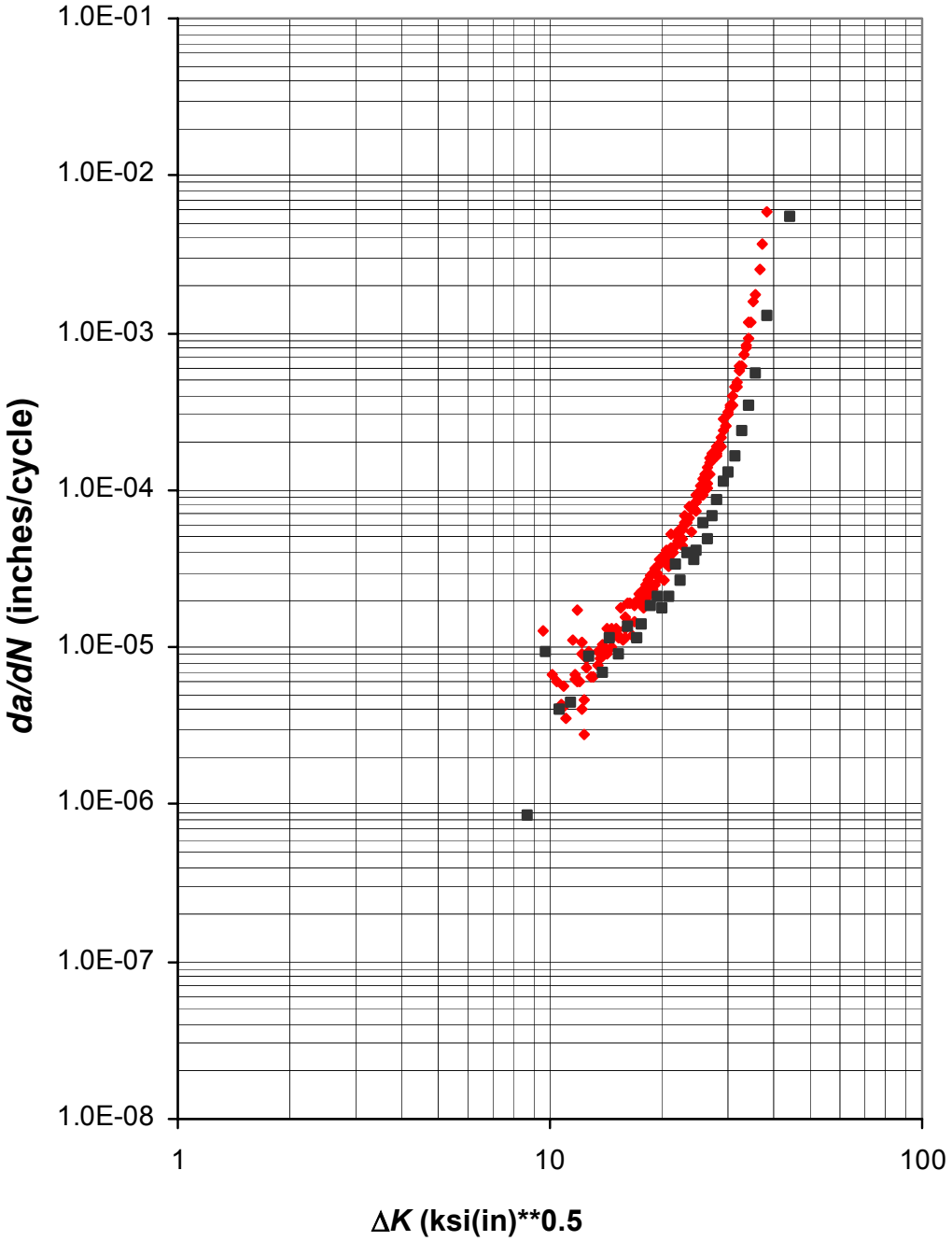


FIGURE C-5. *da/dN* FOR Al 2024-T3 CLAD T-L DIRECTION, R = 0.0, LAB AIR, ROOM TEMPERATURE, SPECIMEN NO. CR-12 (diamond symbols) AND CR-13 (square symbols)

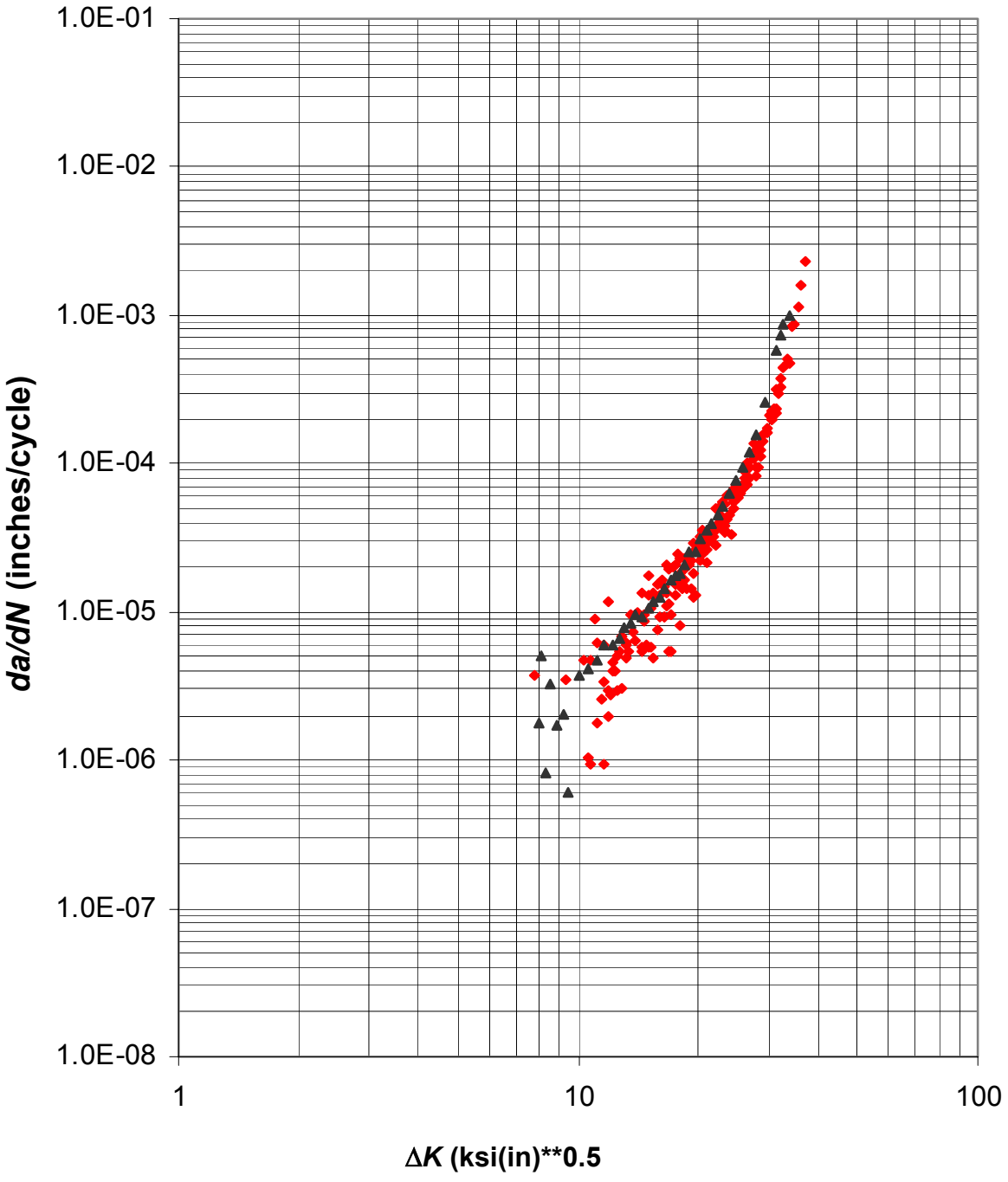


FIGURE C-6. *da/dN* FOR Al 2024-T3 CLAD T-L DIRECTION, R = -0.1, LAB AIR, ROOM TEMPERATURE, SPECIMEN NO. CR-14 (diamond symbols) AND CR-15 (triangle symbols)

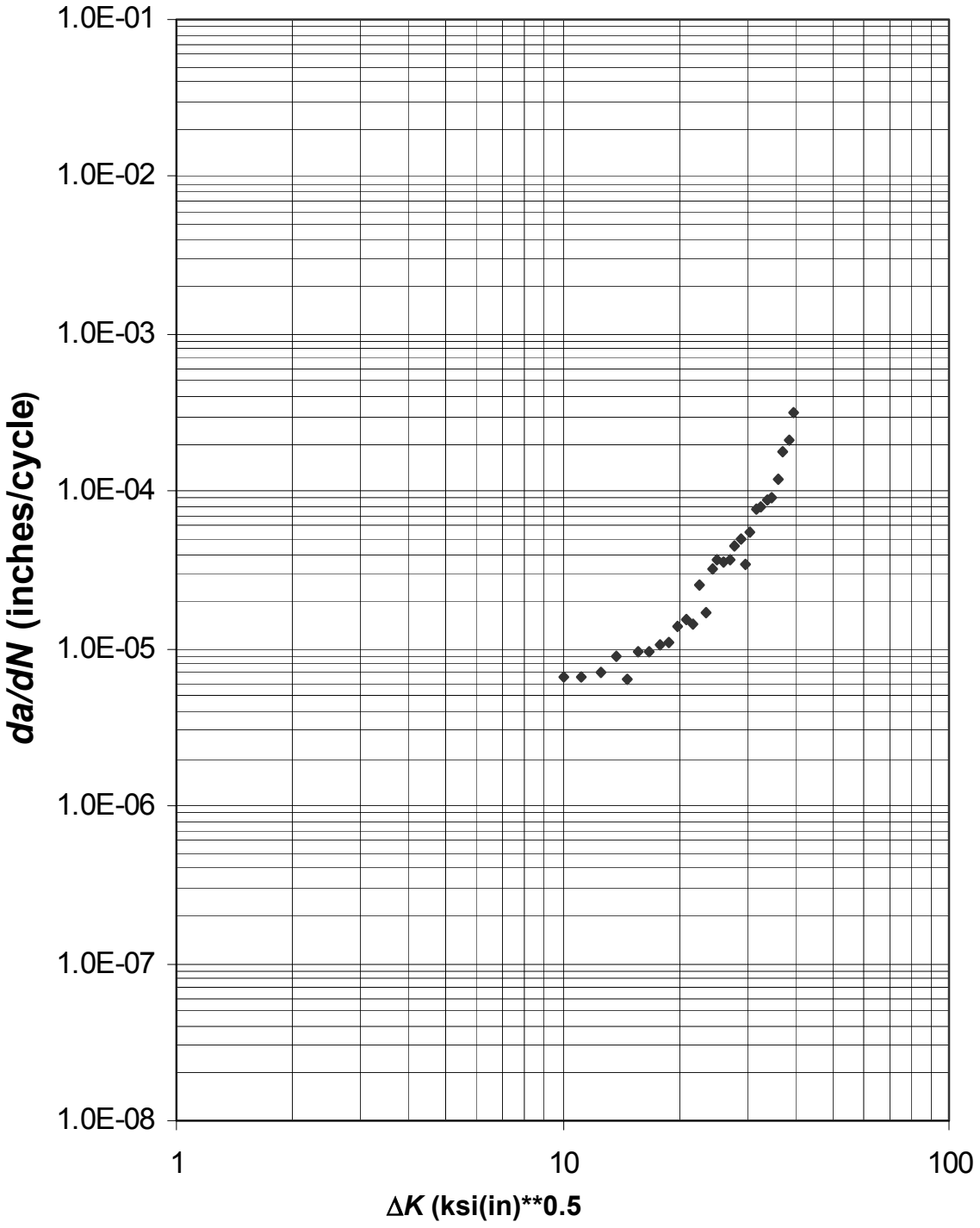


FIGURE C-7. *da/dN* FOR Al 2024-T3 CLAD T-L DIRECTION, R = -0.5, LAB AIR, ROOM TEMPERATURE, SPECIMEN NO. CR-16

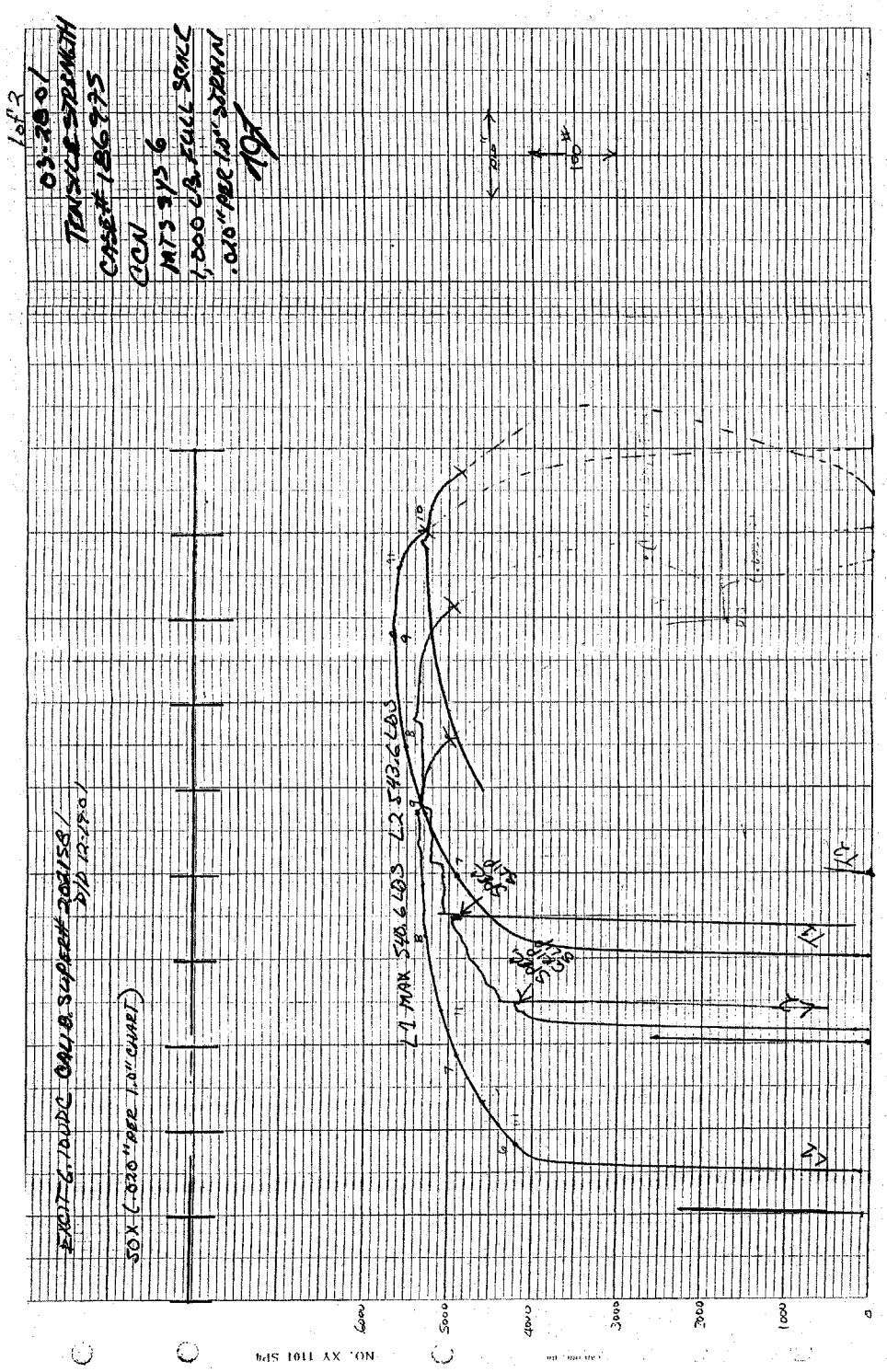


FIGURE C-8. TENSILE TESTING, Al 2024-T3 LOAD VS DISPLACEMENT PLOTS (0.02″ PER 1.0″ SCALE)

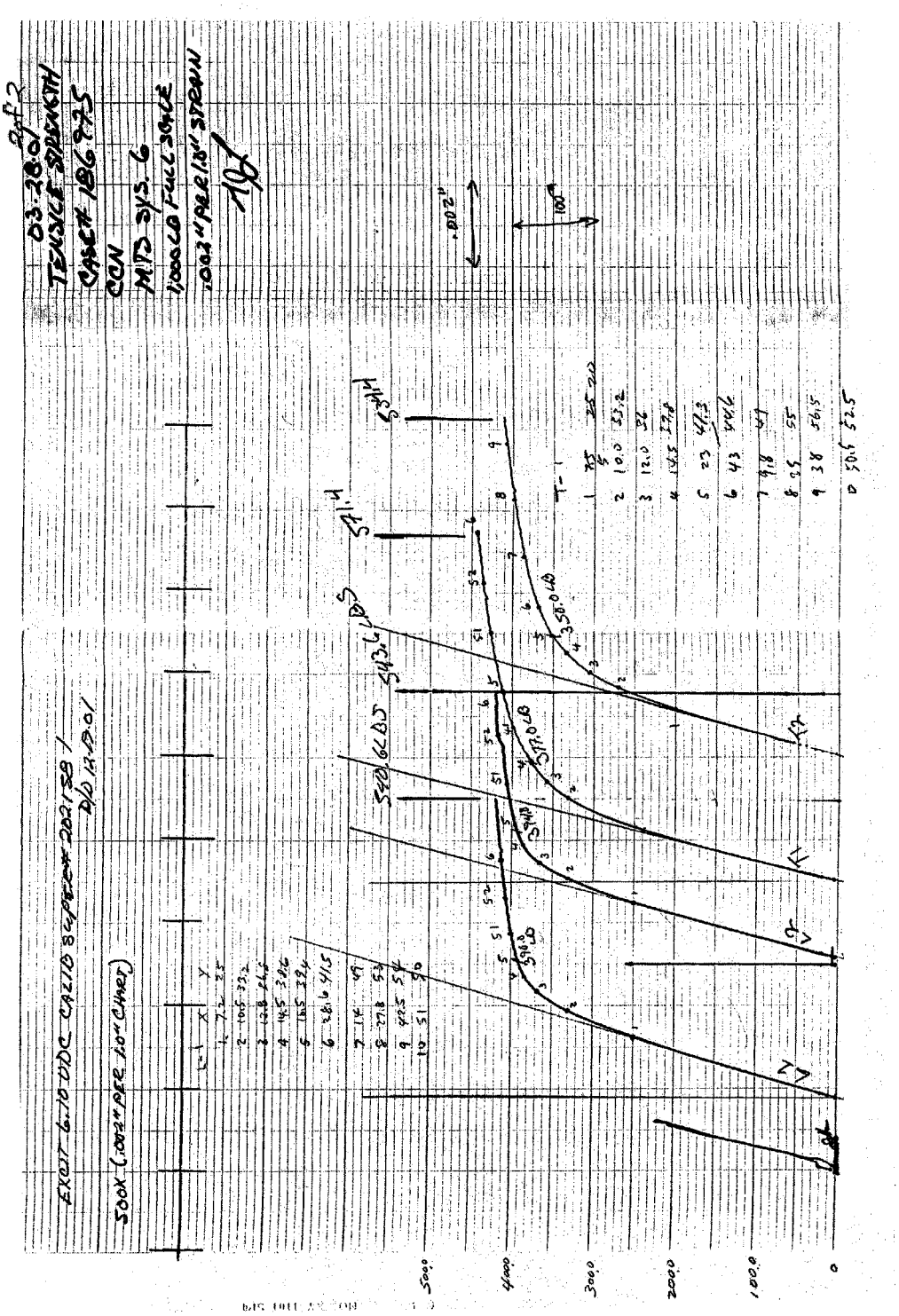


FIGURE C-9. TENSILE TESTING, Al 2024-T3 LOAD VS DISPLACEMENT PLOTS (0.002″ PER 1.0″ SCALE)

MECHANICAL PROPERTIES TESTING LABORATORY

CASE: 186975
SHEET: 1 OF
DATE: 03-28-01

TYPE TEST: TENSILE STR
MATERIAL: 2024-T3
TIME CHARGE:
SUBMITTER: CHING-LONG HSU
TEST RATE: .05"/MIN.
TESTING MACHINE: MTS SYS 6
INSTRUMENTATION: .50" GAGE LENGTH
TECHNICIANS: PREPARED BY:
TESTED BY: TK
CALCULATED BY:

NO.	CODE	THICK	WIDTH	AREA	YIELD LOAD LBS.	YIELD STRESS KSI	ULT LOAD LBS	ULT STRESS KSI	0.750" INT. G.L. ELONG % *	CHART
L1		.0630	.1340	.0084	390.0	46.43	540.6	64.36	~~12.88~~	19.8
L2		.0628	.1335	.0084	394.0	46.90	543.6	64.71	~~20.83~~	19.6
T1		.0625	.1435	.0080	372.0	41.89	571.4	63.49	~~25.83~~	19.6
T2		.0625	.1345	.0084	350.0	41.67	534.4	63.62	~~10.95~~	18.0

* FITBACK TOO SUSPECT
CORRECT % ELO OBTAINED FROM CHART

DATA AND RESULTS CHECKED: [signature]
DATE: 3-29-01

MD-1021 (01 AUG 94) Replaces SSC-1021

FIGURE C-10. TENSILE TESTING, Al 2024-T3 MECHANICAL PROPERTY CALCULATION

ORIENTATION:	T-L	YIELD STRENGTH:	****** PSI
SPECIMEN TYPE:	M(T)	YOUNGS MODULUS:	10.5E+06 PSI
TEMPERATURE:	ROOM TEMPERATURE	THICKNESS:	0.0630 IN
CEB RATIO:	0.9744	WIDTH :	48.000 IN
Y:	0.4 IN	PRECRACK:	7.3635 IN
POISSONS RATIO:	.33		

PT. NO.	P LB	V IN	CEBT	CEBA	F(A/W)	DELTA A PHYS IN	A EFF IN	DELTA A EFF IN	KR EFF KSI-IN**.5
1	19040	.019	0.674	0.657			7.363		32.17
2	29554	.031	0.694	0.676		-0.081	7.558	0.194	50.76
3	39289	.042	0.711	0.692		0.024	7.718	0.354	68.39
4	47319	.055	0.766	0.746		0.378	8.246	0.882	85.99
5	54785	.068	0.822	0.801		0.724	8.764	1.401	103.73
6	57578	.074	0.851	0.829		0.895	9.027	1.663	111.26
7	59794	.081	0.894	0.871		1.098	9.402	2.039	118.93
8	61016	.087	0.948	0.923		1.413	9.865	2.501	125.68
9	63553	.095	0.987	0.961		1.548	10.195	2.831	134.19
10	64547	.103	1.054	1.027		1.915	10.737	3.374	141.92
11	65151	.111	1.128	1.099		2.301	11.319	3.956	149.56
12	62425	.116	1.229	1.198		2.795	12.070	4.706	151.52
13	62532	.123	1.302	1.269		3.158	12.583	5.219	157.70
14	65768	.137	1.375	1.340		3.354	13.072	5.708	172.10
15	63647	.147	1.524	1.485		4.084	14.004	6.640	178.95
16	62426	.155	1.639	1.597		4.583	14.671	7.307	185.08
17	60935	.163	1.773	1.727		5.081	15.382	8.019	191.58
18	57766	.173	1.981	1.930		5.808	16.381	9.017	198.15
19	54181	.183	2.231	2.173		6.648	17.418	10.055	205.11
20	47843	.192	2.652	2.584		7.722	18.849	11.485	211.67

1 PHYSICAL A WAS CALCULATED USING IRWINS PLASTIC ZONE
2 FAILED SPECIMEN STARTING NOTCH REQUIREMENT
3 FAILED FINAL PRECRACK LOAD REQUIREMENT
4 FAILED UNCRACKED LIGAMENT REQUIREMENT (C(T))
5 FAILED NET SECTION YIELD REQUIREMENT (M(T))

FIGURE C-11. R-CURVE TESTING, PANEL NO. 1(KR-1) LABOROTORY CALCULATION SHEET

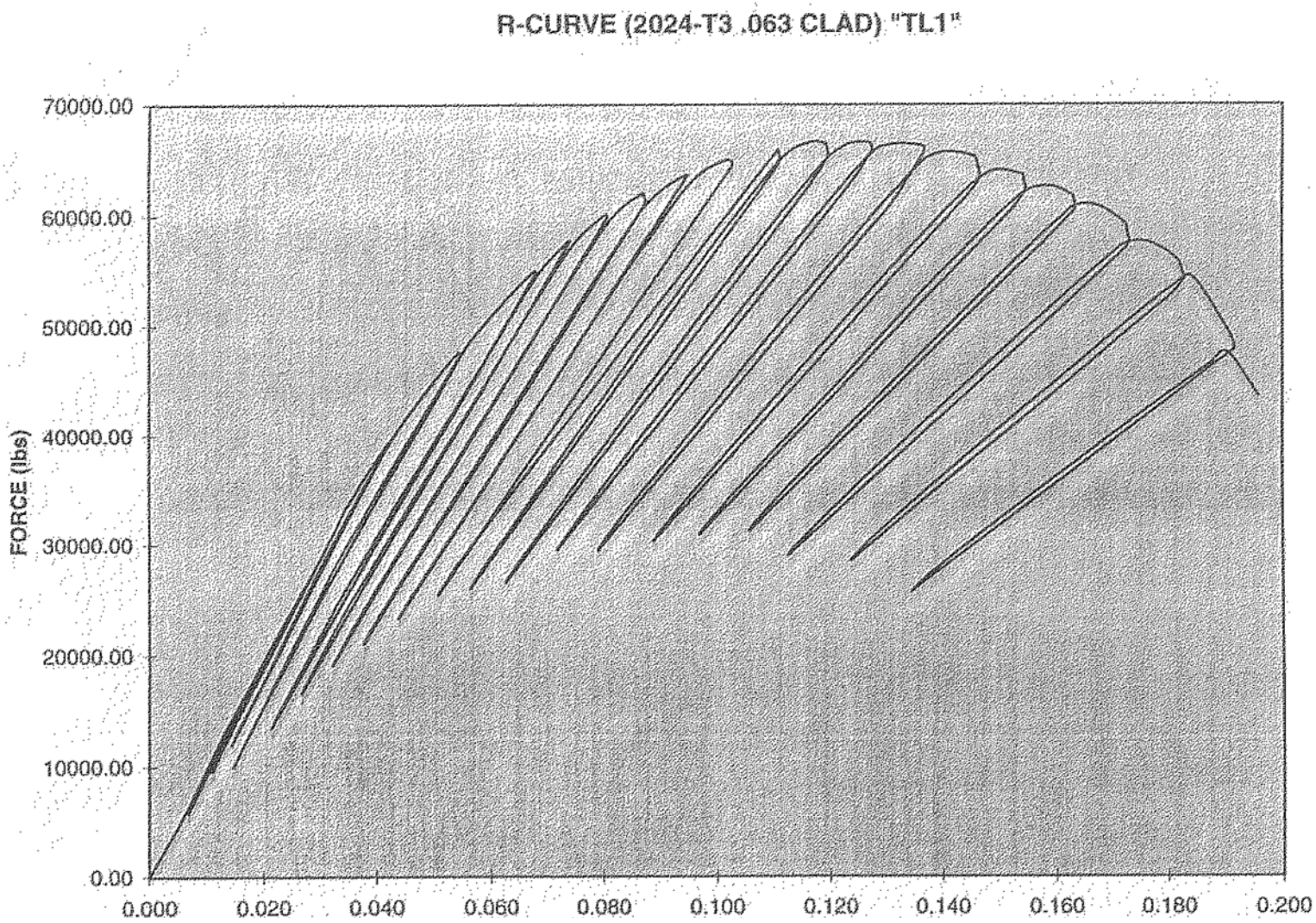


FIGURE C-12. R-CURVE TESTING, PANEL NO. 1(KR-1) LOAD VS COD PLOT

ORIENTATION:	T-L	YIELD STRENGTH:	****** PSI
SPECIMEN TYPE:	M(T)	YOUNGS MODULUS:	10.5E+06 PSI
TEMPERATURE:	ROOM TEMPERATURE	THICKNESS:	0.0630 IN
CEB RATIO:	0.9149	WIDTH :	48.000 IN
Y:	0.4 IN	PRECRACK:	7.2100 IN
POISSONS RATIO:	.33		

PT. NO.	P LB	V IN	CEBT	CEBA	F(A/W)	DELTA A PHYS IN	A EFF IN	DELTA A EFF IN	KR EFF KSI-IN**.5
1	20000	.021	0.701	0.642			7.210		33.35
2	30000	.032	0.699	0.640		-1.025	7.190	-0.020	49.94
3	41700	.048	0.765	0.700		-0.114	7.789	0.579	73.01
4	47600	.059	0.825	0.755		0.415	8.331	1.121	87.09
5	50600	.066	0.856	0.783		0.515	8.597	1.387	94.55
6	56200	.080	0.942	0.862		0.876	9.318	2.108	111.06
7	58200	.093	1.062	0.971		1.057	10.277	3.067	123.65
8	60150	.102	1.125	1.029		1.363	10.761	3.551	132.48
9	61850	.111	1.184	1.083		1.548	11.194	3.984	140.68
10	63360	.119	1.240	1.135		1.533	11.596	4.386	148.47
11	64300	.127	1.304	1.193		1.622	12.039	4.829	155.71
12	65000	.134	1.368	1.251		1.663	12.459	5.249	162.42
13	65500	.142	1.436	1.314		1.876	12.896	5.686	169.13
14	65300	.151	1.535	1.404		1.738	13.496	6.286	176.50
15	65030	.160	1.629	1.490		1.890	14.036	6.826	183.30
16	64800	.168	1.719	1.573		1.839	14.529	7.319	189.94
17	64300	.175	1.800	1.647		1.994	14.950	7.740	195.03
18	63420	.183	1.908	1.745		2.092	15.477	8.267	200.99
19	62000	.191	2.040	1.866		2.766	16.080	8.870	207.03
20	60450	.199	2.175	1.990		3.211	16.652	9.442	212.59
21	56440	.205	2.406	2.201		3.834	17.529	10.319	216.04
22	53800	.213	2.614	2.392		4.599	18.224	11.014	221.57

1 PHYSICAL A WAS CALCULATED USING IRWINS PLASTIC ZONE
2 FAILED SPECIMEN STARTING NOTCH REQUIREMENT
3 FAILED FINAL PRECRACK LOAD REQUIREMENT
4 FAILED UNCRACKED LIGAMENT REQUIREMENT (C(T))
5 FAILED NET SECTION YIELD REQUIREMENT (M(T))

FIGURE C-13. R-CURVE TESTING, PANEL NO. 2 (KR-2) LABOROTORY CALCULATION SHEET

APPENDIX D—CRACK INITIATION

This appendix contains the crack initiation life specimen drawing, noninteraction criteria FEM models, test results, photos of the notch surface, SEM photos, crack shape calculations, crack growth rate calculation, and test/analyses correlation, as discussed in section 7.

Page No.	Description
D-2	Crack initiation life specimen drawing (figure D-1)
D-5	Noninteraction criteria FEM models (figures D-2 to D-4)
D-6	Calculated *da/dN* and ΔK_{eff} for group 1 specimens (tables D-1 to D-5)
D-9	Curve fitting of a vs N for group 1 specimens (figures D-5 to D-9)
D-11	Crack growth correlation of group 1 specimens (figures D-10 to D-15)
D-14	Crack growth correlation of group 2 specimens (figures D-16 to D-20)
D-17	Crack growth correlation of group 3 specimens (figures D-21 to D-22)
D-18	Crack growth correlation of group 4 specimens (figures D-23 to D-27)
D-20	SEM photos (figures D-28 to D-33)
D-23	Crack shape calculation (tables D-6 to D-14)
D-28	Test results a vs N (tables D-15 to D-34)
D-44	Photos of the notch surfaces (figures D-34 to D-55)

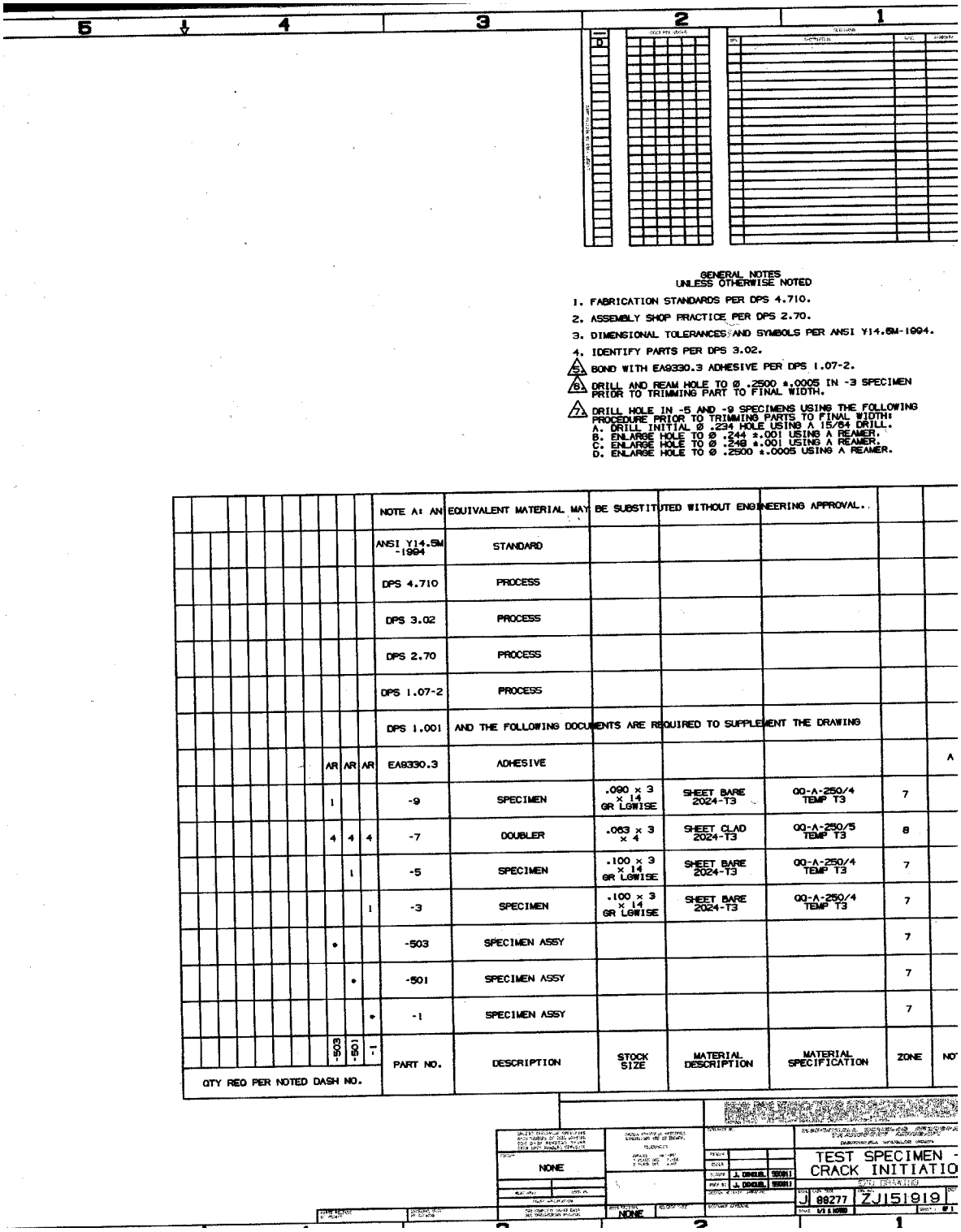


FIGURE D-1. CRACK INITIATION SPECIMEN DETAIL ASSEMBLY DRAWING

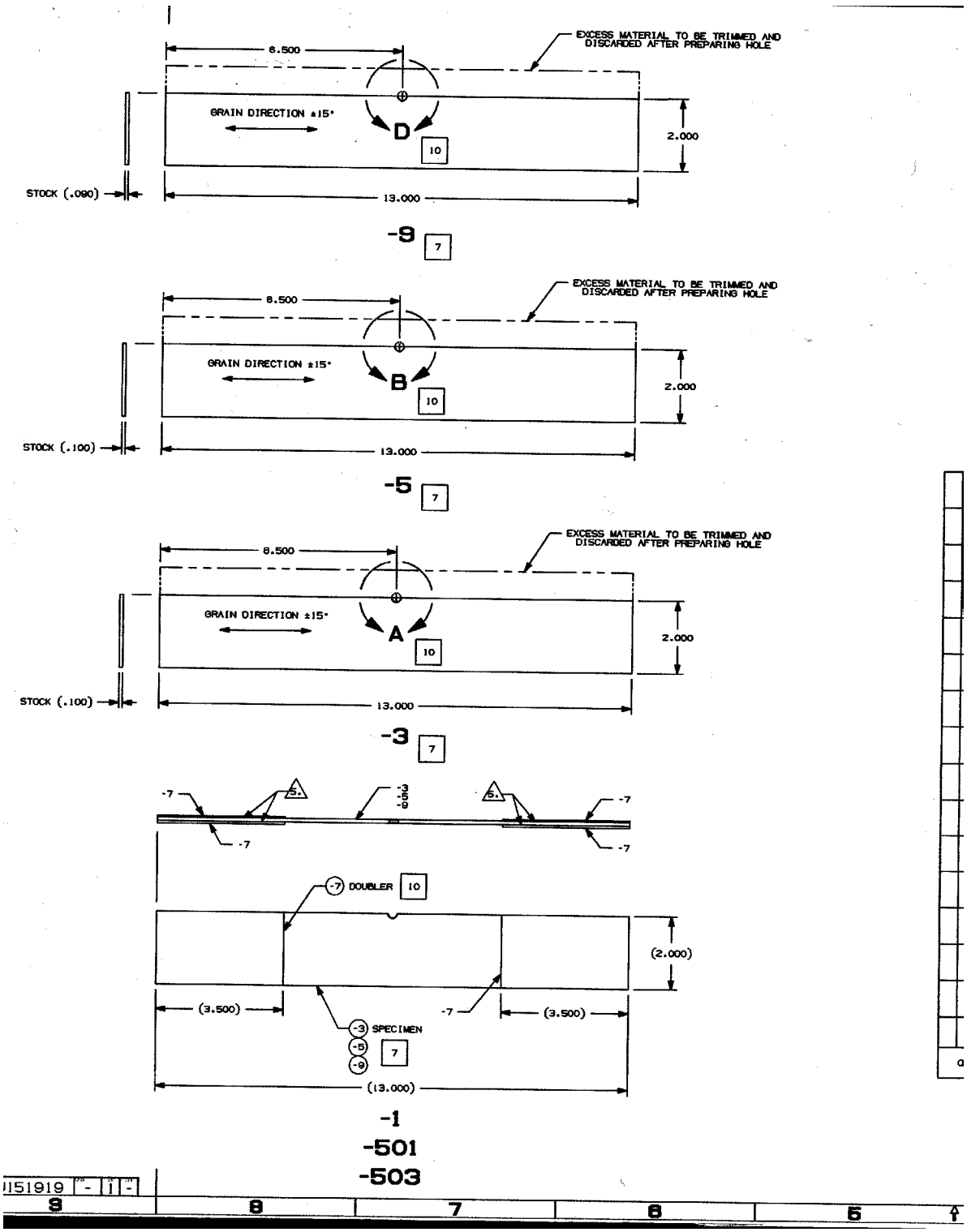


FIGURE D-1. CRACK INITIATION SPECIMEN DETAIL ASSEMBLY DRAWING (Continued)

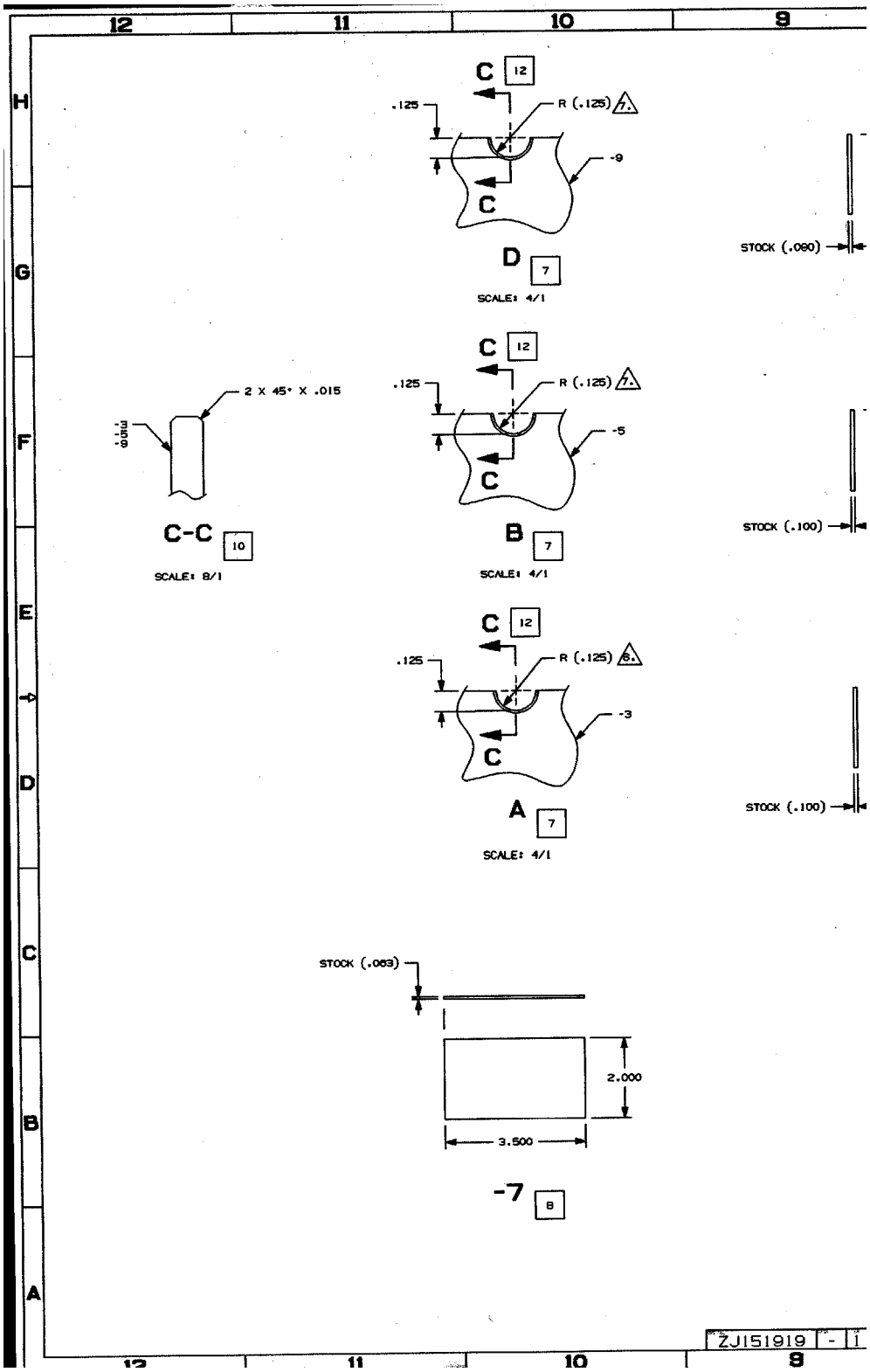


FIGURE D-1. CRACK INITIATION SPECIMEN DETAIL ASSEMBLY DRAWING (Continued)

Figures D-2 through D-4 are in support of Section 5.9, Validation of Crack Noninteraction Criteria.

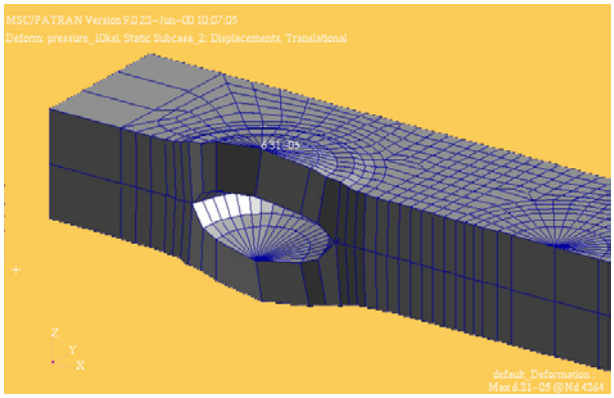


FIGURE D-2. DEFORMED PLOT OF A SINGLE CRACK MODEL
(Exaggerated scale)

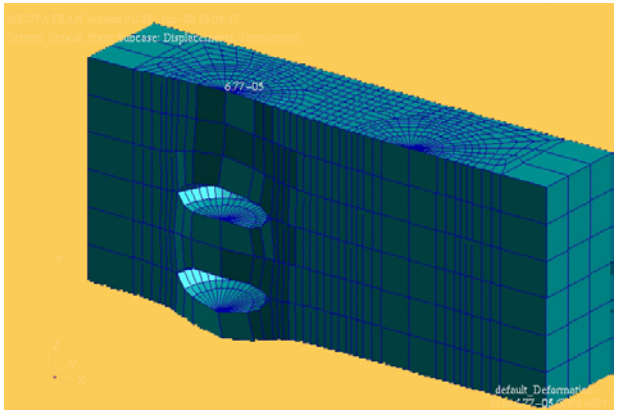


FIGURE D-3. DEFORMED PLOT OF A PARALLEL CRACK MODEL
(Exaggerated scale)

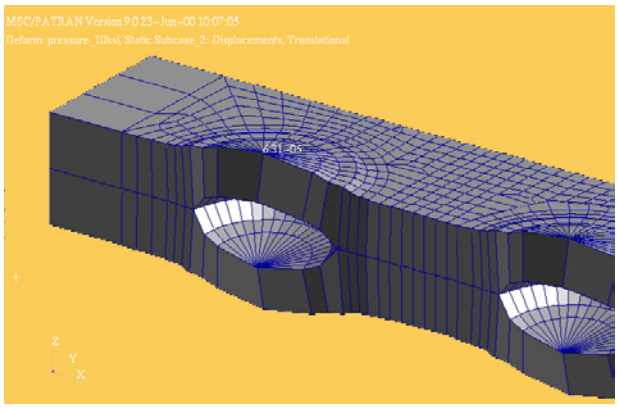


FIGURE D-4. DEFORMED PLOT OF INLINE CRACK MODEL
(Exaggerated scale)

TABLE D-1. SPECIMEN CIL-2 TEST DATA (a VS N) AND CRACK GROWTH RATE

polished notch prep			
σ_{max} = 17 ksi			
R = 0.1			
a (in)	Cycles	*da/dN* (in/cycle)	ΔK_{eff} (ksi (in)$^{1/2}$)
0.000138	440,000	1.492E-08	0.641
0.000551	450,000	4.408E-08	1.078
0.001102	460,000	6.151E-08	1.566
0.001377	465,000	7.247E-08	1.754
0.001652	470,000	8.523E-08	1.913
0.002026	475,000	1.001E-07	2.109
0.002439	485,000	1.373E-07	2.299
0.003246	495,000	1.87E-07	2.624
0.003383	499,000	2.113E-07	2.676
0.003659	503,000	2.385E-07	2.771
0.003796	507,000	2.69E-07	2.819
0.004740	511,000	3.03E-07	3.116
0.005291	519,000	3.835E-07	3.273
0.005960	523,000	4.309E-07	3.451
0.006235	527,000	4.837E-07	3.519
0.007593	531,000	5.424E-07	3.841
0.008832	535,000	6.078E-07	4.100
0.010189	538,000	6.616E-07	4.369
0.010996	541,000	7.199E-07	4.521
0.011802	545,000	8.049E-07	4.660
0.013985	549,000	8.993E-07	5.030
0.015343	552,000	9.768E-07	5.246
0.017231	555,000	1.061E-06	5.539

TABLE D-2. SPECIMEN CIL-13 TEST DATA (a VS N) AND CRACK GROWTH RATE

polished notch prep			
σ_{max} = 17 ksi			
R = 0.1			
a (in)	Cycles	*da/dN* (in/cycle)	ΔK_{eff} (ksi (in)$^{1/2}$)
0.00152	190,000	3.952E-08	1.839
0.00194	210,000	6.499E-08	2.066
0.00375	230,000	1.021E-07	2.803
0.00625	250,000	1.546E-07	3.523
0.00695	254,400	1.686E-07	3.688
0.0076	257,000	1.773E-07	3.842
0.00815	260,000	1.879E-07	3.957
0.00882	263,000	1.989E-07	4.098
0.00952	266,000	2.104E-07	4.239
0.01008	269,000	2.225E-07	4.347
0.01135	273,000	2.394E-07	4.582
0.01246	277,000	2.574E-07	4.775
0.01372	281,000	2.764E-07	4.992
0.01484	285,000	2.965E-07	5.169

TABLE D-3. SPECIMEN CIL-4 TEST DATA (a VS N) AND CRACK GROWTH RATE

polished notch prep						
σ_{max} = 18.85 ksi						
R = 0.1						
a (in)	a (in)		*da/dN* (in/cycle)		ΔK_{eff} (ksi (in)$^{1/2}$)	
Crack 1	Crack 3	Cycles	Crack 1	Crack 3	Crack 1	Crack 3
—	0.00094416	55,000	—	4.6883E-08		1.483
0.00094416	0.00149492	65,000	3.95073E-08	6.79438E-08	1.483	1.859
0.00149492	0.00257677	80,000	5.92149E-08	1.07754E-07	1.859	2.409
0.00271446	0.00365862	93,000	7.94113E-08	1.50546E-07	2.466	2.829
0.00271446	0.00420938	98,000	8.79445E-08	1.69115E-07	2.462	3.011
0.00352093	0.00542892	103,000	9.69011E-08	1.88878E-07	2.779	3.371
0.00352093	0.00597968	106,000	1.02478E-07	2.01314E-07	2.779	3.514
0.00365862	0.00664846	108,500	1.07241E-07	2.12011E-07	2.825	3.684
0.00407169	0.00733691	111,000	1.1211E-07	2.23014E-07	2.965	3.844
0.00420938	0.00828107	114,000	1.18091E-07	2.36622E-07	3.007	4.047
0.00515354	0.00922523	117,000	1.24223E-07	2.50675E-07	3.296	4.248
0.00584199	0.01030708	120,000	1.30507E-07	2.65174E-07	3.487	4.461
0.00611737	0.01221507	123,000	1.36941E-07	2.80123E-07	3.551	4.810
0.00637308	0.01315923	126,000	1.43526E-07	2.95524E-07	3.614	4.969
—	0.01614907	129,000	—	3.11379E-07		5.448

TABLE D-4. SPECIMEN CIL-14 TEST DATA (a VS N) AND CRACK GROWTH RATE

polished notch prep			
σ_{max} = 18.85 ksi			
R = 0.1			
a (in)	Cycles	*da/dN* (in/cycle)	ΔK_{eff} (ksi (in)$^{1/2}$)
0.00204568	120,000	1.31734E-07	2.160
0.00298984	123,000	1.54318E-07	2.577
0.00340291	129,000	2.09393E-07	2.735
0.00462245	132,000	2.42628E-07	3.139
0.00476014	135,000	2.80209E-07	3.178
0.00556661	138,000	3.22589E-07	3.406
0.00678615	141,000	3.70254E-07	3.714
0.00773031	144,000	4.23731E-07	3.932
0.01018906	147,000	4.83586E-07	4.437
0.01127091	148,000	5.05058E-07	4.638

TABLE D-5. SPECIMEN CIL-15 TEST DATA (a VS N) AND CRACK GROWTH RATE

polished notch prep			
σ_{max} = 18.85 ksi			
R = 0.1			
a (in)	Cycles	*da/dN* (in/cycle)	ΔK_{eff} (ksi (in)$^{1/2}$)
0.002046	65,000	1.20107E-07	2.160
0.00299	68,000	1.36287E-07	2.577
0.003521	75,000	1.79327E-07	2.779
0.00476	83,000	2.38197E-07	3.178
0.005291	86,000	2.63105E-07	3.332
0.006117	89,000	2.89627E-07	3.551
0.007199	92,000	3.1781E-07	3.811
0.007868	95,000	3.47698E-07	3.964
0.009501	98,000	3.79335E-07	4.301
0.013572	101,000	4.12765E-07	5.036
0.013848	106,000	4.72585E-07	5.078
0.016011	109,000	5.11011E-07	5.425

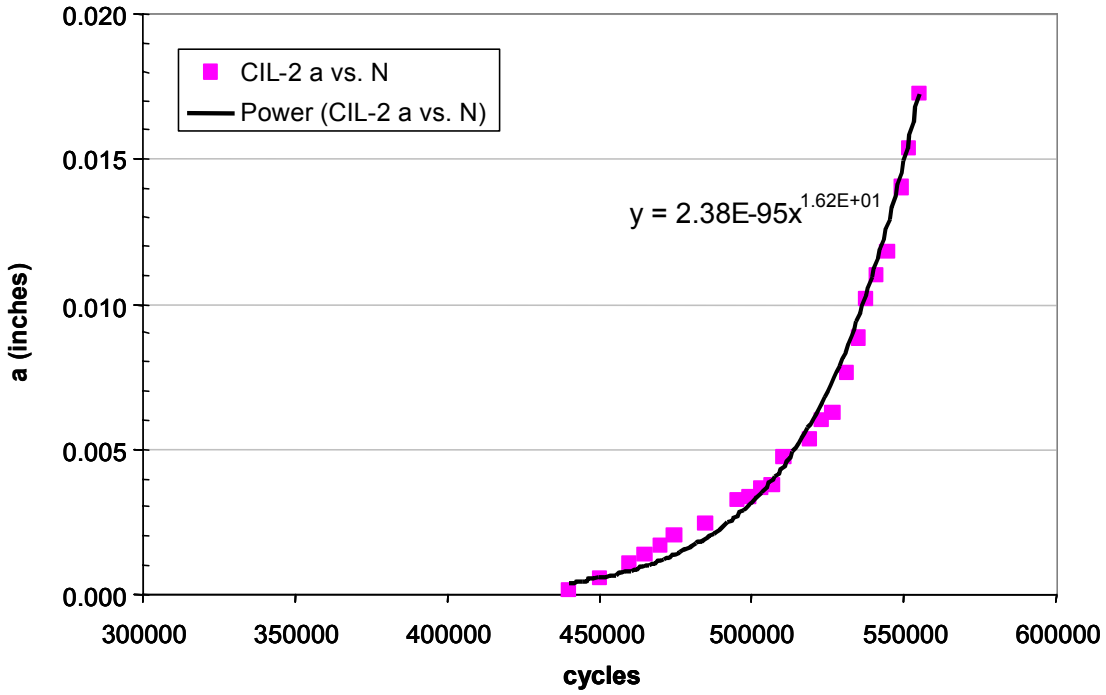


FIGURE D-5. CIL-2 CRACK GROWTH TEST DATA (SYMBOLS) AND TRENDLINE (CURVE)

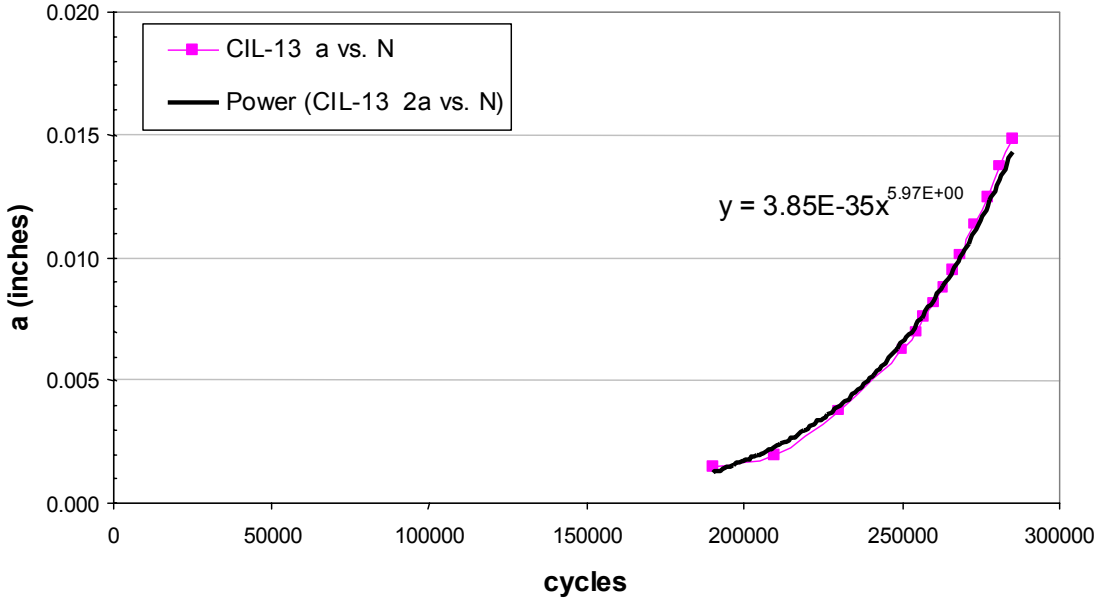


FIGURE D-6. CIL-13 CRACK GROWTH TEST DATA (SYMBOLS) AND TRENDLINE (CURVE)

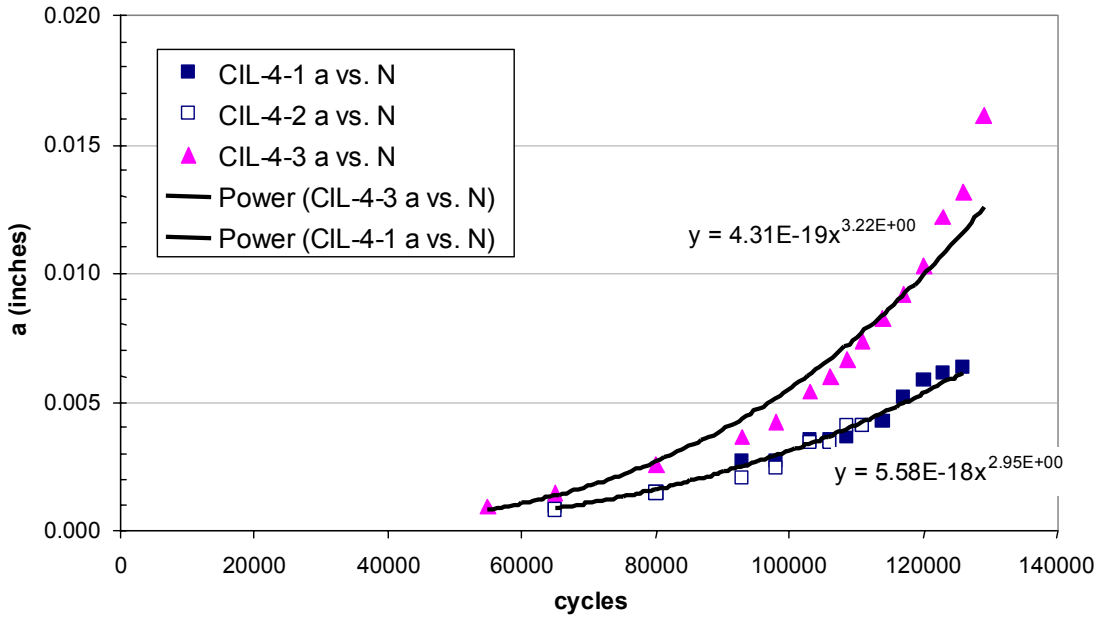


FIGURE D-7. CIL-4 CRACK GROWTH TEST DATA (SYMBOLS) AND TRENDLINE (CURVES)

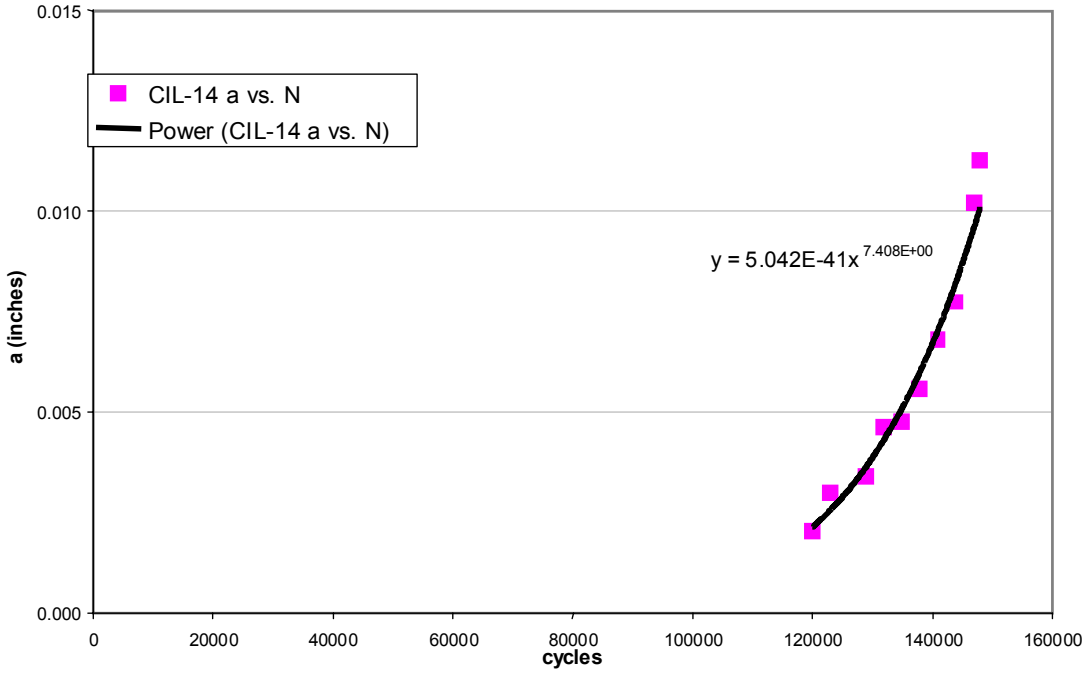


FIGURE D-8. CIL-14 CRACK GROWTH TEST DATA (SYMBOLS) AND TRENDLINE (CURVE)

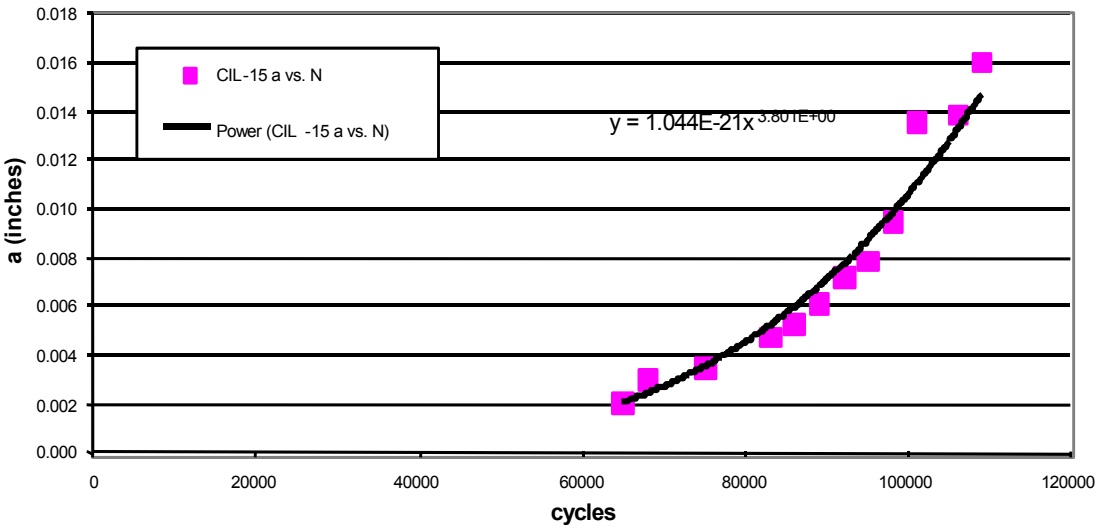


FIGURE D-9. CIL-15 CRACK GROWTH TEST DATA (SYMBOLS) AND TRENDLINE (CURVE)

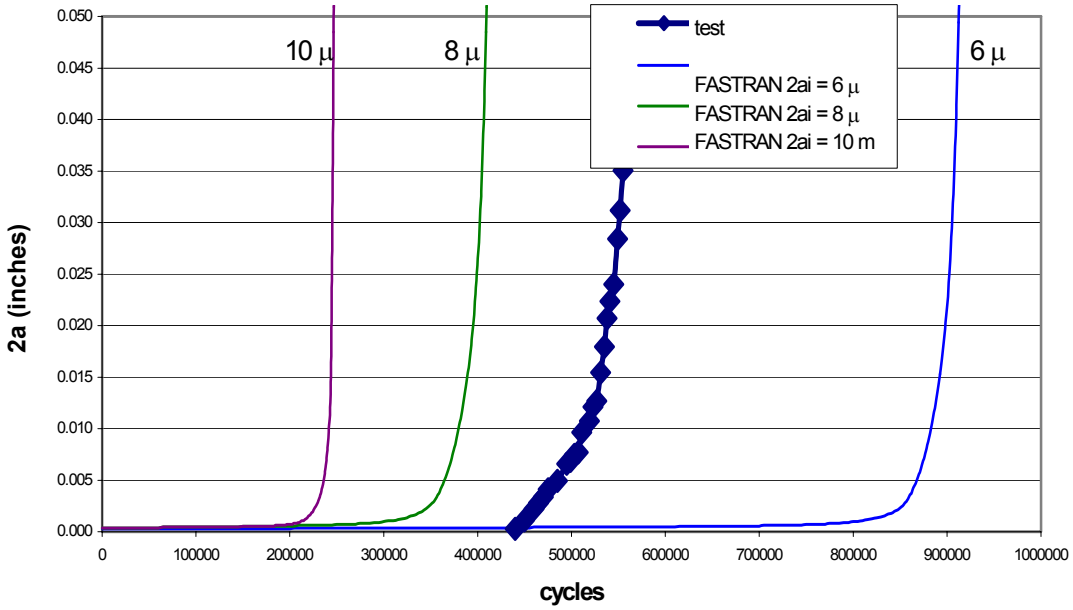


FIGURE D-10. CIL-2 TEST DATA VS FASTRAN FOR DIFFERENT INITIAL FLAW SIZES

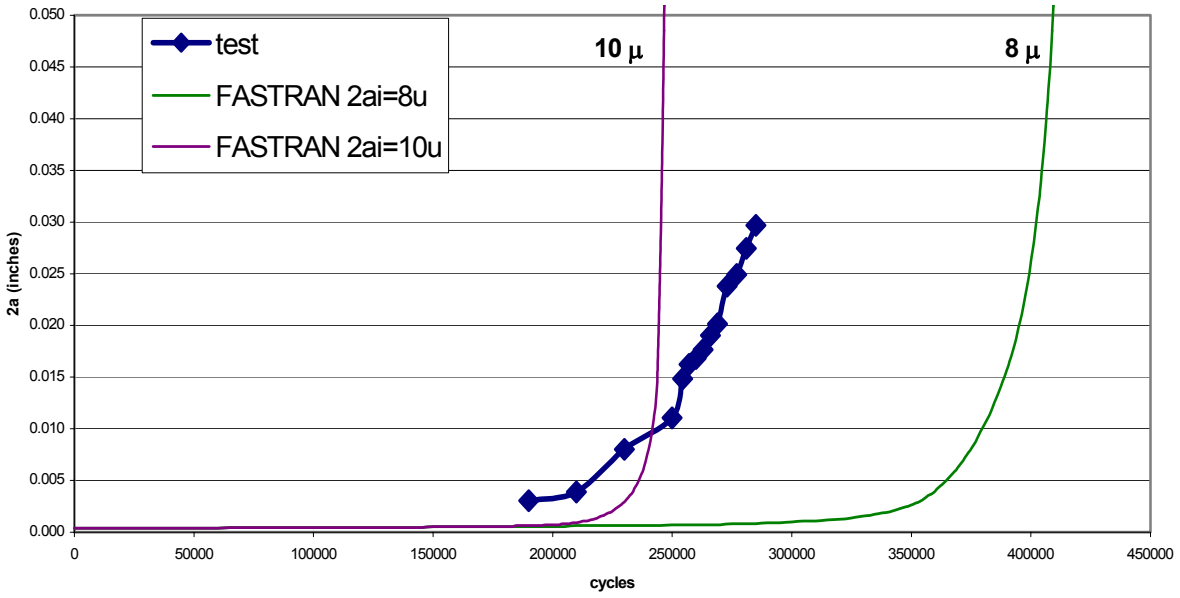


FIGURE D-11. CIL-13 TEST DATA VS FASTRAN

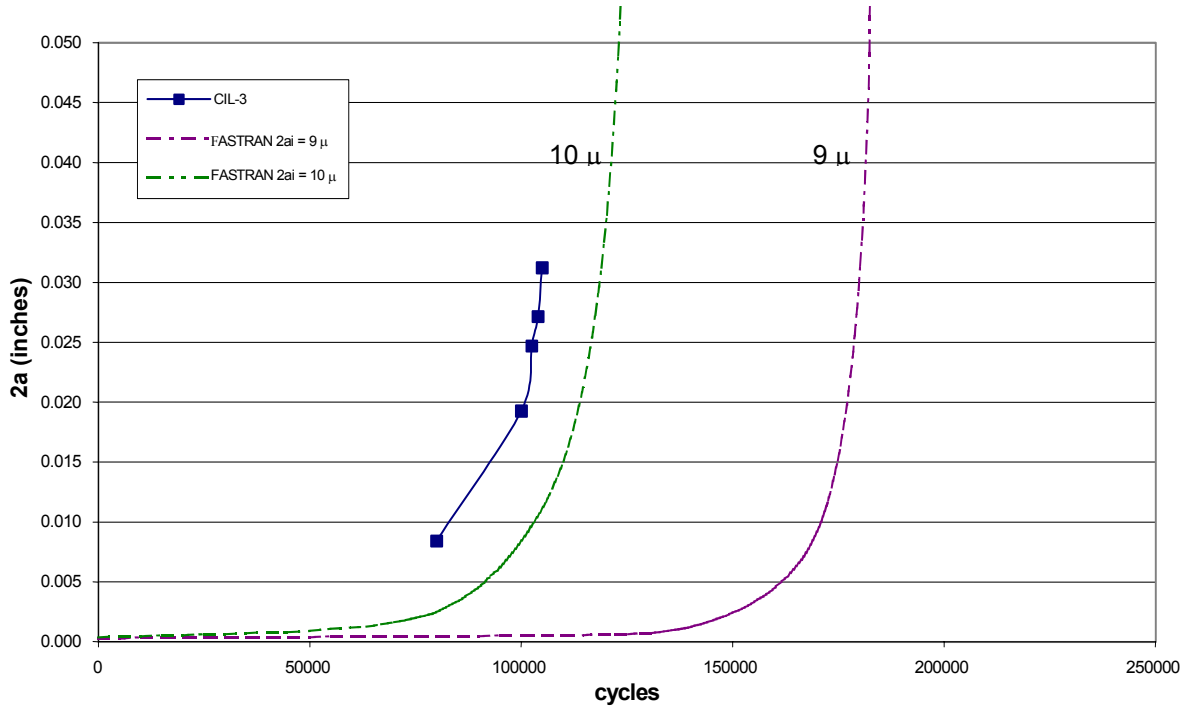


FIGURE D-12. CIL-3 TEST DATA VS FASTRAN

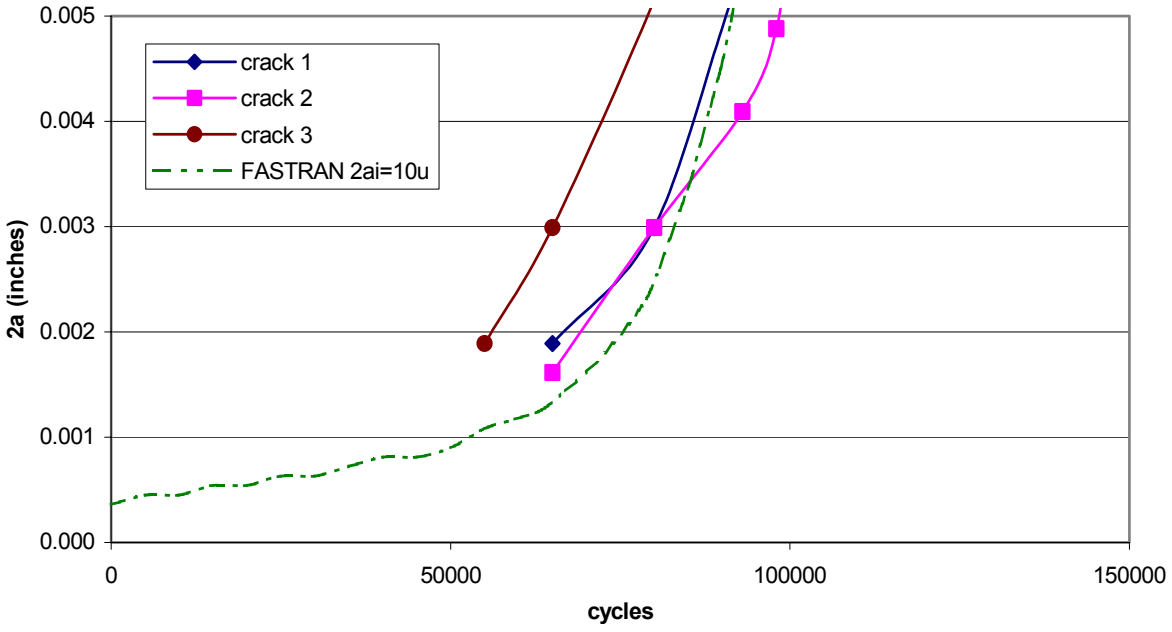


FIGURE D-13. CIL-4: CRACK GROWTH TO 0.005″

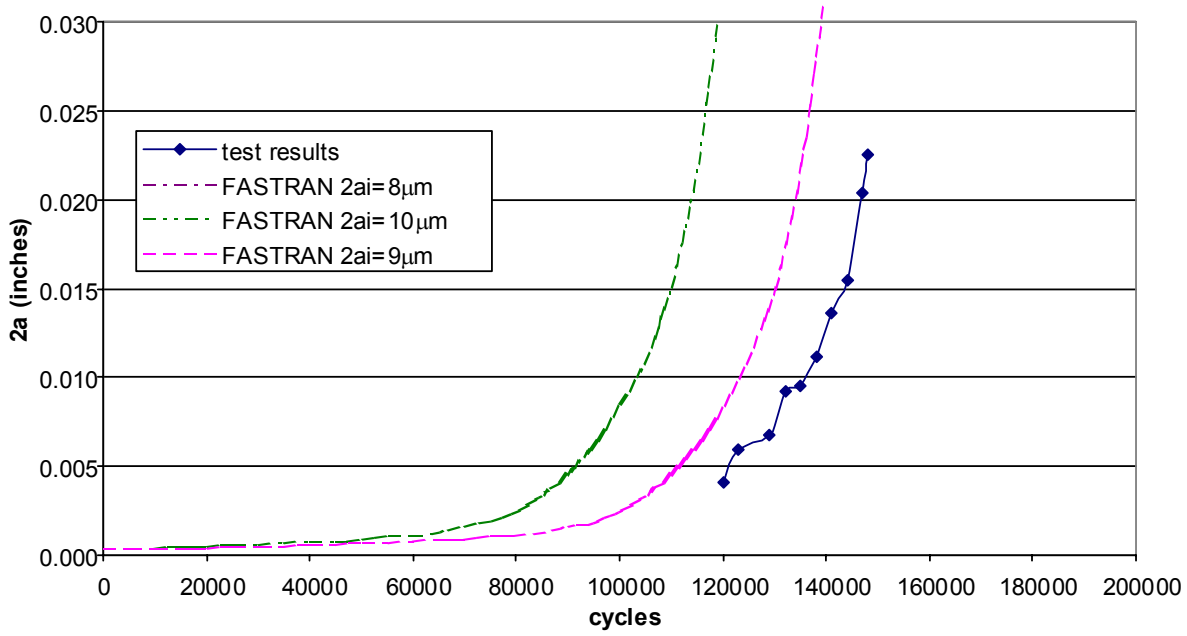


FIGURE D-14. CIL-14 TEST DATA VS FASTRAN

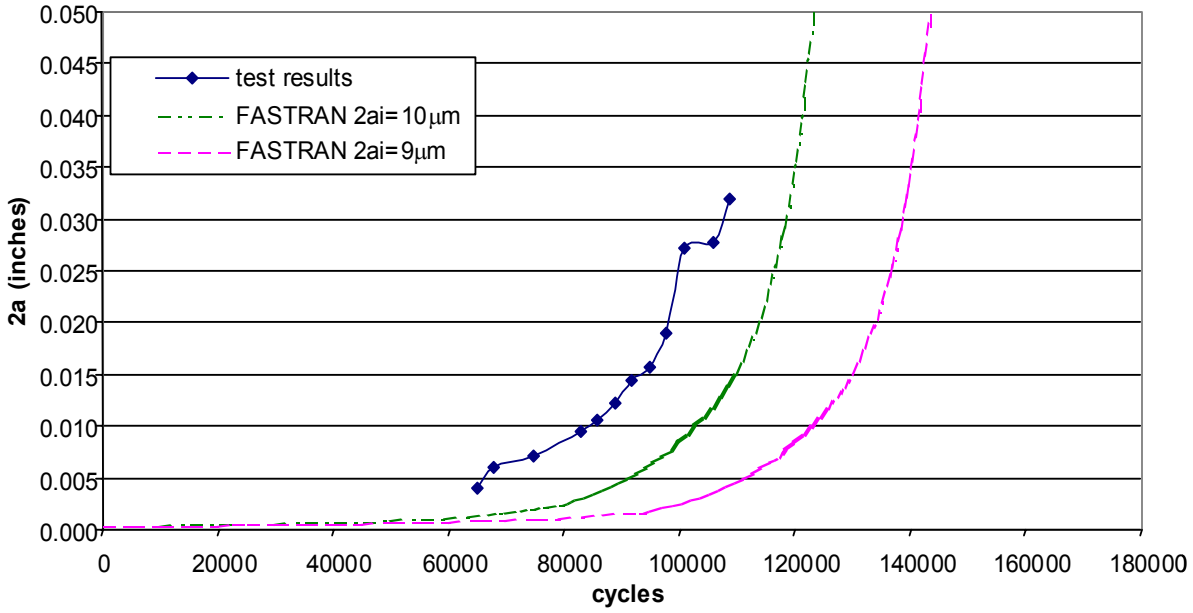


FIGURE D-15. CIL-15 TEST DATA VS FASTRAN

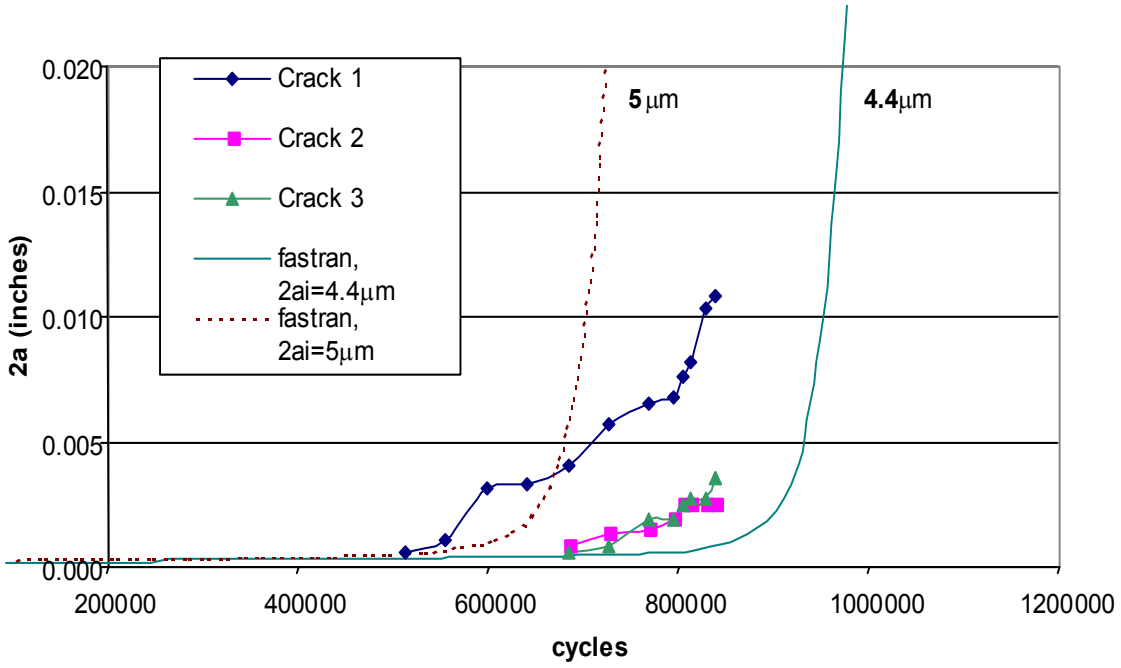


FIGURE D-16. CIL-18 TEST DATA VS FASTRAN (SPECTRUM, POLISHED NOTCH)

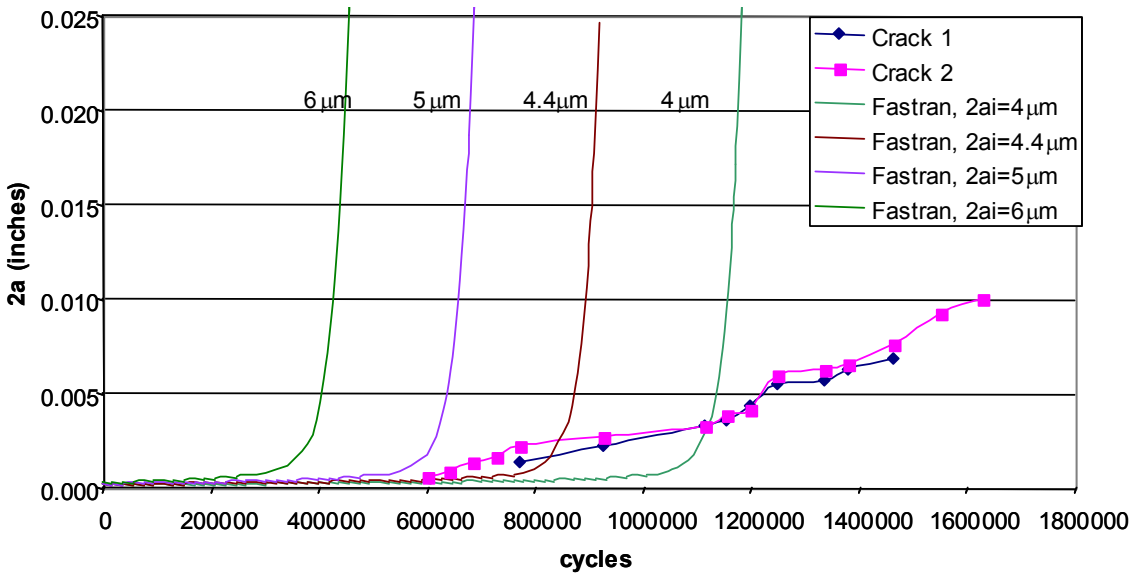


FIGURE D-17. CIL-23 TEST VS FASTRAN (SPECTRUM, POLISHED NOTCH)

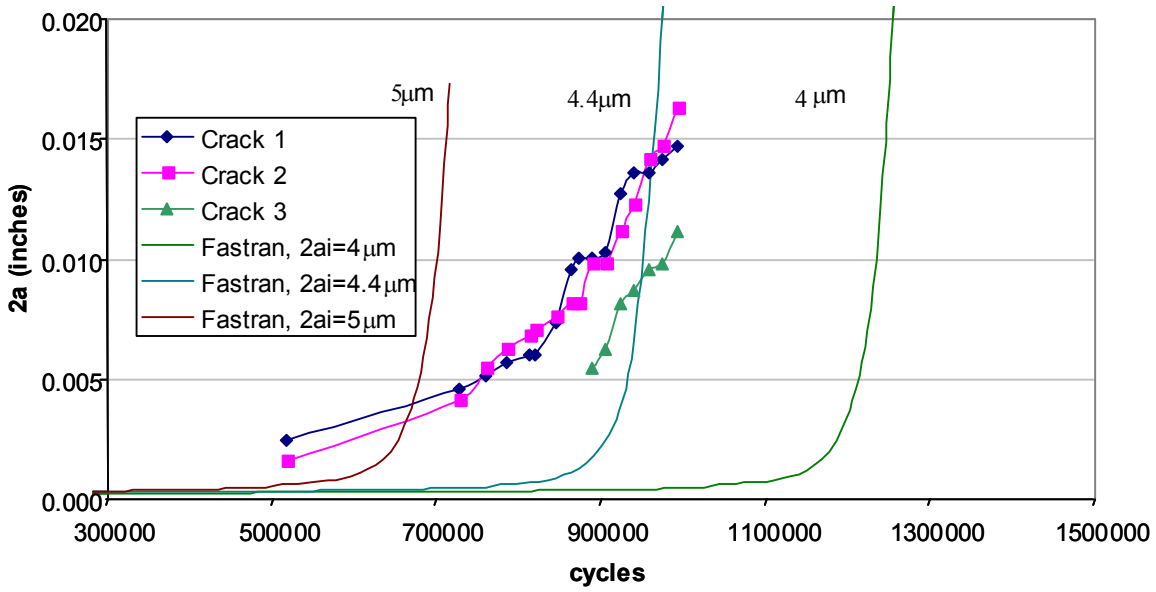


FIGURE D-18. CIL-9 TEST VS FASTRAN (SPECTRUM, PRODUCTION NOTCH)

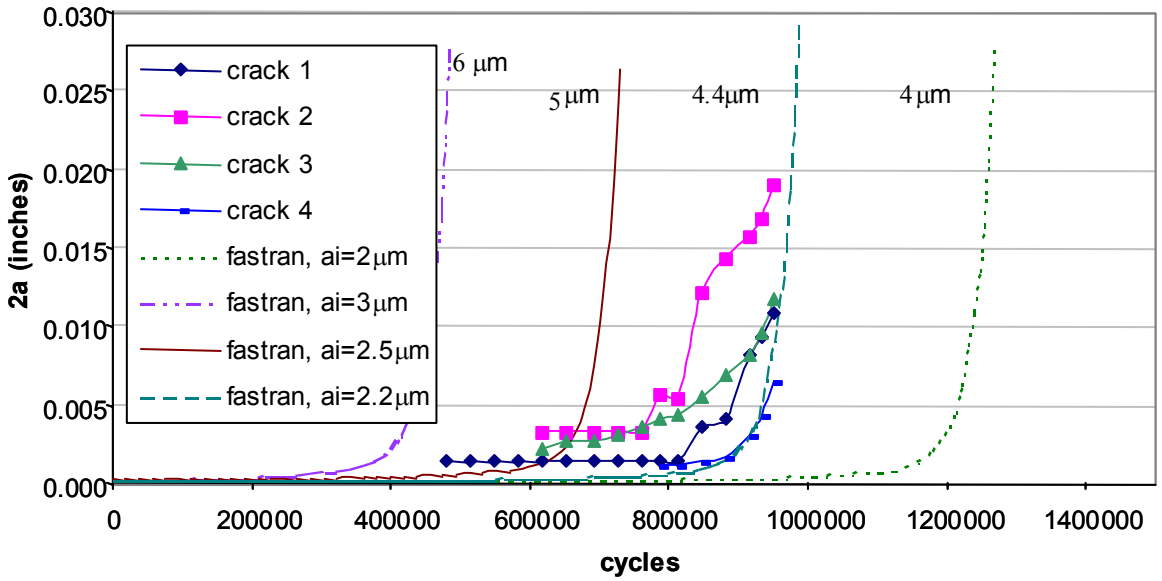


FIGURE D-19. CIL-10 TEST VS FASTRAN (SPECTRUM, PRODUCTION NOTCH)

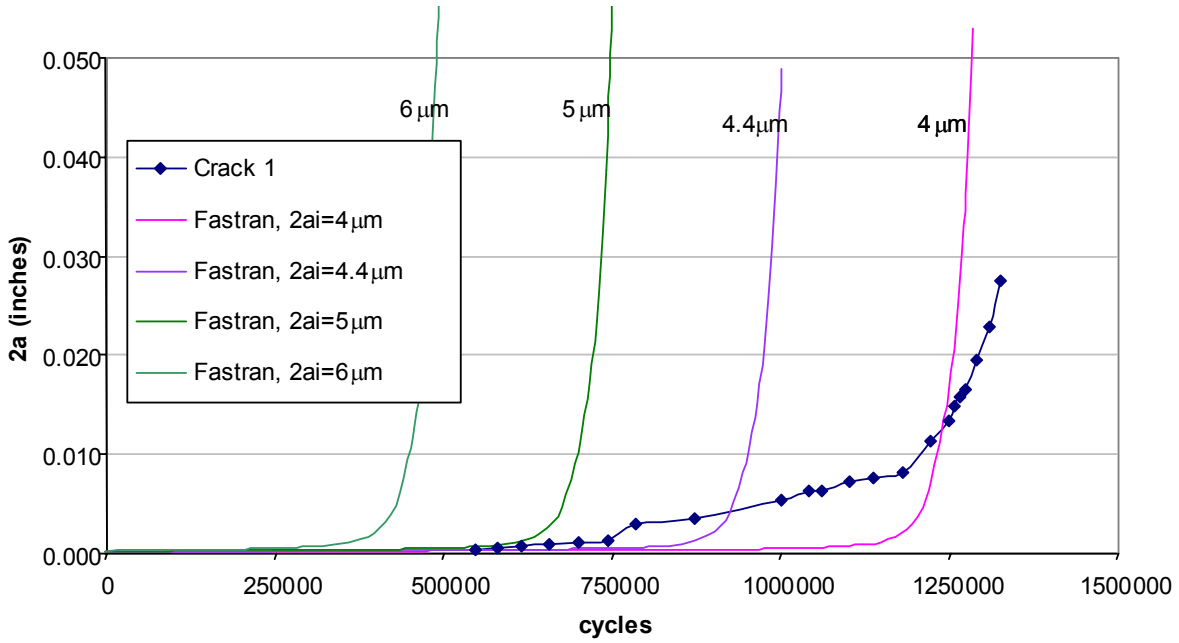


FIGURE D-20. CIL-21 TEST VS FASTRAN (SPECTRUM, PRODUCTION NOTCH)

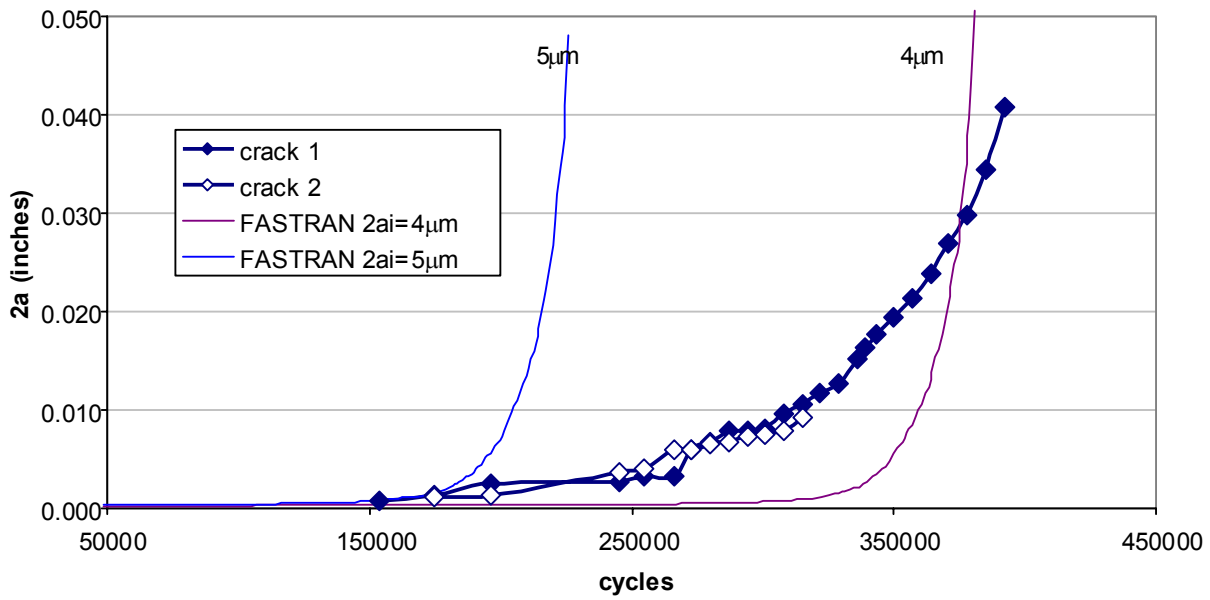


FIGURE D-21. CIL-37 TEST VS FASTRAN, σ_{max} = 21.03 ksi (OVERLOAD MARKERS)

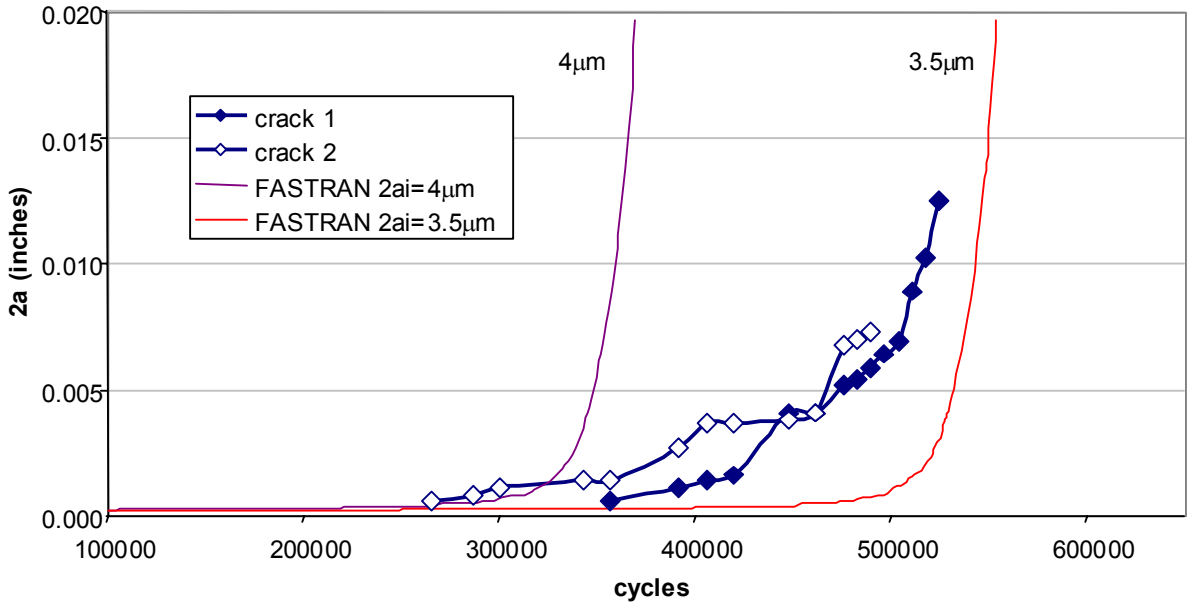


FIGURE D-22. CIL-38 TEST VS FASTRAN, σ_{max} = 21.03 ksi (OVERLOAD MARKERS)

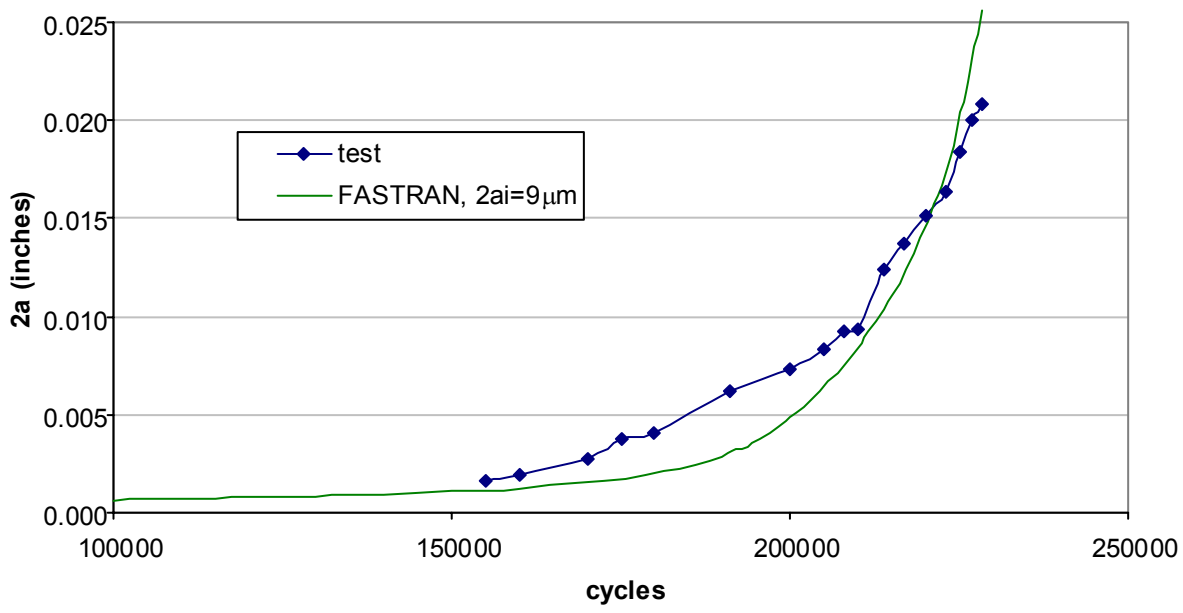


FIGURE D-23. CIL-31 TEST VS FASTRAN (CA, σ_{max} = 26 ksi, R = 0.5)

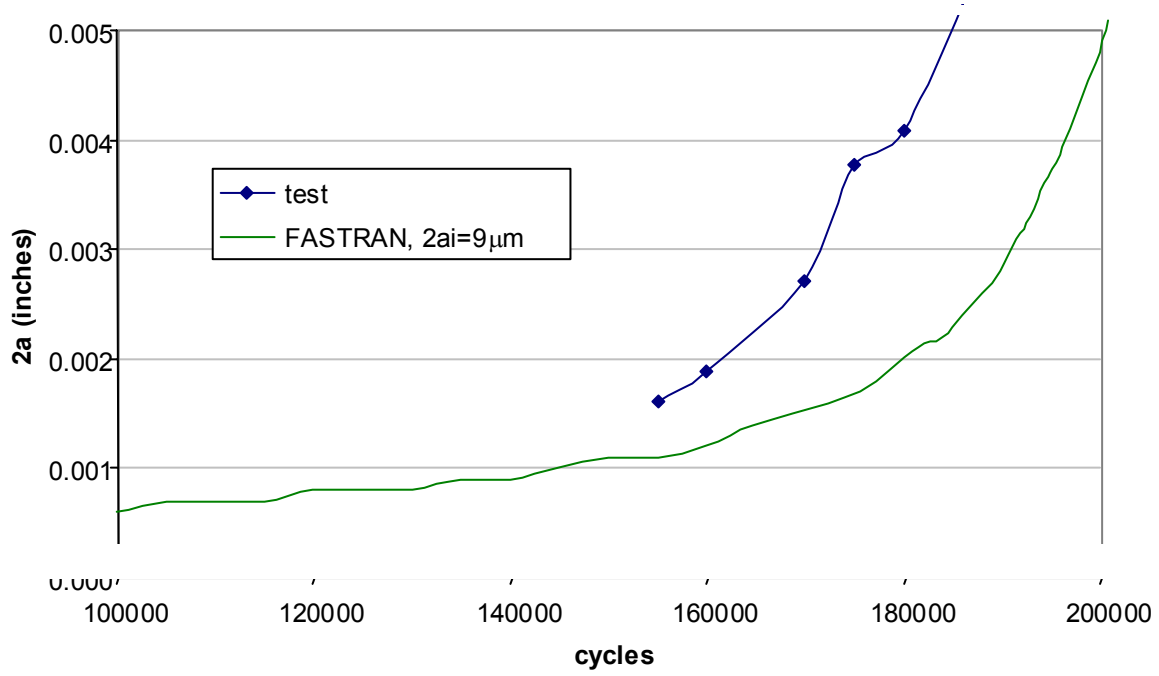


FIGURE D-24. CIL-31 TEST VS FASTRAN AT SMALL CRACK SIZE

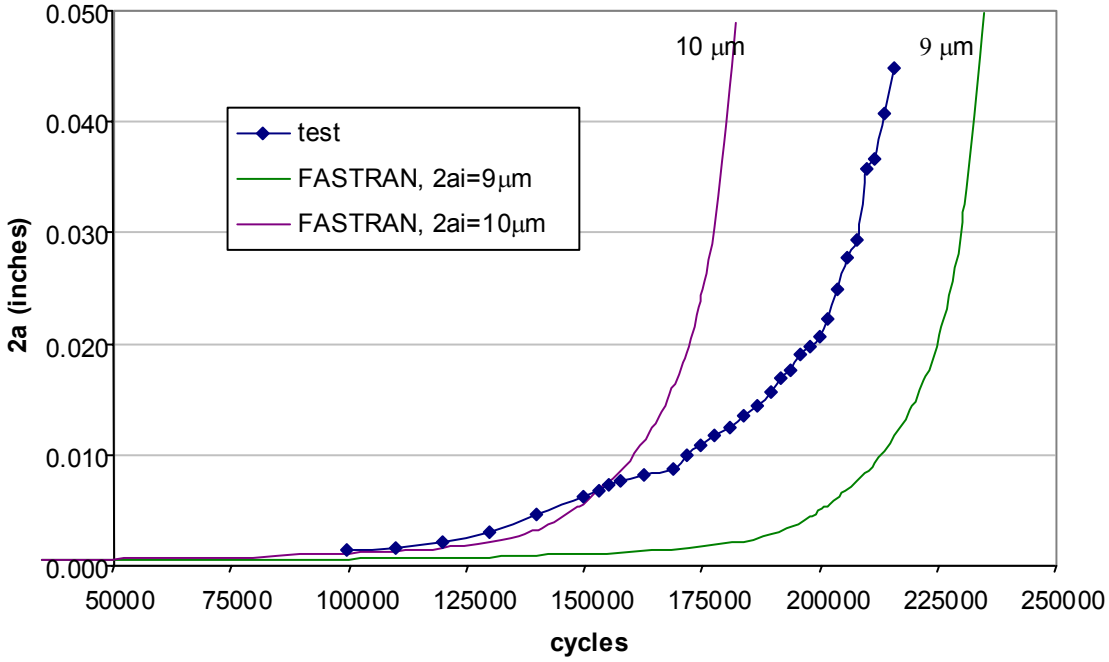


FIGURE D-25. CIL-32 TEST VS FASTRAN (CA, σ_{max} = 26 ksi, R = 0.5)

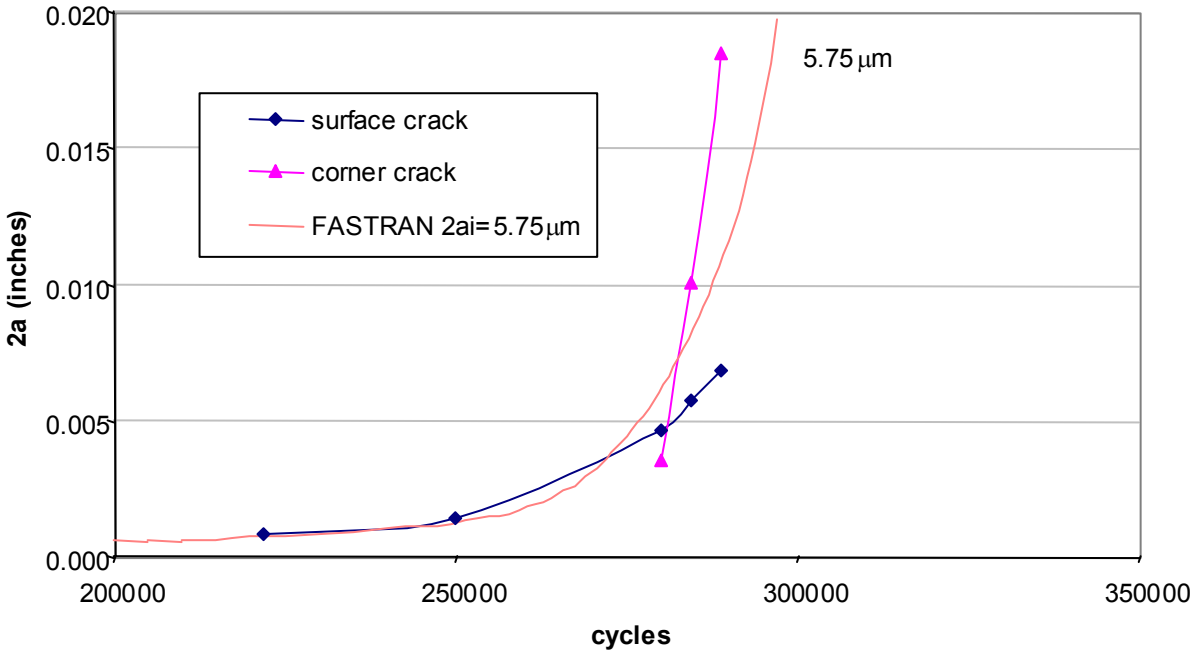


FIGURE D-26. CIL-34 TEST VS FASTRAN (CA, σ_{max} = 19.6 ksi, R = 0.1)

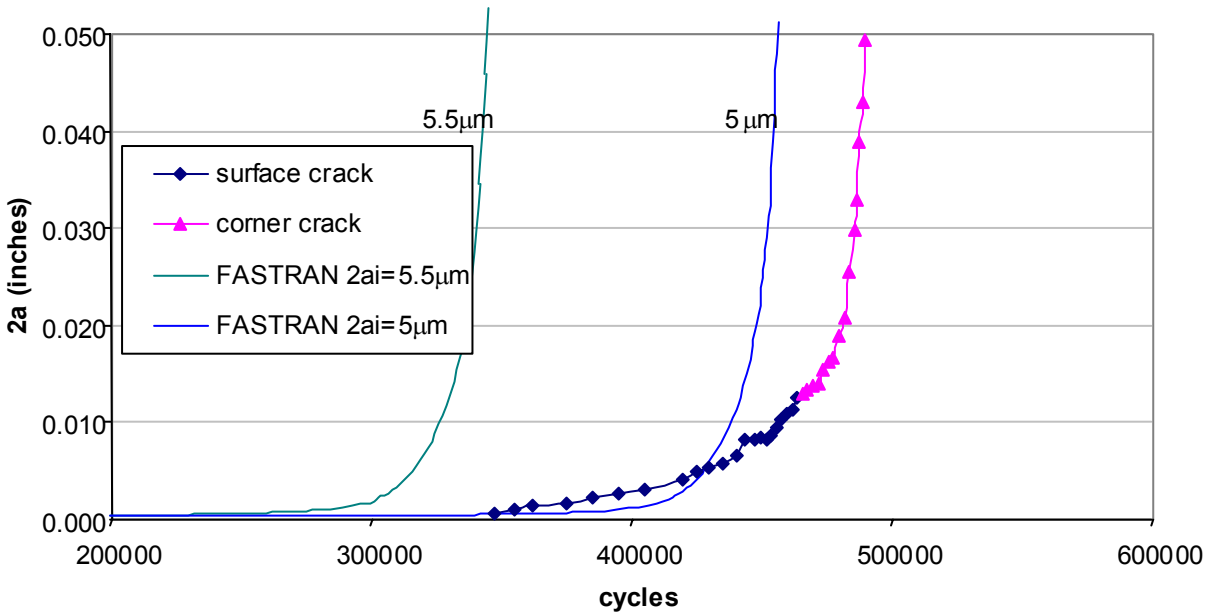


FIGURE D-27. CIL-39 TEST VS FASTRAN (CA, σ_{max} =19.6 ksi, R = 0.1)

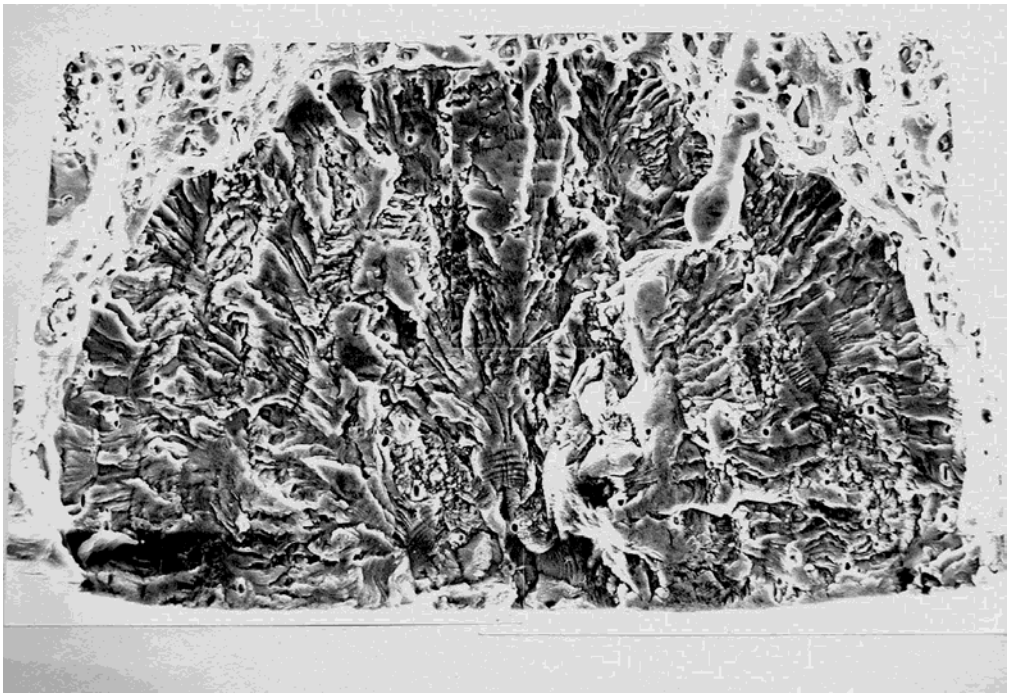


FIGURE D-28. PHOTOGRAPH OF CIL-18 CRACK

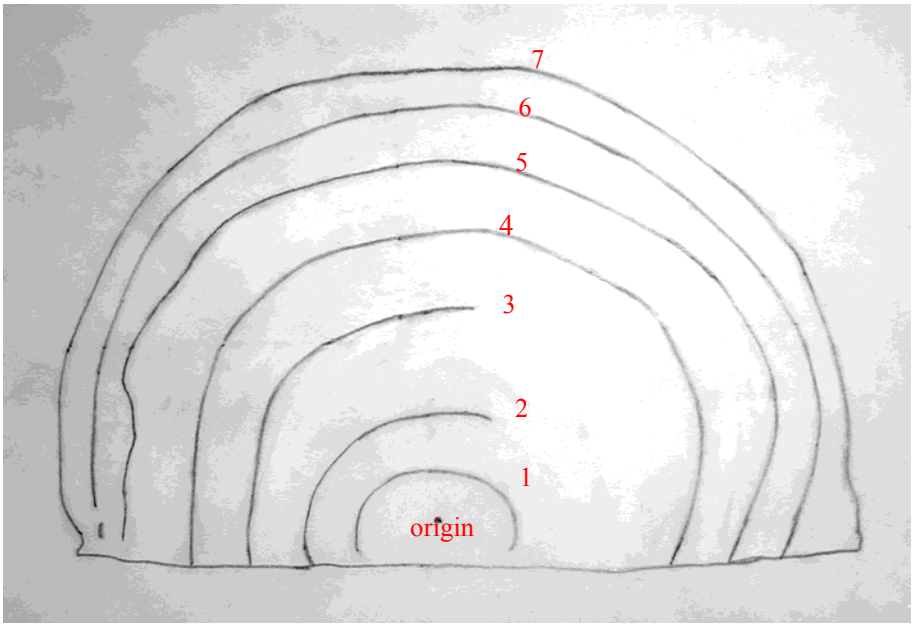


FIGURE D-29. TRACING OF THE BEACH MARKS ON CIL-18 CRACK

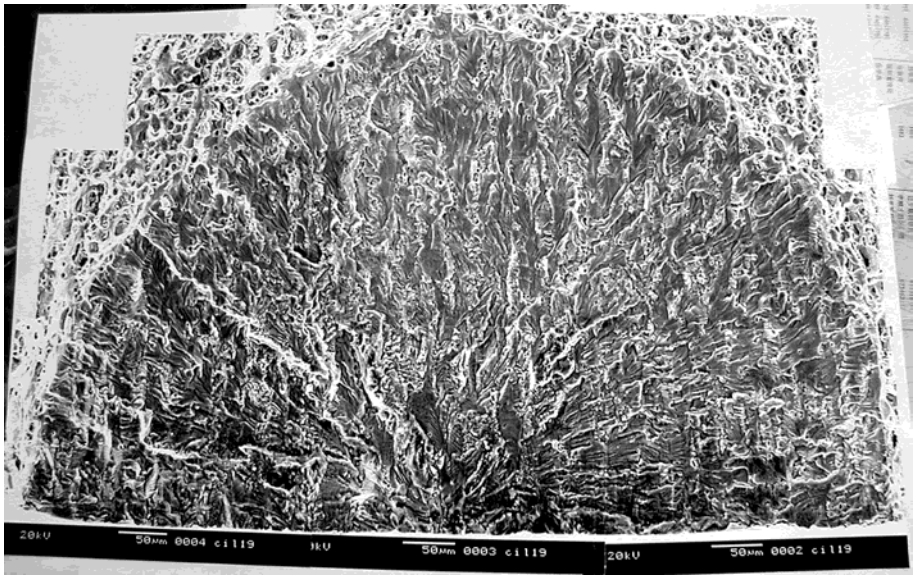


FIGURE D-30. PHOTOGRAPH OF CIL-19 CRACK

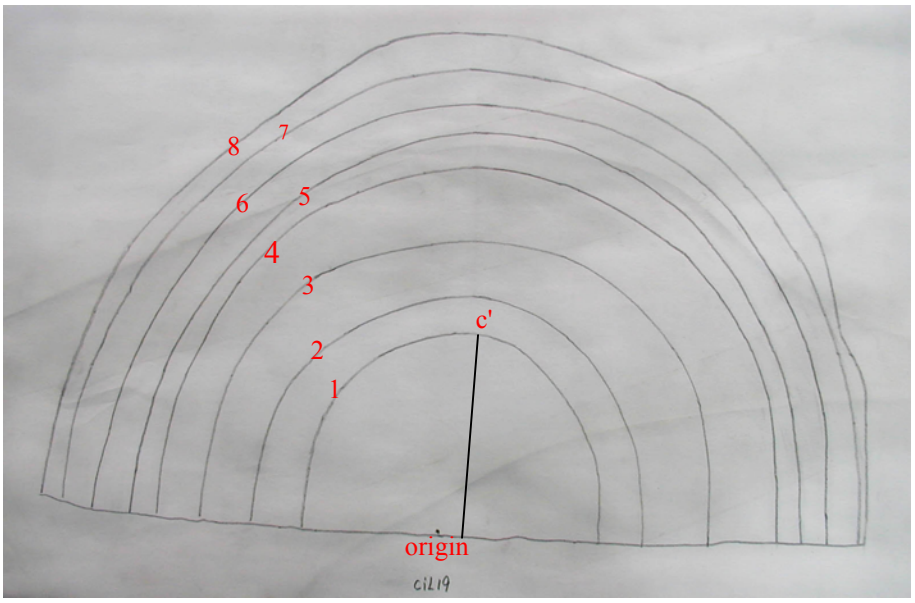


FIGURE D-31. TRACING OF THE BEACH MARKS ON CIL-19 CRACK

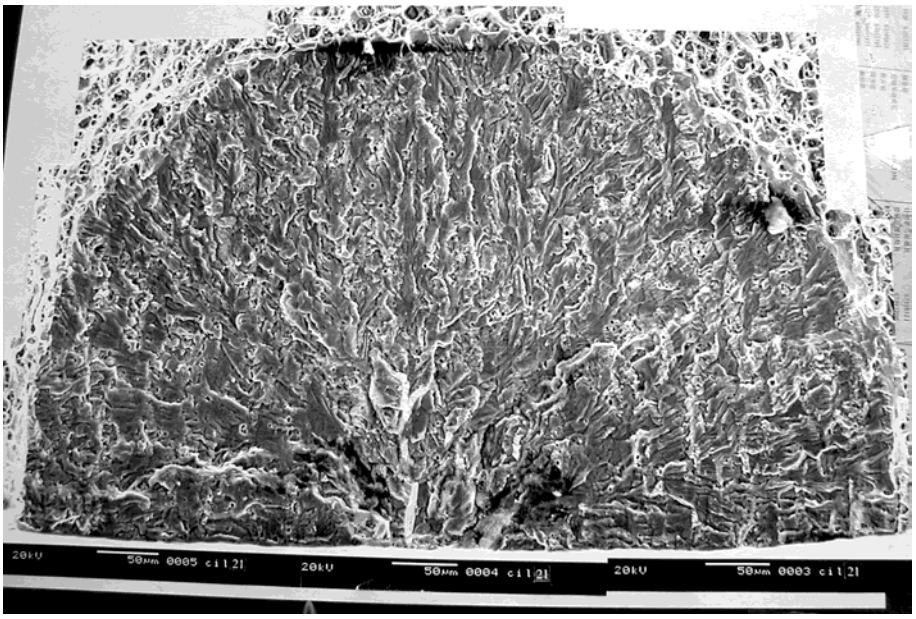


FIGURE D-32. PHOTOGRAPH OF CIL-21 CRACK

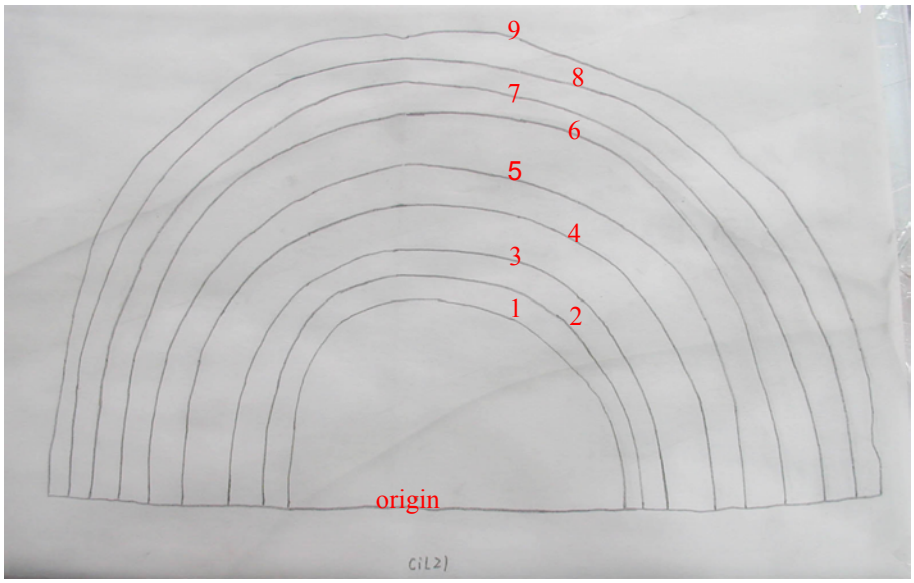


FIGURE D-33. TRACING OF THE BEACH MARKS ON CIL-21 CRACK

TABLE D-6. SEM CRACK SHAPE DATA FOR CIL-9

CIL-9 Production quality notch, 0.1-inch-thick specimen, spectrum c= crack depth; a= half crack length; t= half thickness						
	c (microns)	a (microns)	c (in)	a (in)	c/a	a/t
Crack 1	102	60	0.004013	0.00236	1.176	0.020
	150	77	0.005901	0.003029	1.027	0.030
	194	97	0.007632	0.003816	1.000	0.038
	244	116	0.009599	0.004563	0.951	0.048
	302	145	0.011881	0.005704	0.960	0.059
	172	171	0.006766	0.006727	1.988	0.034
	198	210	0.007789	0.008261	2.121	0.039
Crack 2	69	84	0.002714	0.003305	1.217	0.027
	99	114	0.003895	0.004485	1.152	0.039
	122	143	0.004799	0.005626	1.172	0.048
	146	172	0.005744	0.006766	1.178	0.057
	172	199	0.006766	0.007829	1.157	0.068
	204	224	0.008025	0.008812	1.098	0.080
	224	248	0.008812	0.009756	1.107	0.088

TABLE D-7. SEM CRACK SHAPE DATA FOR CIL-10

CIL-10 Production notch 0.1-inch-thick specimen, spectrum loads c= crack depth; a= half crack length; t= half thickness					
c (microns)	a (microns)	c (in)	a (in)	c/a	a/t
103.3	116.7	0.004064	0.004591	1.130	0.041
185	186.6	0.007278	0.007341	1.009	0.073
250	243.3	0.009835	0.009571	0.973	0.098
316.6	310	0.012455	0.012195	0.979	0.125
375	370	0.014753	0.014556	0.987	0.148
416.6	423.3	0.016389	0.016653	1.016	0.164

TABLE D-8. SEM CRACK SHAPE DATA FOR CIL-21

CIL-21 Production notch, 0.1-inch-thick specimen, spectrum loads c= crack depth; a= half crack length; t= half thickness					
c (microns)	a (microns)	c (in)	a (in)	c/a	a/t
166	137.5	0.00653	0.005409	1.207	0.108
186	155	0.007317	0.006098	1.200	0.122
210	180	0.008261	0.007081	1.167	0.142
250	220	0.009835	0.008655	1.136	0.173
286	246.5	0.011251	0.009697	1.160	0.194
334	277	0.01314	0.010897	1.206	0.218
366	307.5	0.014398	0.012097	1.190	0.242
389	331	0.015303	0.013022	1.175	0.261
415	351	0.016326	0.013808	1.182	0.276

TABLE D-9. SEM CRACK SHAPE DATA FOR CIL-18

CIL-18 Polished notch 0.1-inch-thick specimen, spectrum loads c= crack depth; a= half crack length; t= half thickness					
c (microns)	a (microns)	c (in)	a (in)	c/a	a/t
18.50	29.25	0.000728	0.001151	0.632	0.023
40.00	48.80	0.001574	0.00192	0.820	0.038
78.40	70.30	0.003084	0.002766	1.115	0.055
108.00	92.15	0.004249	0.003625	1.172	0.073
135.40	116.20	0.005327	0.004571	1.165	0.091
156.90	130.60	0.006172	0.005138	1.201	0.103
170.90	145.40	0.006723	0.00572	1.175	0.114

TABLE D-10. SEM CRACK SHAPE DATA FOR CIL-19

CIL-19 Polished notch, 0.1-inch-thick specimen, spectrum loads a = half the crack length c = the crack depth c' = the perpendicular distance between origin and highest point in beach mark t = half thickness								
c (μm)	a (μm)	c (in)	a (in)	c/a	a/t	c' (μm)	c' (in)	c'/a
197.5	149.5	0.00777	0.005881	1.321	0.118	205	0.008065	1.371
235	198	0.009245	0.007789	1.187	0.156	237.5	0.009343	1.199
292.5	259.5	0.011507	0.010209	1.127	0.204	296.3	0.011656	1.142
372.5	318	0.014654	0.01251	1.171	0.250	375	0.014753	1.179
410	345	0.016129	0.013572	1.188	0.272	415	0.016326	1.203
442.5	379.5	0.017408	0.01493	1.166	0.299	447.5	0.017605	1.179
481	411.5	0.018923	0.016188	1.169	0.324	485	0.01908	1.179
525	427.5	0.020654	0.016818	1.228	0.337	526	0.020693	1.230

TABLE D-11. SEM CRACK SHAPE DATA FOR CIL-23

CIL-23 Polished notch 0.09-inch-thick specimen, spectrum loads c= crack depth; a= half crack length; t= half thickness					
c (microns)	a (microns)	c (in)	a (in)	c/a	a/t
185	172.5	0.007278	0.006786	0.932	0.073
252.5	232.5	0.009933	0.009147	0.921	0.099
322.5	300	0.012687	0.011802	0.930	0.127
430	400	0.016916	0.015736	0.930	0.169
575	540	0.022621	0.021244	0.939	0.226
712.5	667.5	0.02803	0.026259	0.937	0.281
875	825	0.034423	0.032456	0.943	0.344
1112.5	1020	0.043766	0.040127	0.917	0.438
1300	1172.5	0.051142	0.046126	0.902	0.512

TABLE D-12. SEM CRACK SHAPE DATA FOR CIL-37

CIL-37 Production notch 0.1-inch-thick specimen, constant amplitude with overload marker cycles c= crack depth; a= half crack length; t= half thickness						
	c (microns)	a (microns)	c (in)	a (in)	c/a	a/t
Crack 1	308	420	0.012117	0.016523	1.364	0.121
	404	500	0.015893	0.01967	1.238	0.159
	492	584	0.019355	0.022975	1.187	0.194
	604	678	0.023761	0.026673	1.123	0.238
	700	756	0.027538	0.029741	1.080	0.276
Crack 2	316	384	0.012431	0.015107	1.215	0.124
	388	438	0.015264	0.017231	1.129	0.153
	488	520	0.019198	0.020457	1.066	0.192
	608	612	0.023919	0.024076	1.007	0.239
	668	672	0.026279	0.026436	1.006	0.263

TABLE D-13. SEM CRACK SHAPE DATA FOR CIL-38

CIL-38	Production notch 0.1-inch-thick specimen, constant amplitude with overload marker cycles c= crack depth; a= half crack length; t= half thickness					
	c (microns)	a (microns)	c (in)	a (in)	c/a	a/t
Crack 1	111.5	105.8	0.004386	0.004162	0.949	0.044
	165.9	145.9	0.006527	0.00574	0.879	0.065
	210.2	188.7	0.008269	0.007423	0.898	0.083
	248.8	236	0.009788	0.009284	0.949	0.098
Crack 2	156.7	206.6	0.006165	0.008128	1.318	0.062
	203.3	253.3	0.007998	0.009965	1.246	0.080
	260	293.3	0.010228	0.011538	1.128	0.102
	336.6	346.6	0.013242	0.013635	1.030	0.133
	383.3	380	0.015079	0.014949	0.991	0.151
	445.6	421.6	0.01753	0.016586	0.946	0.175
	511.6	456.6	0.020126	0.017963	0.892	0.201

TABLE D-14. SEM CRACK SHAPE DATA FOR CIL-40

CIL-40	Polished notch 0.1-inch-thick specimen, constant amplitude with overload marker cycles c= crack depth; a= half crack length; t= half thickness					
	c (microns)	a (microns)	c (in)	a (in)	c/a	a/t
Crack 1	75.7	145.7	0.002978	0.005732	1.925	0.030
	128.6	188.6	0.005059	0.00742	1.467	0.051
	174.3	230	0.006857	0.009048	1.320	0.069
	194.3	265.7	0.007644	0.010453	1.367	0.076
Crack 2	127.1	165.7	0.005	0.006519	1.304	0.050
	177.1	197.1	0.006967	0.007754	1.113	0.070
	237.1	250	0.009328	0.009835	1.054	0.093
	282.8	287.1	0.011125	0.011295	1.015	0.111
	314.3	331.4	0.012365	0.013037	1.054	0.124

TABLE D-15. CRACK GROWTH DATA FOR CIL-2, CONSTANT AMPLITUDE

polished notch prep	
σ_{max} = 17 ksi	
R = 0.1	
Cycles	Crack Length, 2a (in)
440,000	0.00027538
450,000	0.00110152
460,000	0.00220304
465,000	0.0027538
470,000	0.00330456
475,000	0.00405202
485,000	0.00487816
495,000	0.0064911
499,000	0.00676648
503,000	0.00731724
507,000	0.00759262
511,000	0.00948094
519,000	0.01058246
523,000	0.01192002
527,000	0.01247078
531,000	0.01518524
535,000	0.01766366
538,000	0.02037812
541,000	0.02199106
545,000	0.023604
549,000	0.02797074
552,000	0.0306852
555,000	0.03446184

TABLE D-16. CRACK GROWTH DATA FOR CIL-13, CONSTANT AMPLITUDE

polished notch prep	
σ_{max} = 17 ksi	
R = 0.1	
Cycles	Crack Length, 2a (in)
190,000	0.00299
210,000	0.003816
230,000	0.007868
250,000	0.010858
254,400	0.014595
257,000	0.015972
260,000	0.016523
263,000	0.017349
266,000	0.018726
269,000	0.019827
273,000	0.023407
277,000	0.024509
281,000	0.026987
285,000	0.02919
288,000	(rejected)
290,000	(rejected)

TABLE D-17. CRACK GROWTH DATA FOR CIL-3, CONSTANT AMPLITUDE

polished notch prep	
σ_{max} = 19.6 ksi	
R = 0.1	
Cycles	2a (in)
80,000	0.008419
100,000	0.019277
102,500	0.024706
104,000	0.027145
105,000	0.031236

TABLE D-18. CRACK GROWTH DATA FOR CIL-4, CONSTANT AMPLITUDE

polished notch prep			
σ_{max} = 18.9 ksi			
R = 0.1			
	Crack Length, 2a (in)		
Cycles	Crack 1	Crack 2	Crack 3
55,000			0.001888
65,000	0.001888	0.001613	0.00299
80,000	0.00299	0.00299	0.005154
93,000	0.005429	0.004091	0.007317
98,000	0.005429	0.004878	0.008419
103,000	0.007042	0.006806	0.010858
106,000	0.007042	0.006806	0.011959
108,500	0.007317	0.008143	0.013297
111,000	0.008143	0.008143	0.014674
114,000	0.008419	(invalid)	0.016562
117,000	0.010307	(invalid)	0.01845
120,000	0.011684	(invalid)	0.020614
123,000	0.012235	(invalid)	0.02443
126,000	0.012746	(invalid)	0.026318
(invalid)	(invalid)	(invalid)	0.032298

TABLE D-19. CRACK GROWTH DATA FOR CIL-14, CONSTANT AMPLITUDE

polished notch prep	
σ_{max} = 18.9 ksi	
R = 0.1	
Cycles	Crack Length, 2a (in)
120,000	0.004091
123,000	0.00598
129,000	0.006806
132,000	0.009245
135,000	0.00952
138,000	0.011133
141,000	0.013572
144,000	0.015461
147,000	0.020378
148,000	0.022542

TABLE D-20. CRACK GROWTH DATA FOR CIL-15, CONSTANT AMPLITUDE

polished notch prep	
σ_{max} = 18.9 ksi	
R = 0.1	
Cycles	Crack Length, 2a (in)
65,000	0.004091
68,000	0.00598
75,000	0.007042
83,000	0.00952
86,000	0.010582
89,000	0.012235
92,000	0.014398
95,000	0.015736
98,000	0.019001
101,000	0.027145
106,000	0.027695
109,000	0.032023

TABLE D-21. CRACK GROWTH DATA FOR CIL-9, SPECTRUM LOADING

production notch prep			
σ_{max} = 26.6 ksi			
	Crack Length, 2a (in)		
Cycles	Crack 1	Crack 2	Crack 3
518,296	0.002439	0.001613	
728,110	0.004603	0.004091	
762,374	0.005154	0.005429	
788,072	0.005704	0.006255	
813,770	0.00598	0.006806	
822,336	0.00598	0.007042	
848,034	0.007317	0.007593	
865,166	0.00952	0.008143	
873,732	0.010032	0.008143	
890,864	0.010032	0.009756	0.005429
907,996	0.010307	0.009756	0.006255
925,128	0.012746	0.011133	0.008143
942,260	0.013572	0.012235	0.008694
959,392	0.013572	0.014123	0.00952
976,524	0.014123	0.014674	0.009756
993,656	0.014674	0.016287	0.011133

TABLE D-22. CRACK GROWTH DATA FOR CIL-10, SPECTRUM LOADING

production notch prep				
σ_{max} = 26.6 ksi				
	Crack Length, 2a (in)			
Cycles	Crack 1	Crack 2	Crack 3	Crack 4
479,696	0.001377			
513,960	0.001377			
548,224	0.001377			
582,488	0.001377			
616,752	0.001377	0.003265	0.002164	
651,016	0.001377	0.003265	0.002714	
693,846	0.001377	0.003265	0.002714	
728,110	0.001377	0.003265	0.00299	
762,374	0.001377	0.003265	0.003541	
788,072	0.001377	0.005704	0.004091	0.001102
813,770	0.001377	0.005429	0.004327	0.001102
848,034	0.003541	0.012235	0.005429	0.001377
882,298	0.004091	0.014398	0.006806	0.001613
916,562	0.008143	0.015736	0.008143	0.00299
934,127	0.009245	0.016838	0.00952	0.004327
951,259	0.010858	0.019001	0.011684	0.00653

TABLE D-23. CRACK GROWTH DATA FOR CIL-21, SPECTRUM LOADING

production notch prep	
σ_{max} = 26.6 ksi	
Cycles	Crack Length, 2a (in)
548,224	0.000393
582,488	0.000551
616,752	0.000826
659,582	0.000944
702,412	0.001062
745,242	0.001338
788,072	0.003029
873,732	0.003541
1,002,222	0.005429
1,045,052	0.006255
1,062,184	0.006373
1,105,014	0.007317
1,139,278	0.007593
1,182,108	0.008143
1,224,938	0.011409
1,250,636	0.013297
1,259,202	0.014949
1,267,768	0.015736
1,276,334	0.016562
1,293,466	0.019552
1,310,598	0.022817
1,327,730	0.02742

TABLE D-24. CRACK GROWTH DATA FOR CIL-18, SPECTRUM LOADING

polished notch prep			
σ_{max} = 26.6 ksi			
	Crack Length, 2a (in)		
Cycles	Crack 1	Crack 2	Crack 3
513,960	0.000551		
556,790	0.001102		
599,620	0.003108		
642,450	0.003265		
685,280	0.004052	0.000826	0.000551
728,110	0.005704	0.001338	0.000826
770,940	0.00653	0.001456	0.001928
796,638	0.006766	0.001928	0.001928
805,204	0.007593	0.002478	0.002478
813,770	0.008143	0.002478	0.002714
830,902	0.010307	0.002478	0.002714
839,468	0.010858	0.002478	0.003541

TABLE D-25. CRACK GROWTH DATA FOR CIL-19, SPECTRUM LOADING

polished notch prep	
σ_{max} = 26.6 ksi	
Cycles	Crack Length, 2a (in)
445,432	0.001062
488,262	0.002439
531,092	0.004878
573,922	0.005429
616,752	0.006255
651,016	0.007042
685,280	0.007593
719,544	0.008694
753,808	0.010858
822,336	0.013848
856,600	0.016838
873,732	0.01845
890,864	0.02089
907,996	0.023879
916,562	0.024981
925,128	0.026043
942,260	0.029859
959,392	0.035013

TABLE D-26. CRACK GROWTH DATA FOR CIL-23, SPECTRUM LOADING

polished notch prep		
σ_{max} = 26.6 ksi		
	Crack Length, 2a (in)	
Cycles	Crack 1	Crack 2
599,620		0.000551
642,450		0.000826
685,280		0.001377
728,110		0.001613
770,940	0.001377	0.002164
928,188	0.002164	0.002714
1,113,580	0.003265	0.003265
1,156,410	0.003541	0.003816
1,199,240	0.004327	0.004091
1,250,636	0.005429	0.00598
1,336,296	0.005704	0.006255
1,379,126	0.006255	0.00653
1,464,786	0.006806	0.007593
1,550,446	(invalid)	0.009245
1,627,540	(invalid)	0.010032

TABLE D-27. CRACK GROWTH DATA FOR CIL-12, CONSTANT AMPLITUDE WITH UNDERLOAD MARKER CYCLES

t = 0.09 in	
polished notch prep	
σ_{max} = 18.1 ksi	
Cycles	Crack Length, 2a (in)
196,460	0.001338
206,800	0.004091
217,140	0.00598
222,310	0.006766
227,480	0.007868
232,650	0.008458
237,820	0.008852
242,990	0.011684
248,160	0.014241
253,330	0.016129
258,500	0.018293
263,670	0.021165
268,840	0.024824
274,010	0.031079
276,676	0.03757

TABLE D-28. CRACK GROWTH DATA FOR CIL-40, CONSTANT AMPLITUDE WITH OVERLOAD MARKER CYCLES

t = 0.10 in				
polished notch prep				
σ_{max} = 21.03 ksi				
	Crack Length, 2a (in)			
Cycles	Crack 1	Crack 2	Crack 3	Crack 4
56,008	0.000826			
63,009				
70,010	0.001102			
84,012	0.001377			
112,016	0.002164	0.001377		0.002164
126,018	0.002714			0.002439
140,020	0.003541	0.002164		0.003265
154,022	0.003816	0.00299	0.001495	0.004091
161,023	0.00476	0.003541		0.004209
168,024		0.003816	0.002164	0.004603
182,026	0.005704	0.004209		0.005429
189,027	0.007317	0.004878		0.00653
196,028	0.00775			0.006806
203,029	0.008419			
210,030	0.00897			
217,031	0.00952			
224,032	0.010582			
231,033	0.011133			
238,034	0.011684			
245,035	0.012746			

TABLE D-29. CRACK GROWTH DATA FOR CIL-37, CONSTANT AMPLITUDE WITH OVERLOAD MARKER CYCLES

t = 0.10 in		
production quality notch prep		
σ_{max} = 21.03 ksi		
	Crack Length, 2a (in)	
Cycles	Crack 1	Crack 2
154,022	0.000826	
175,025	0.001377	0.001102
196,028	0.002439	0.001377
245,035	0.002714	0.003659
254,869	0.003265	0.004091
266,038	0.003265	0.00598
273,039	0.00598	0.00598
280,040	0.006806	0.00653
287,041	0.007868	0.006806
294,042	0.007868	0.007317
301,043	0.008143	0.007593
308,044	0.00952	0.007868
315,045	0.010582	0.009245
322,046	0.011684	
329,047	0.012746	
336,048	0.015185	
339,048	0.016287	
343,049	0.017664	
350,050	0.019395	
357,051	0.02144	
364,052	0.023879	
371,053	0.026869	
378,054	0.029859	
385,055	0.034462	
392,056	0.040717	

TABLE D-30. CRACK GROWTH DATA FOR CIL-38, CONSTANT AMPLITUDE WITH OVERLOAD MARKER CYCLES

t = 0.10 in		
production quality notch prep		
σ_{max} = 21.03 ksi		
	Crack Length, (in)	
Cycles	Crack 1 (corner crack)	Crack 2 (surface crack)
266,038	0	0.000551
287,041	0	0.000826
301,043	0	0.001102
343,049	0	0.001377
357,051	0.000551	0.001377
392,056	0.001102	0.002714
406,058	0.001377	0.003659
420,060	0.001613	0.003659
448,064	0.004091	0.003816
462,066	0.004091	0.004091
476,068	0.005154	0.006806
483,069	0.005429	0.007042
490,070	0.005822	0.007317
497,071	0.006412	0.008143
504,072	0.006963	0.009245
511,073	0.008891	0.010543
518,074	0.010228	0.011684
525,075	0.01251	0.013297

TABLE D-31. CRACK GROWTH DATA FOR CIL-31, CONSTANT AMPLITUDE R = 0.5

production notch prep		
σ_{max} = 26.1 ksi		
Cycles	Crack Length, 2a (in)	
	Crack 1	Crack 2
155,000	0.001613	
160,000	0.001888	
170,000	0.002714	
175,000	0.003777	
180,000	0.004091	
191,000	0.006216	
200,000	0.007317	0.002203
205,000	0.008301	0.002203
208,000	0.009284	invalid
210,000	0.009363	invalid
214,000	0.012353	invalid
217,000	0.01369	invalid
220,000	0.015107	invalid
223,000	0.016365	invalid
225,000	0.018411	invalid
227,000	0.019985	invalid
228,500	0.020811	invalid

TABLE D-32. CRACK GROWTH DATA FOR CIL-32, CONSTANT AMPLITUDE R = 0.5

production notch prep	
σ_{max} = 26.1 ksi	
Cycles	Crack Length, 2a (in)
100,000	0.001377
110,000	0.001613
120,000	0.002164
130,000	0.00299
140,000	0.004603
150,000	0.006255
153,200	0.006806
155,500	0.007317
158,000	0.007593
163,000	0.008143
169,000	0.008694
172,000	0.010032
175,000	0.010858
178,000	0.011684
181,000	0.012471
184,000	0.013572
187,000	0.014398
190,000	0.015736
192,000	0.016838
194,000	0.017664
196,000	0.019001
198,000	0.019827
200,000	0.020614
202,000	0.022266
204,000	0.024981
206,000	0.027695
208,000	0.029308
210,000	0.035839
212,000	0.036665
214,000	0.040717
216,000	0.044808

TABLE D-33. CRACK GROWTH DATA FOR CIL-34, CONSTANT AMPLITUDE R = 0.1

production notch prep		
σ_{max} = 19.6 ksi		
	Crack Length, (in)	
Cycles	Crack 1 (surface)	Crack 2 (corner)
222,000	0.000826	
250,000	0.001377	
280,000	0.004603	0.003541
284,500	0.005704	0.010032
289,000	0.006806	0.01845
291,000		0.029308
294,000		0.038829
296,000		0.053188
298,000		0.072189

TABLE D-34. CRACK GROWTH DATA FOR CIL-39, CONSTANT AMPLITUDE R = 0.1

production notch prep		
σ_{max} = 19.6 ksi		
Cycles	Crack Length, (in)	
	Surface Crack	Corner Crack
347,500	0.000551	
355,000	0.001102	
362,500	0.001377	
375,000	0.001692	
385,000	0.021637	
395,000	0.002714	
405,000	0.00299	
420,000	0.004091	
425,000	0.004878	
430,000	0.00535	
435,000	0.005704	
441,000	0.00653	
444,000	0.008143	
448,000	0.008261	
450,000	0.008458	
452,000	0.008261	
454,000	0.008694	
456,000	0.00952	
458,000	0.010307	
460,000	0.010858	
462,000	0.011409	
464,000	0.012628	
466,000		0.013061
468,000		0.013336
470,000		0.01373
472,000		0.014084
474,000		0.015343
476,000		0.016326
478,000		0.01668
480,000		0.018962
482,000		0.020811
484,000		0.025571
486,000		0.02978
487,000		0.033006
488,000		0.038829
489,000		0.042959
490,000		0.049293

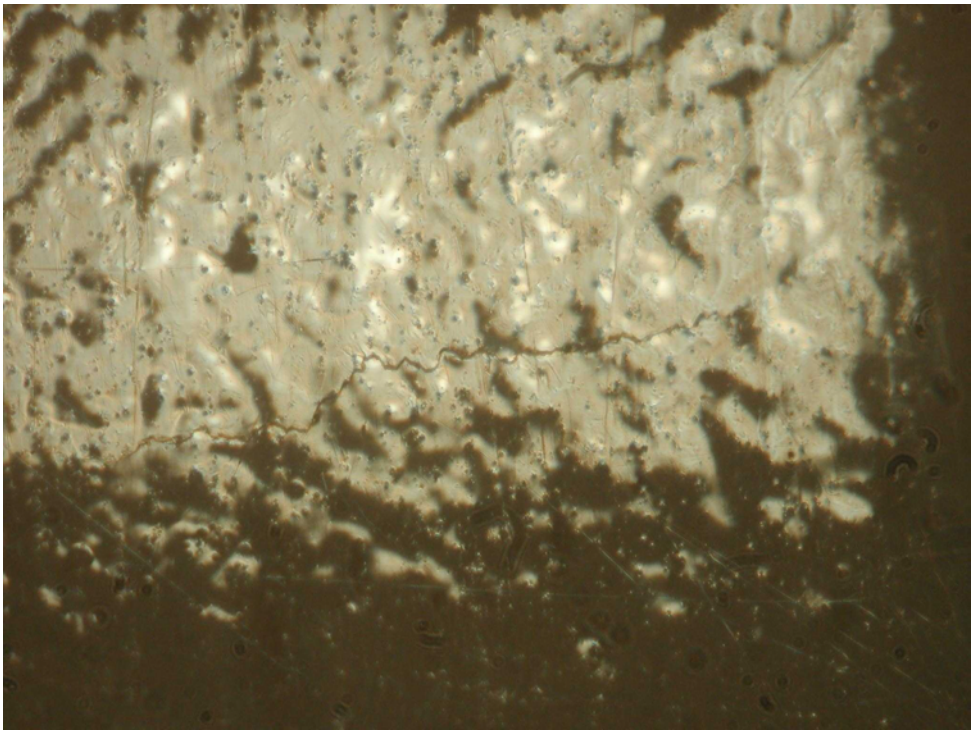


FIGURE D-34. TEST SPECIMEN CIL-2 AT 550,000 CYCLES

FIGURE D-35. TEST SPECIMEN CIL-13 AT 290,000 CYCLES

FIGURE D-36. TEST SPECIMEN CIL-13 AT 290,000 CYCLES

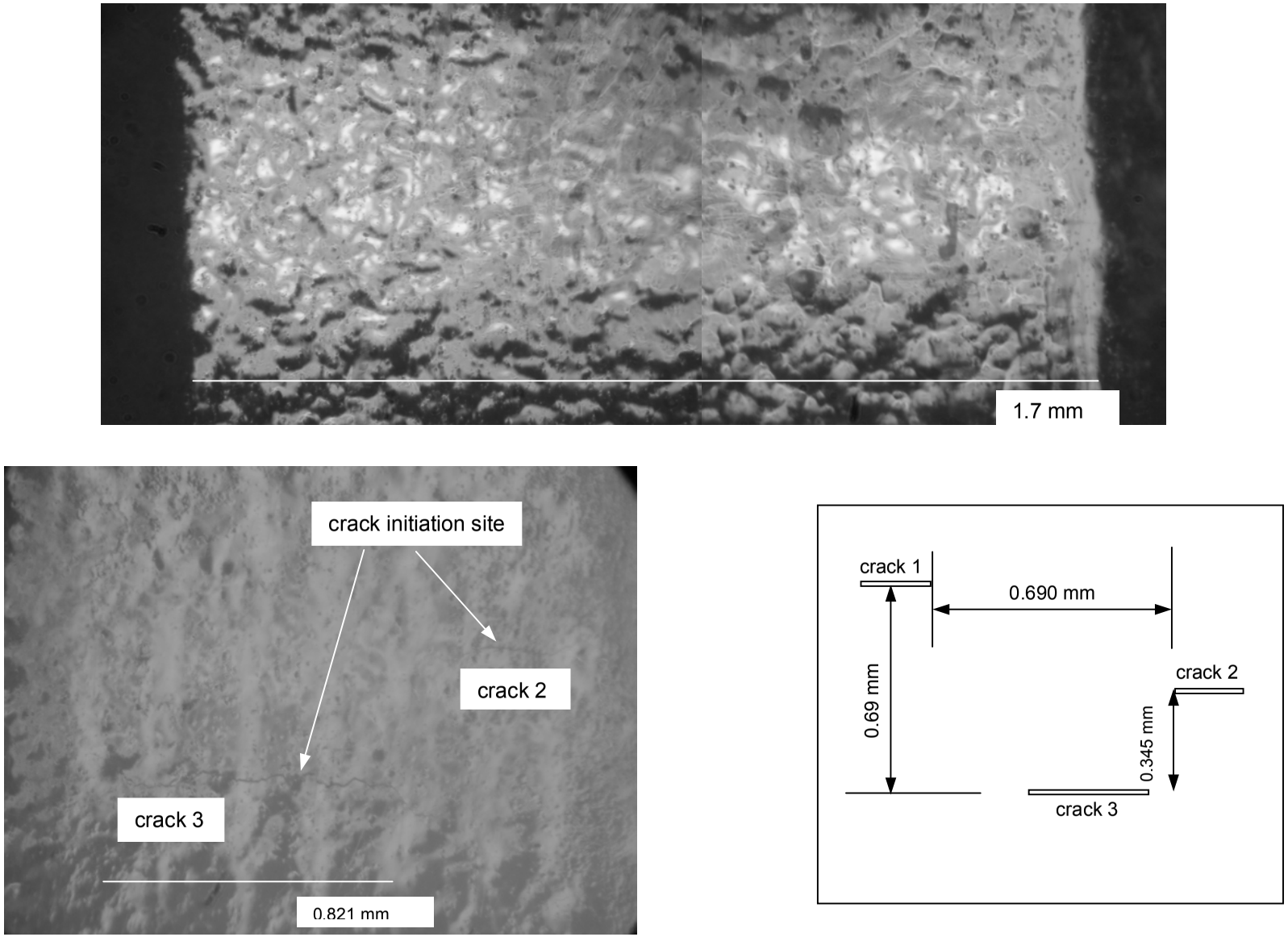


FIGURE D-37. PHOTOS OF TEST SPECIMEN CIL-4 AND SCHEMATIC SHOWING LOCATION OF THREE CRACK CYCLES

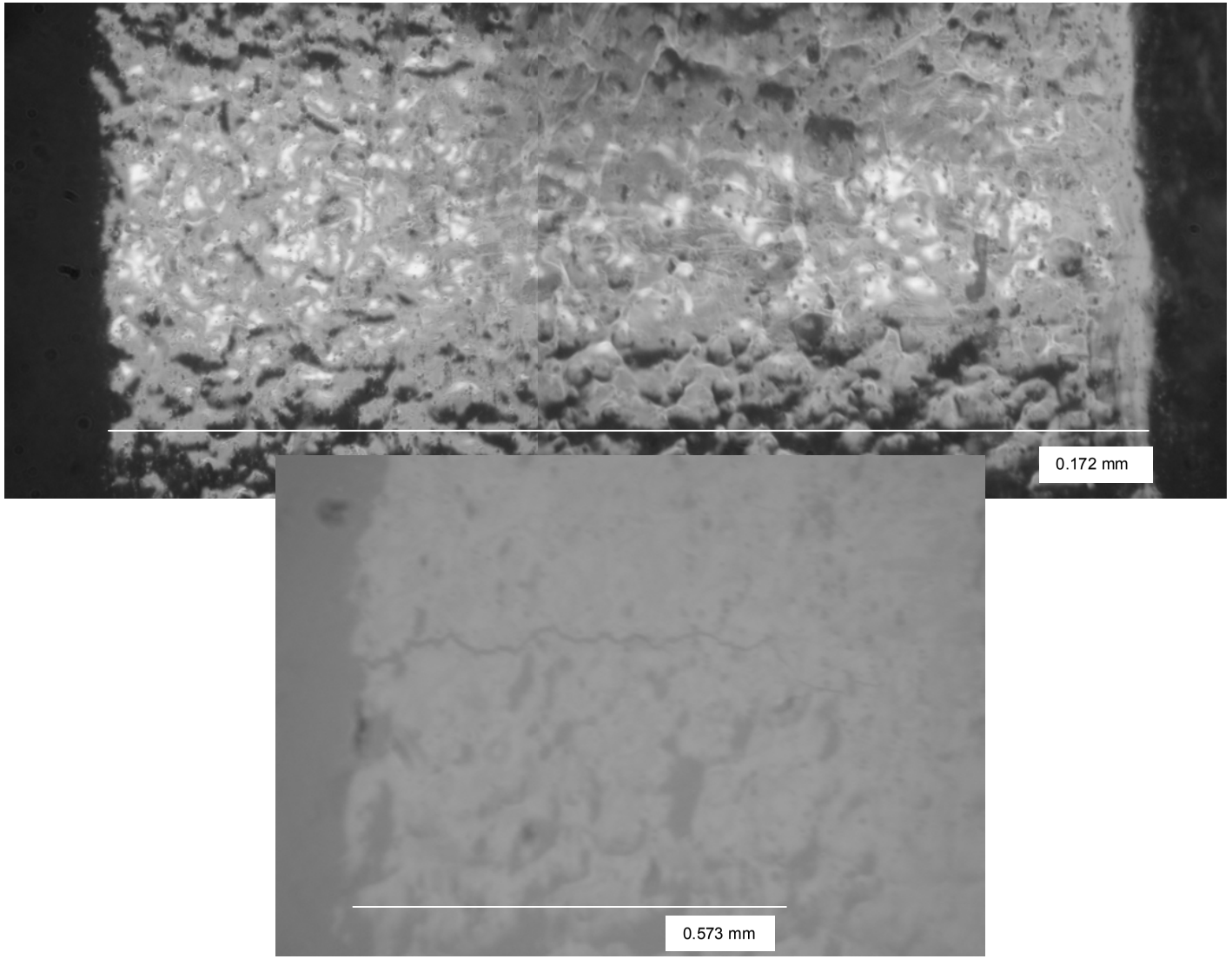
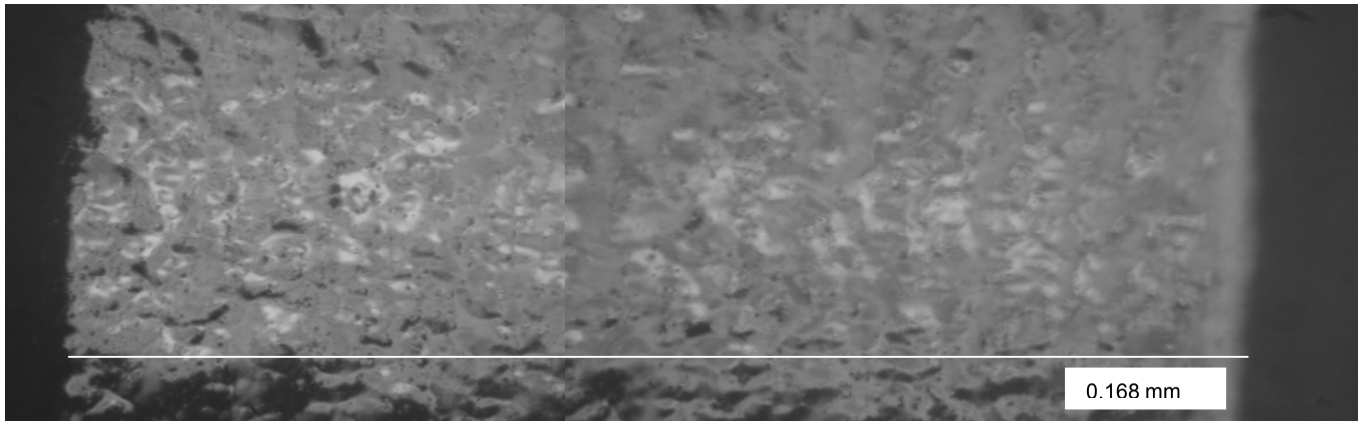


FIGURE D-38. PHOTOS OF TEST SPECIMEN CIL-14



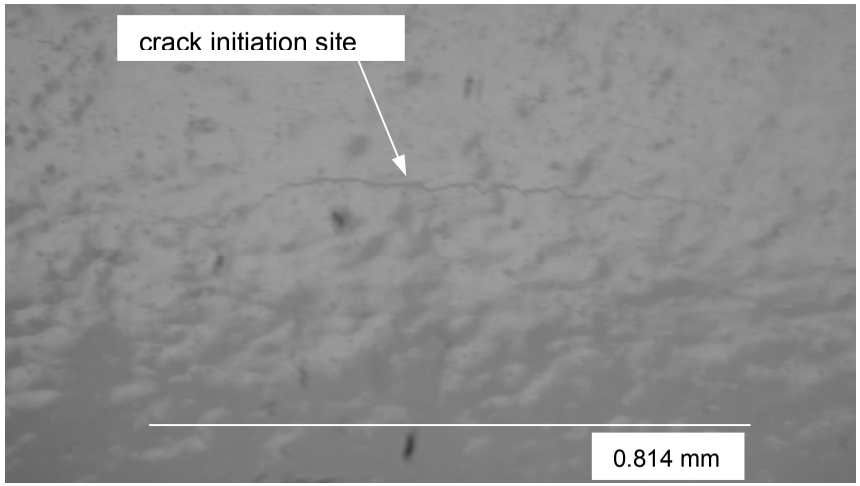


FIGURE D-39. PHOTOS OF TEST SPECIMEN CIL-15

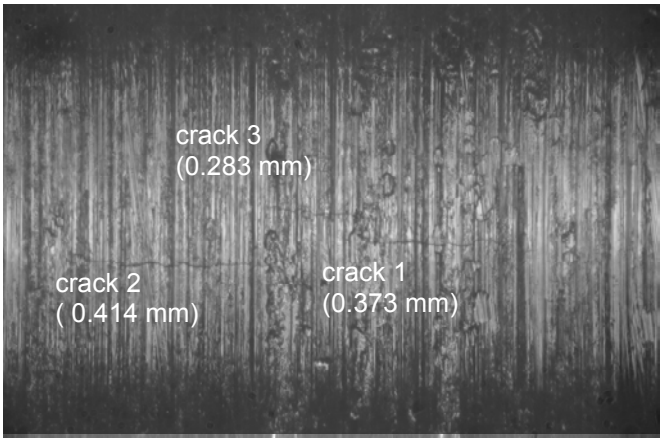


FIGURE D-40. PHOTO OF TEST SPECIMEN CIL-9

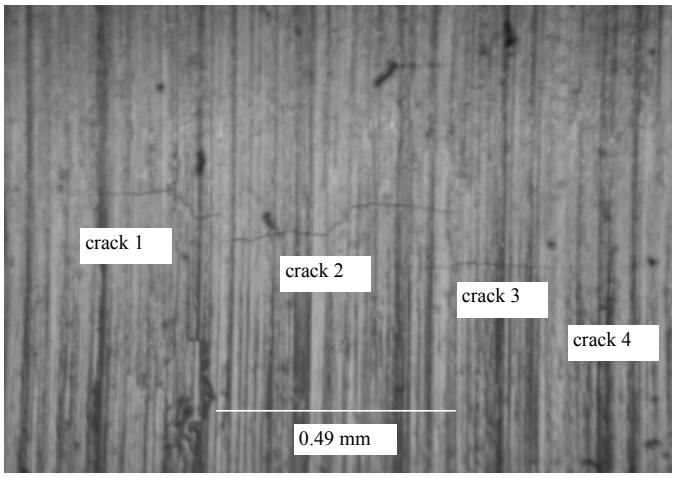


FIGURE D-41. PHOTO OF TEST SPECIMEN CIL-10

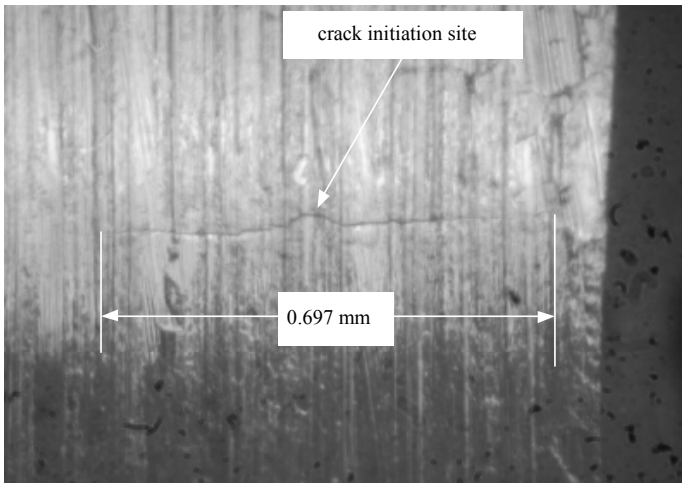
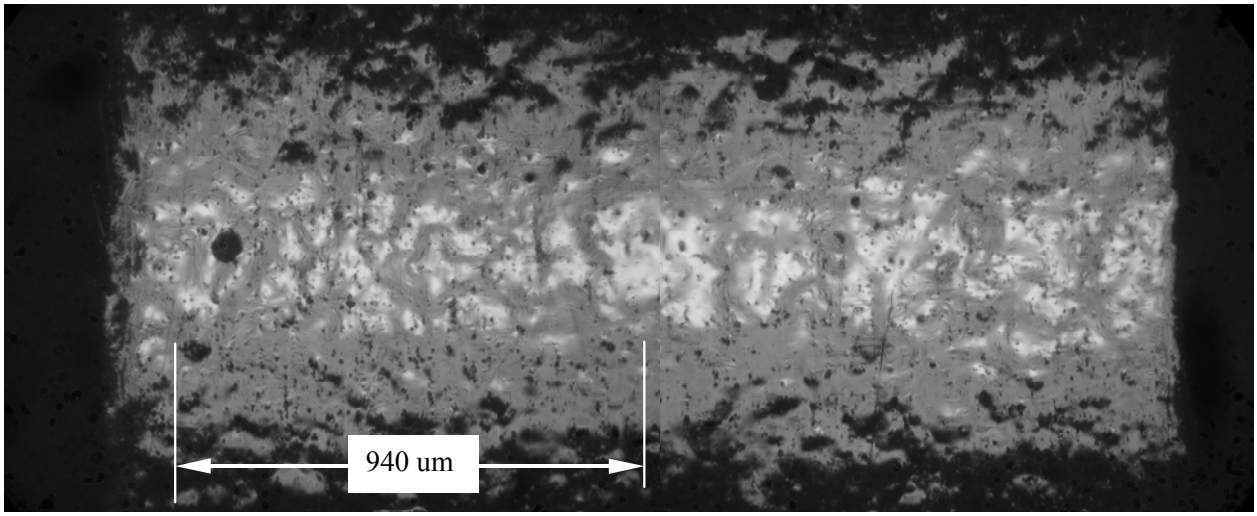


FIGURE D-42. PHOTO OF TEST SPECIMEN CIL-21



Notch surface at 0 cycles

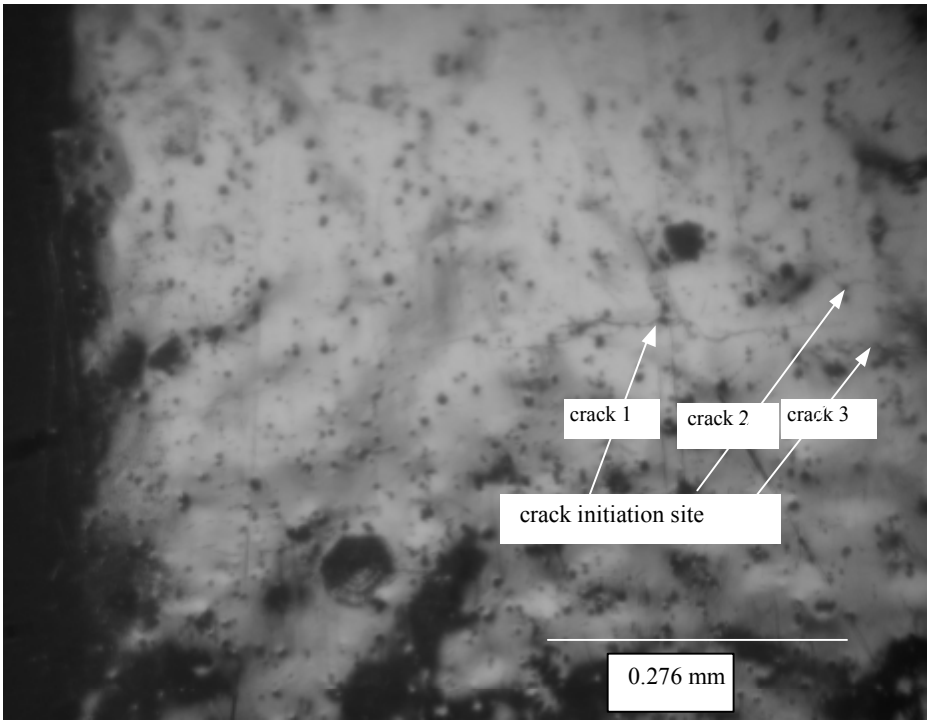
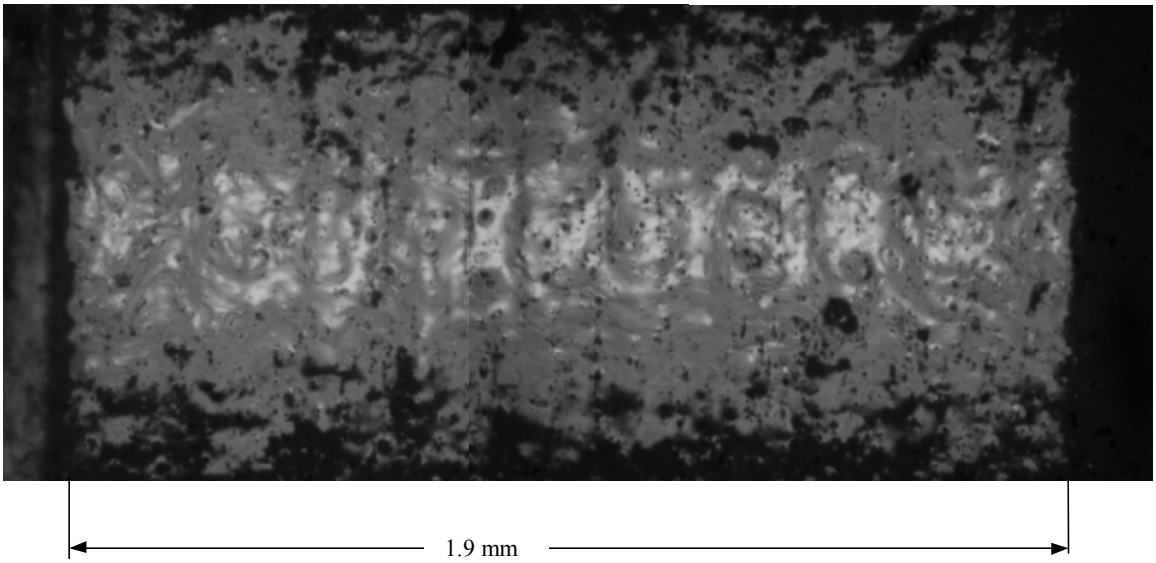


FIGURE D-43. PHOTOS OF TEST SPECIMEN CIL-18



Notch surface at 0 cycles

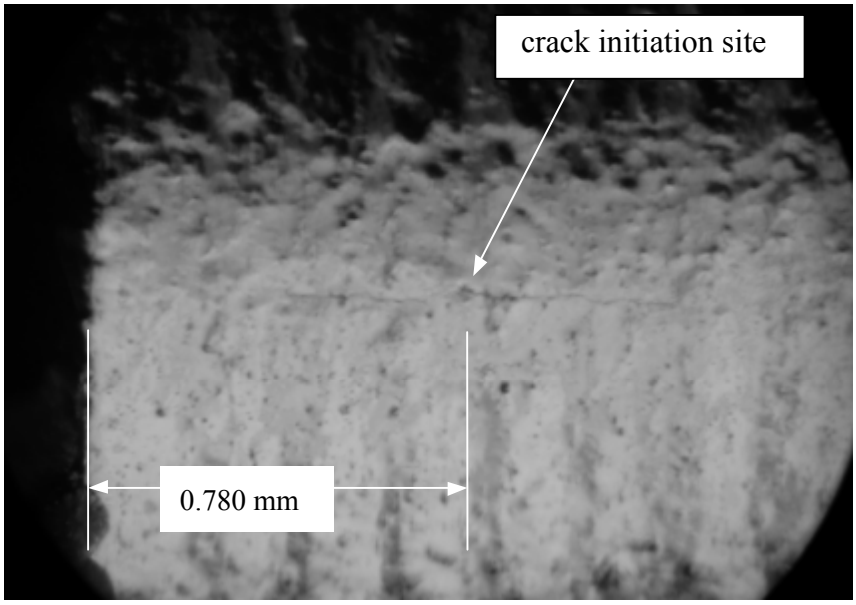
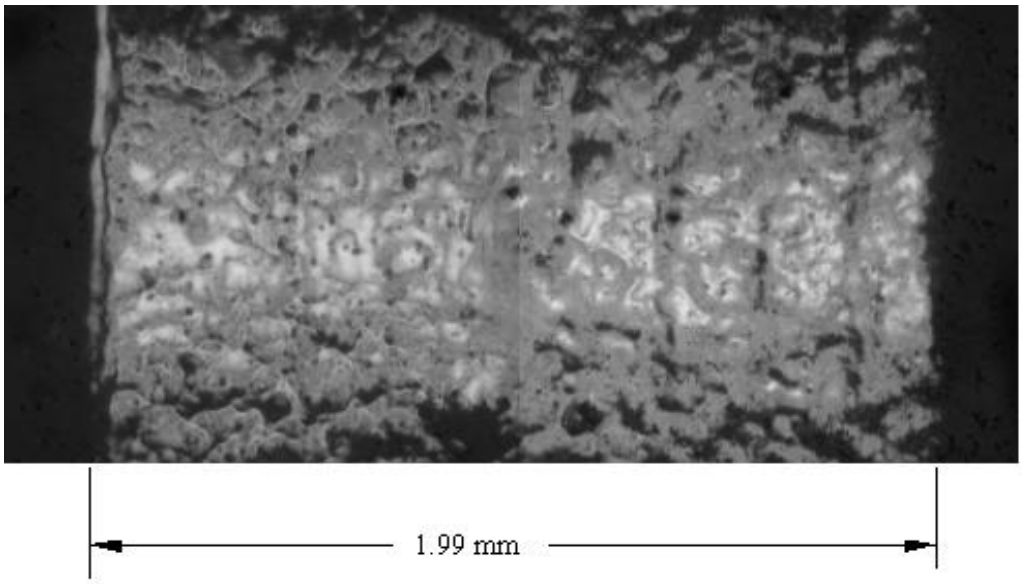
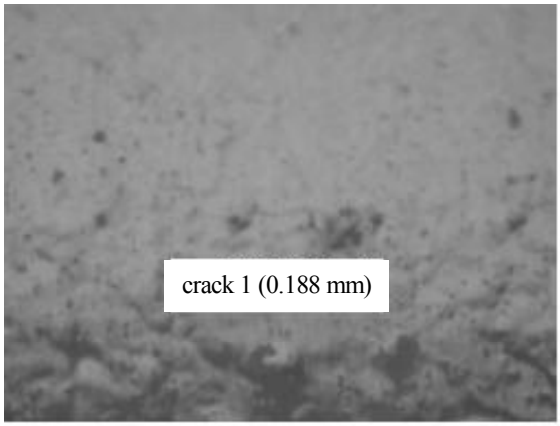
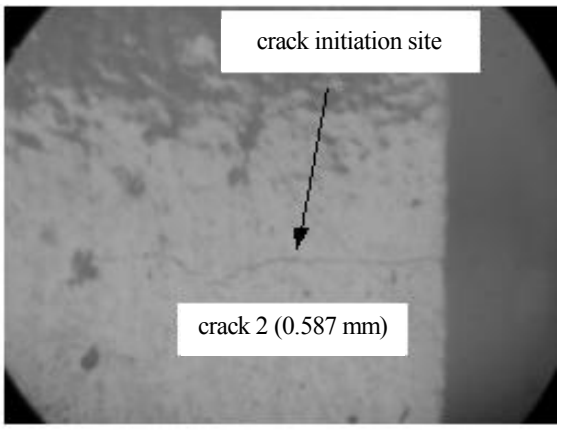


FIGURE D-44. PHOTOS OF TEST SPECIMEN CIL-19



Notch surface at 0 cycles





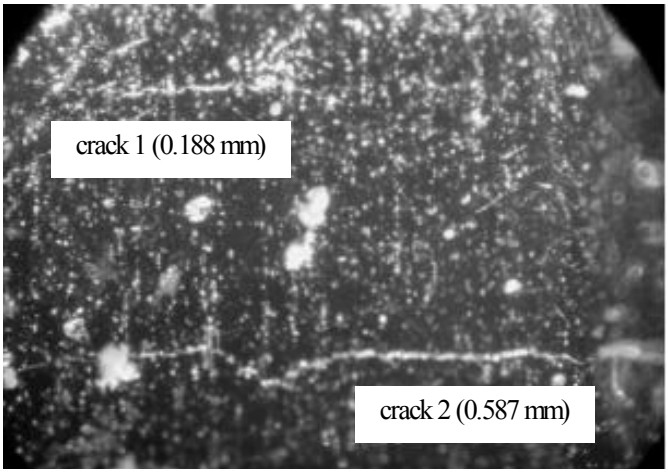


FIGURE D-45. PHOTOS OF TEST SPECIMEN CIL-23

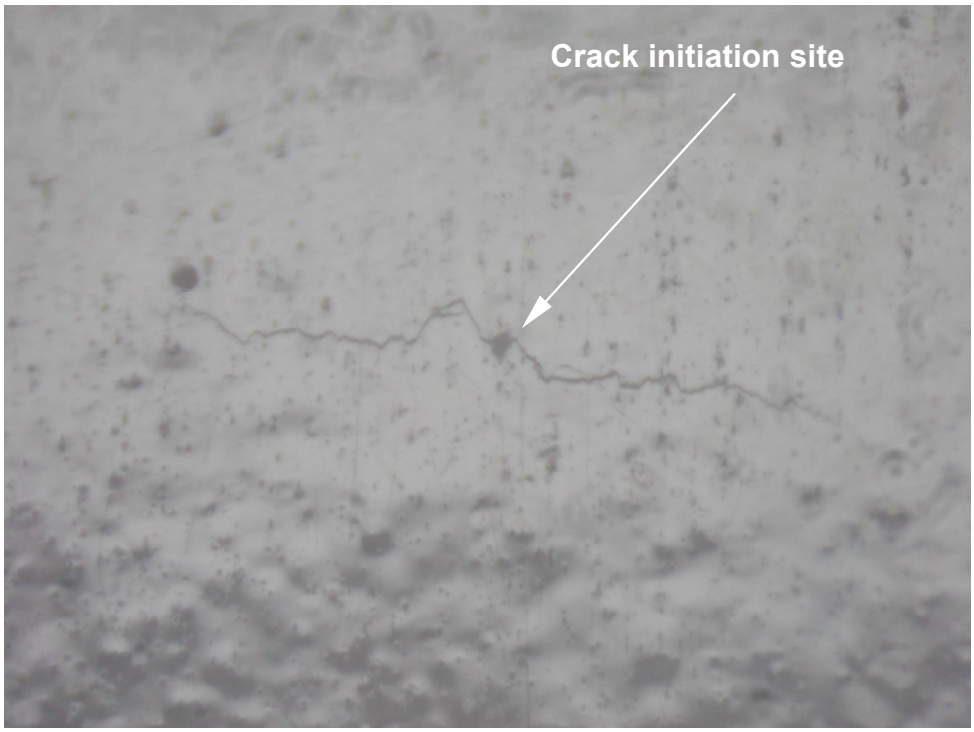
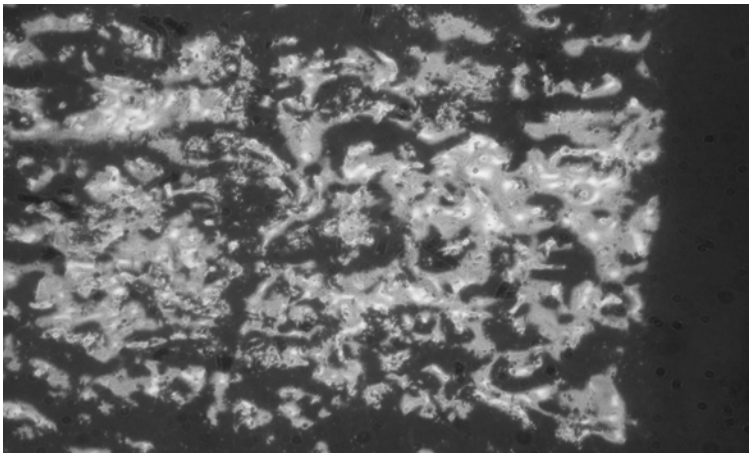
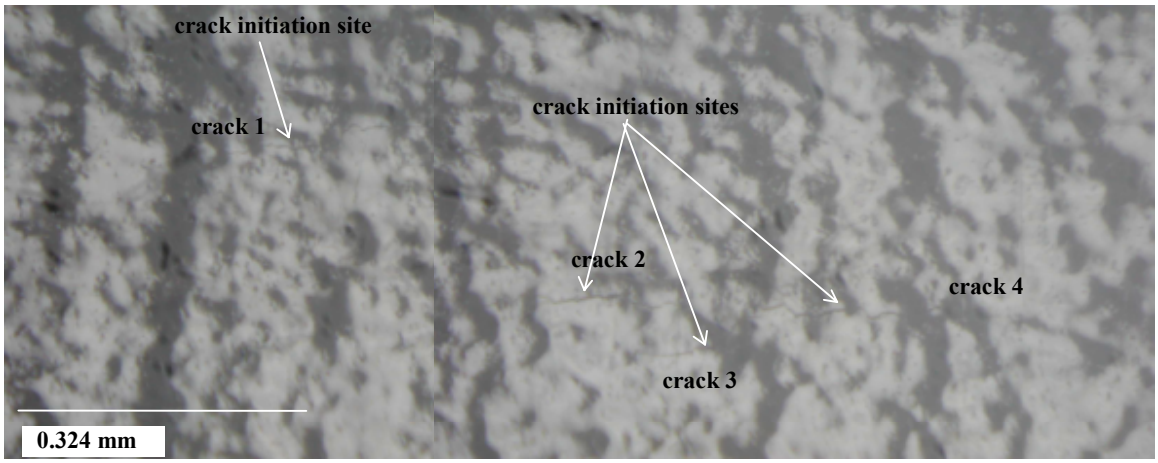


FIGURE D-46. TEST SPECIMEN CIL-12



Notch surface at 0 cycles



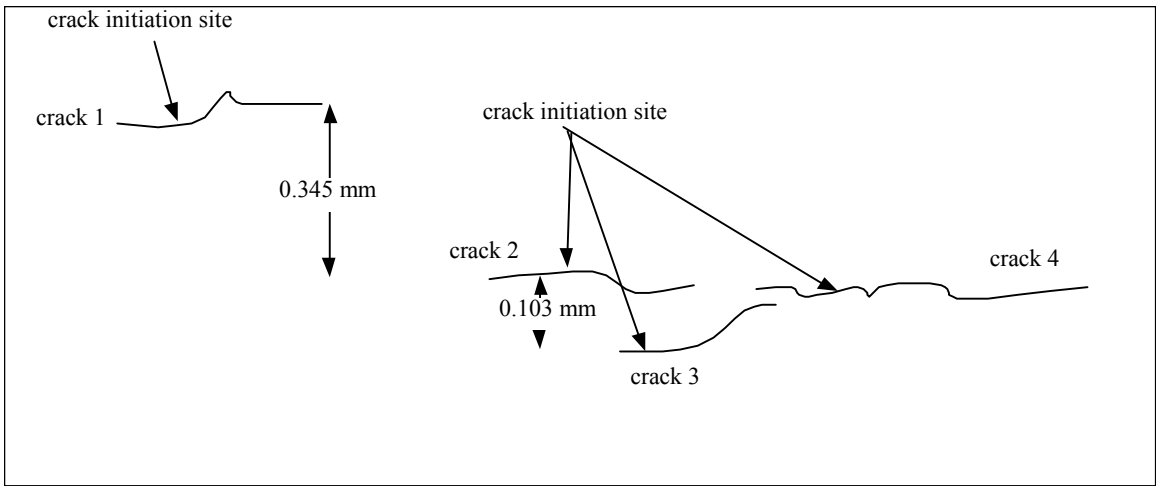
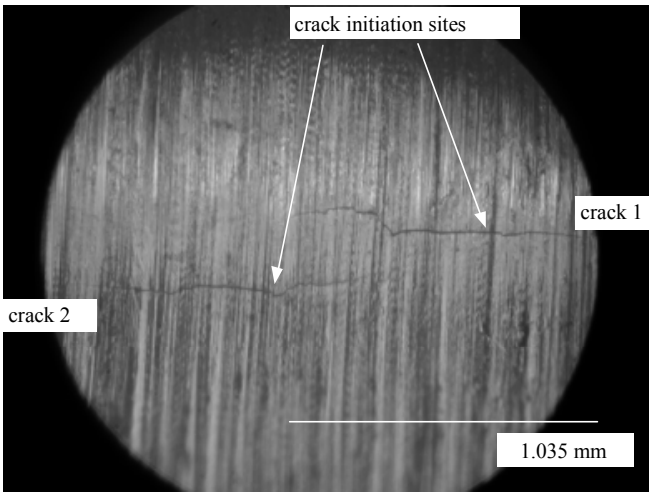


FIGURE D-47. TEST SPECIMEN CIL-40

Notch surface at 0 cycles



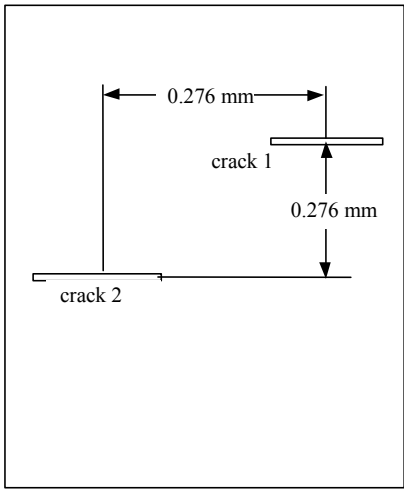
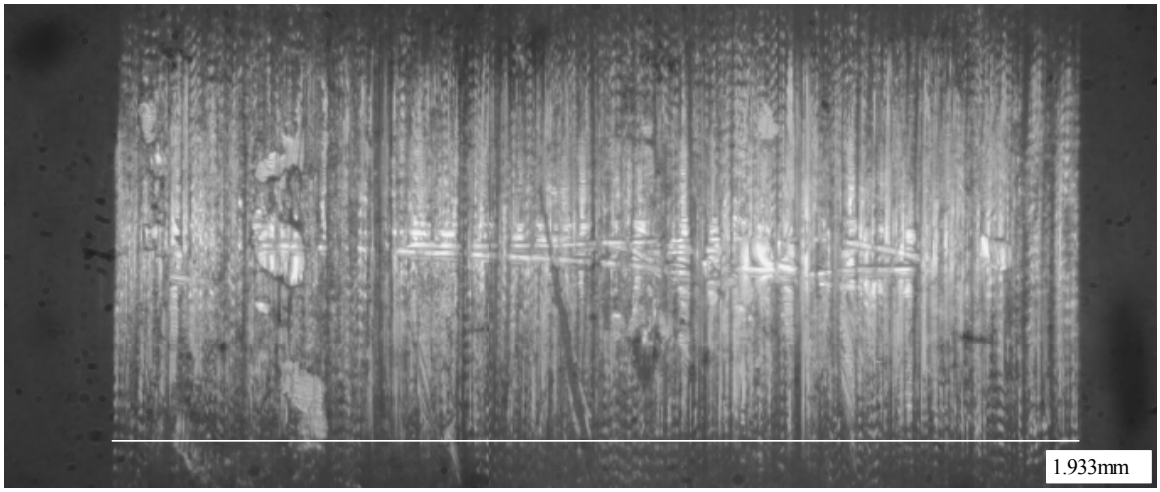
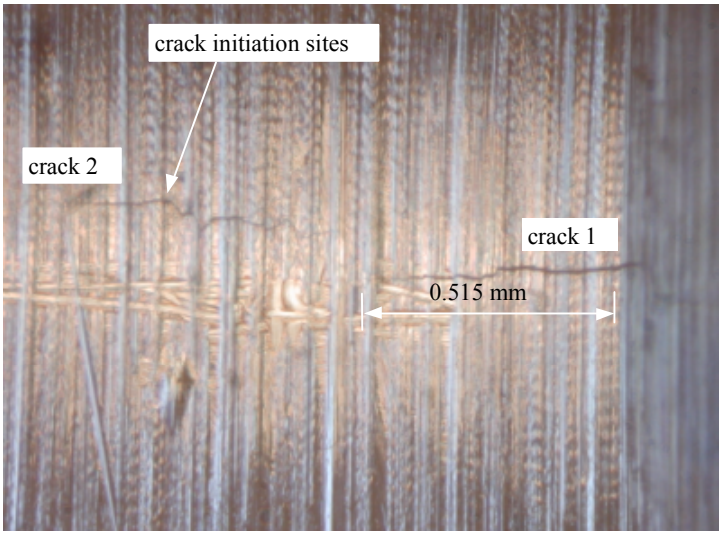


FIGURE D-48. TEST SPECIMEN CIL-37



Notch surface at 0 cycles



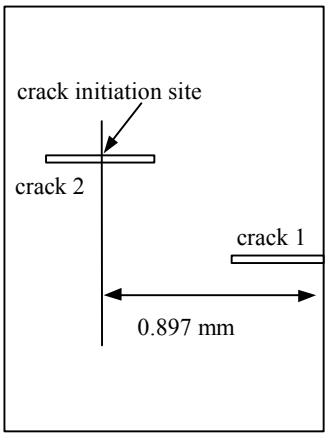
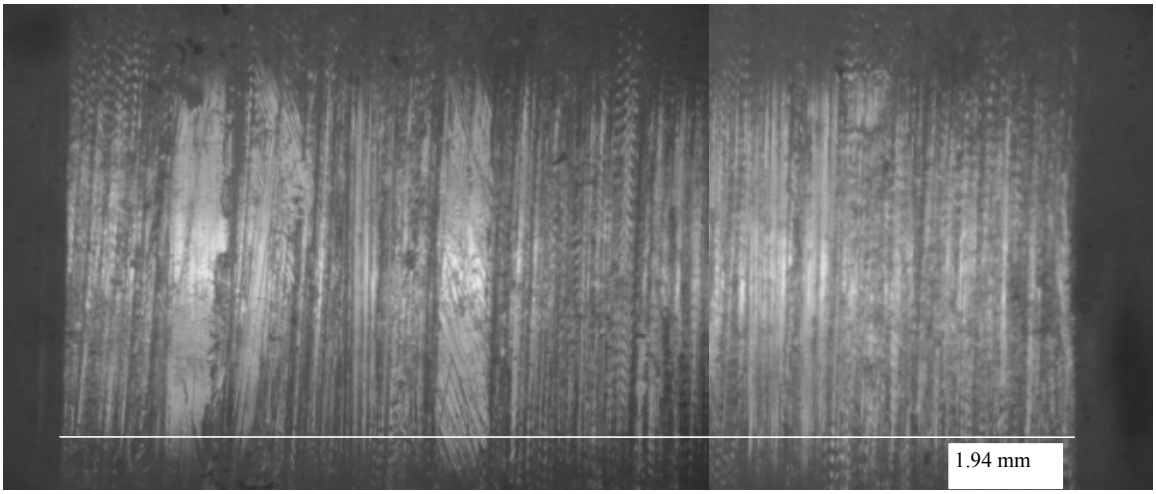
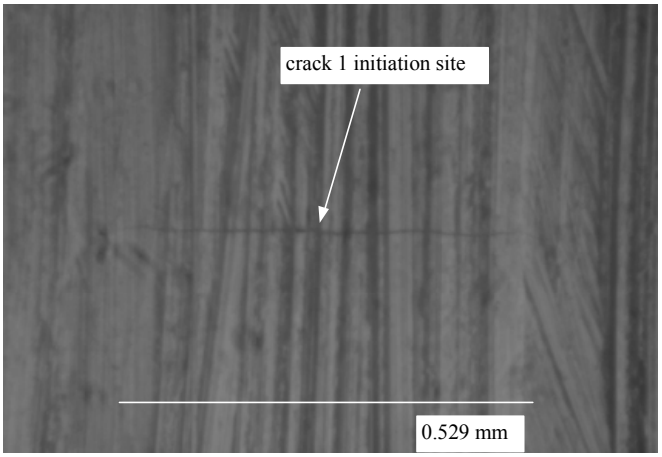


FIGURE D-49. TEST SPECIMEN CIL-38



Notch surface at 0 cycles



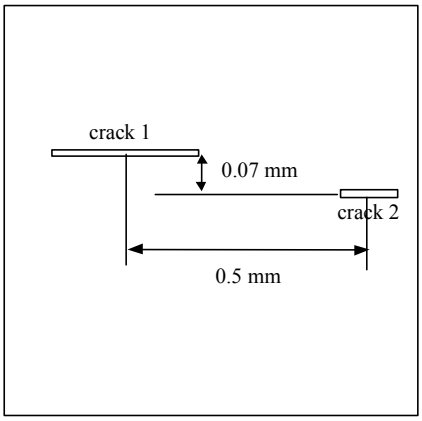
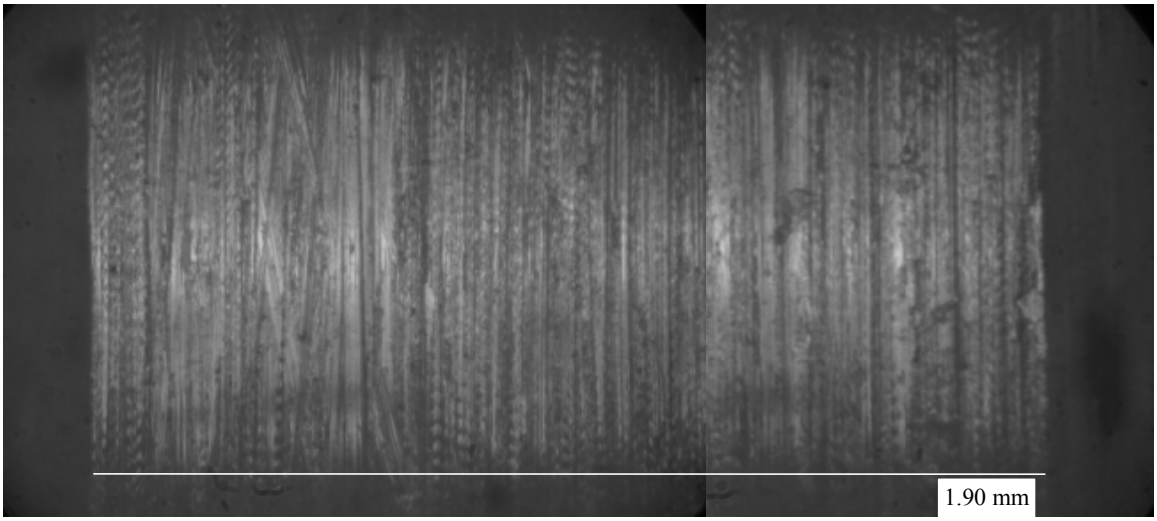


FIGURE D-50. TEST SPECIMEN CIL-31 CRACK LOCATIONS



Notch surface at 0 cycles

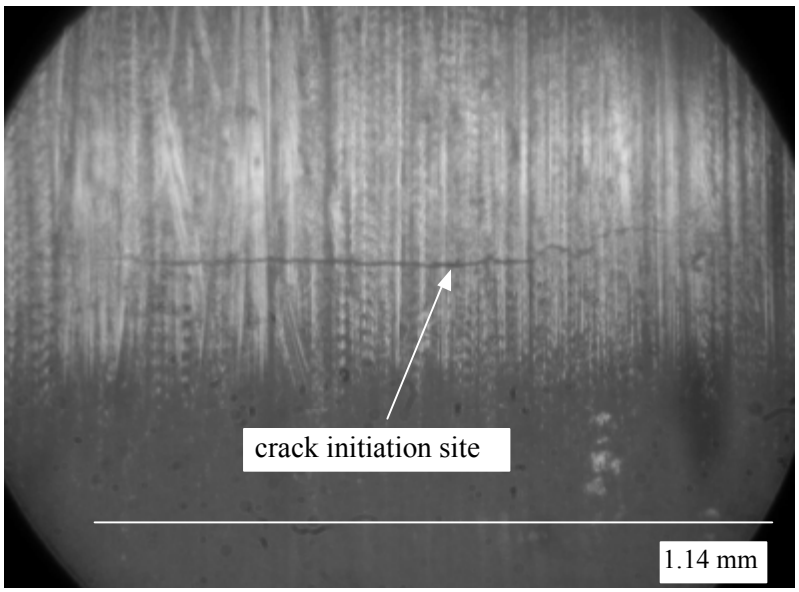
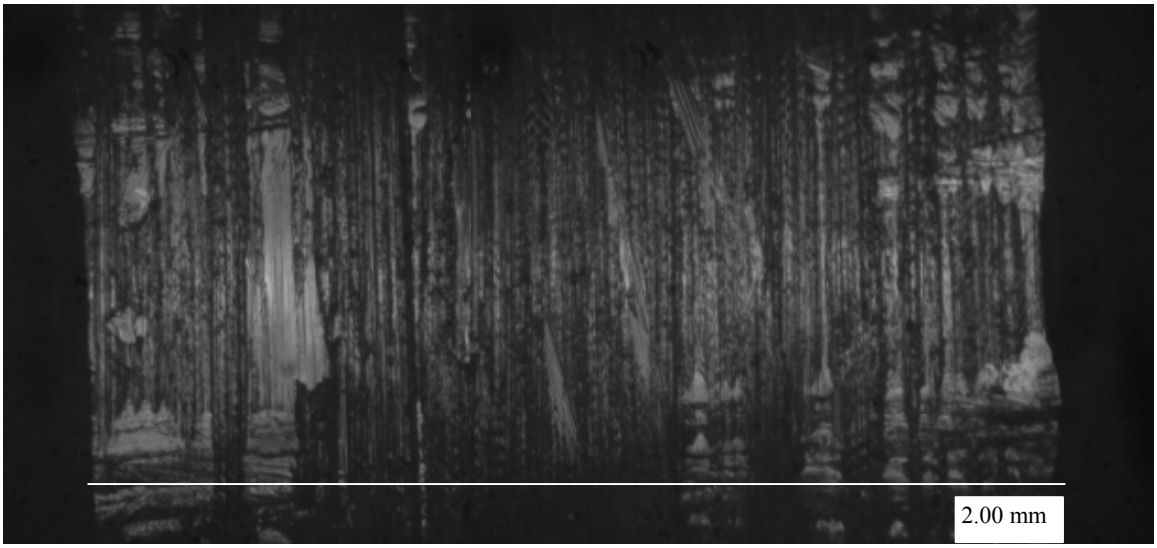


FIGURE D-51. TEST SPECIMEN CIL-32 CRACK LOCATIONS



Notch surface at 0 cycles

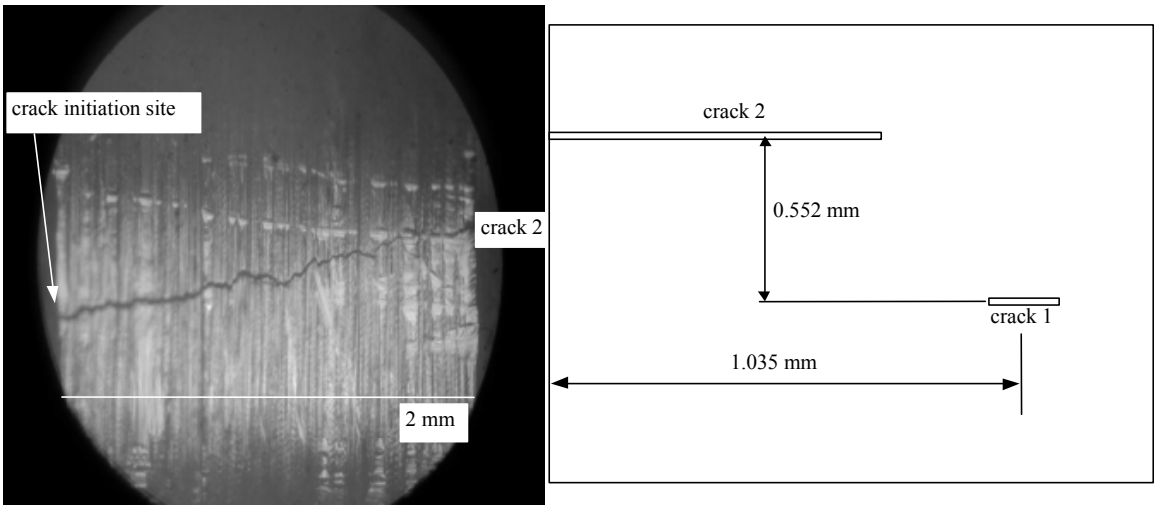


FIGURE D-52. TEST SPECIMEN CIL-34 CRACK LOCATIONS

Notch surface at 0 cycles

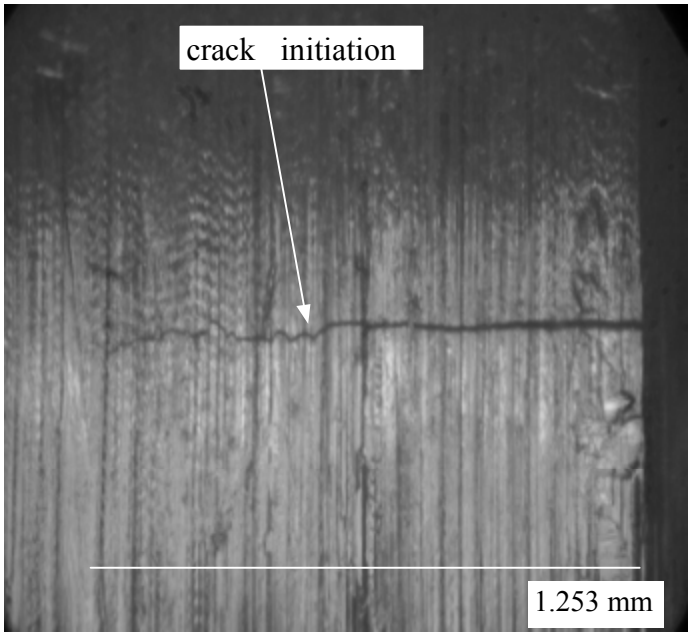


FIGURE D-53. TEST SPECIMEN CIL-39 CRACK LOCATIONS

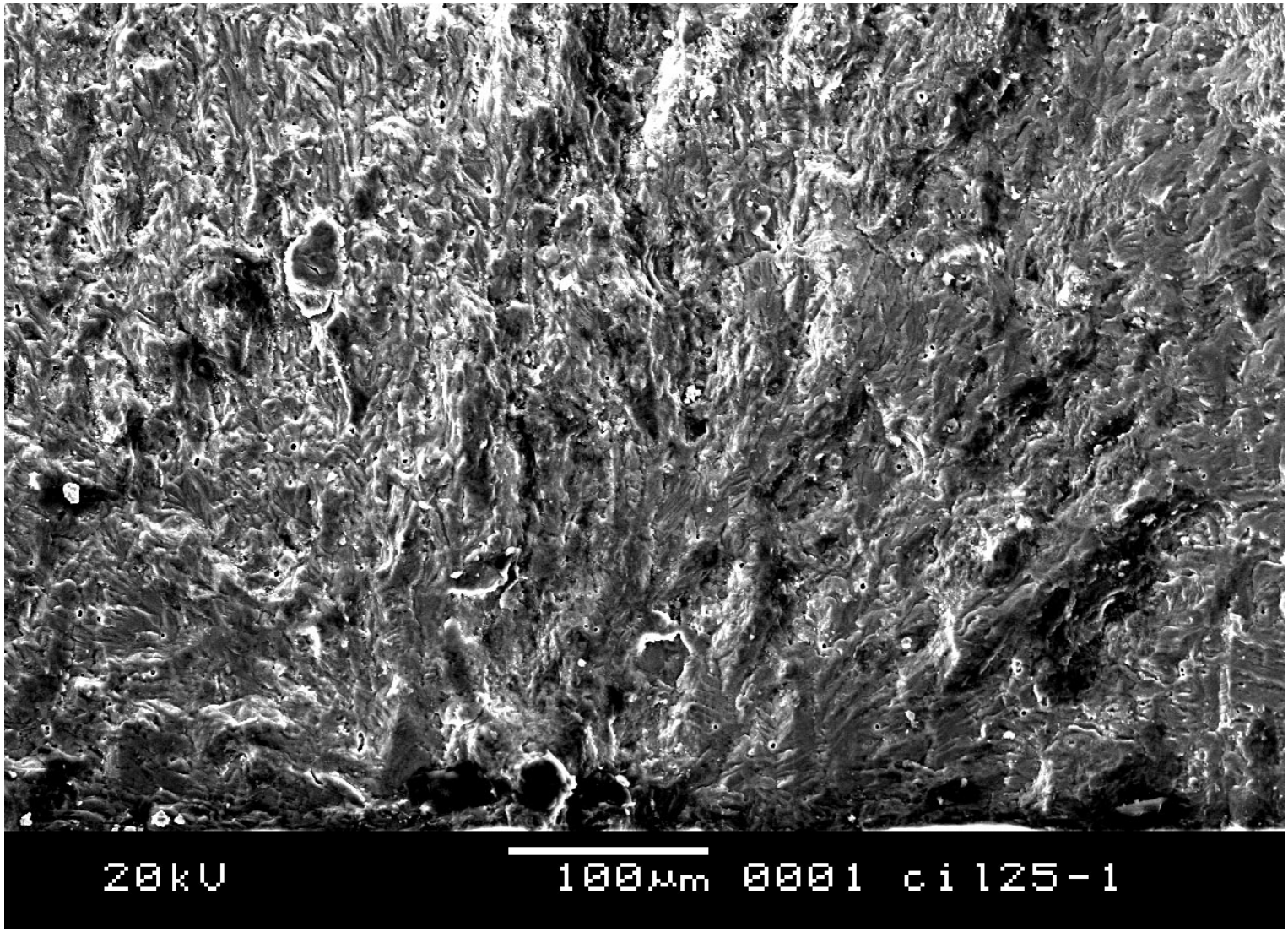


FIGURE D-54. SEM PHOTO OF TEST SPECIMEN CIL-25 (BROKE AT 325,285 CYCLES)

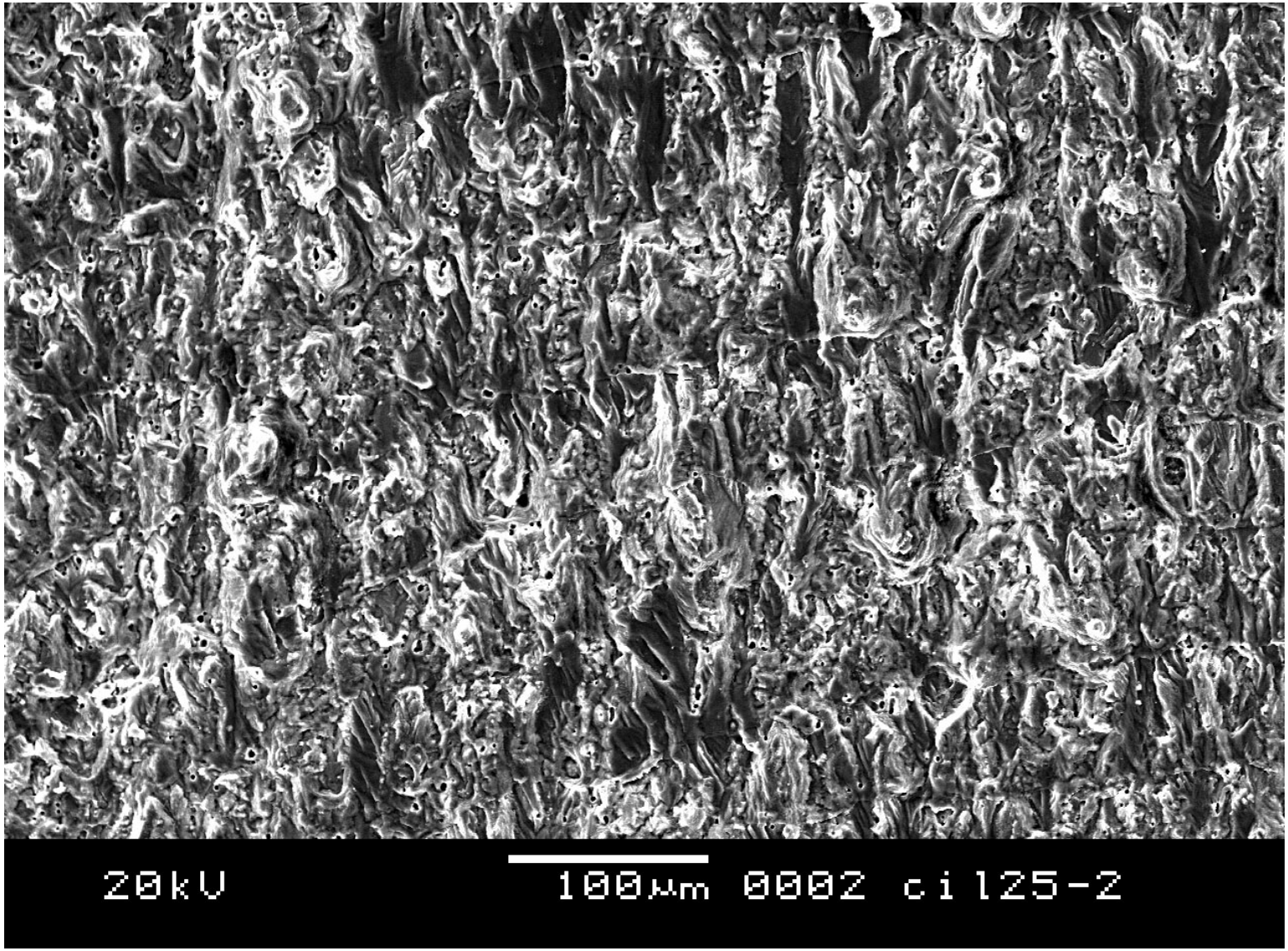


FIGURE D-55. SEM PHOTO OF TEST SPECIMEN CIL-25 FRACTURE SURFACE

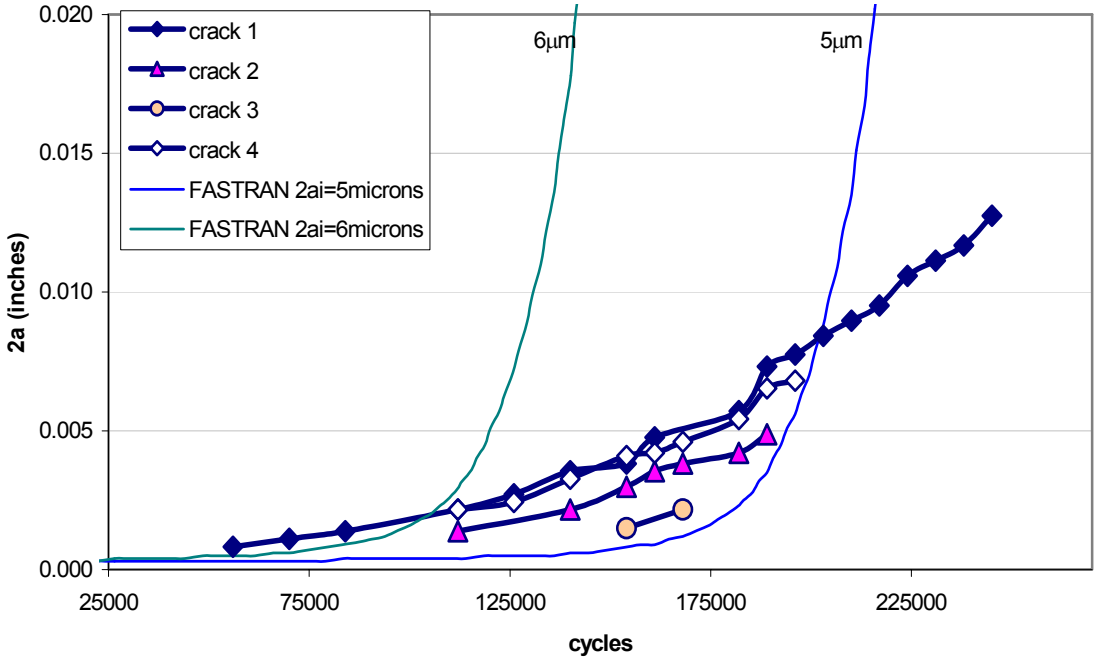


FIGURE D-56. CIL-40 TEST VS FASTRAN, σ_{max}=21 ksi (OVERLOAD MARKERS)

APPENDIX E—EQUIVALENT INITIAL FLAW SIZE

This appendix contains the equivalent initial flaw size (EIFS) specimen drawings, strain gage locations, inspection area and rivet numbering, nondestructive inspection references, scanning electron microscope (SEM) results, measured specimen dimensions, finite element method stress plots, strain survey, residual strength caused by rivet installation, average EIFS sizes, crack growth histories and the correlation, as discussed in section 6.

Page No.	Description
E-2	EIFS specimen drawings (figure E-1)
E-16	Strain gage locations (figure E-2)
E-19	Inspection area and rivet numbering (figure E-3)
E-22	Rotating self-nulling eddy-current references (figures E-4 to E-7)
E-25	SEM results (figure E-8)
E-42	Measured specimen dimensions (figure E-9)
E-58	Stress fringe plots (figures E-10 to E-14)
E-62	Strain survey test/analyses correlation (figures E-15 to E-18)
E-66	Example of bearing stress factor and bypass stress factor calculation
E-67	Original crack growth analysis
E-70	Effects of the rivet surface contact stress
E-79	Measured crack growth histories and collapsed crack growth histories
E-89	Average EIFS sizes of individual specimen
E-92	Crack growth test/analyses correlation (figures E-50 to E-65)

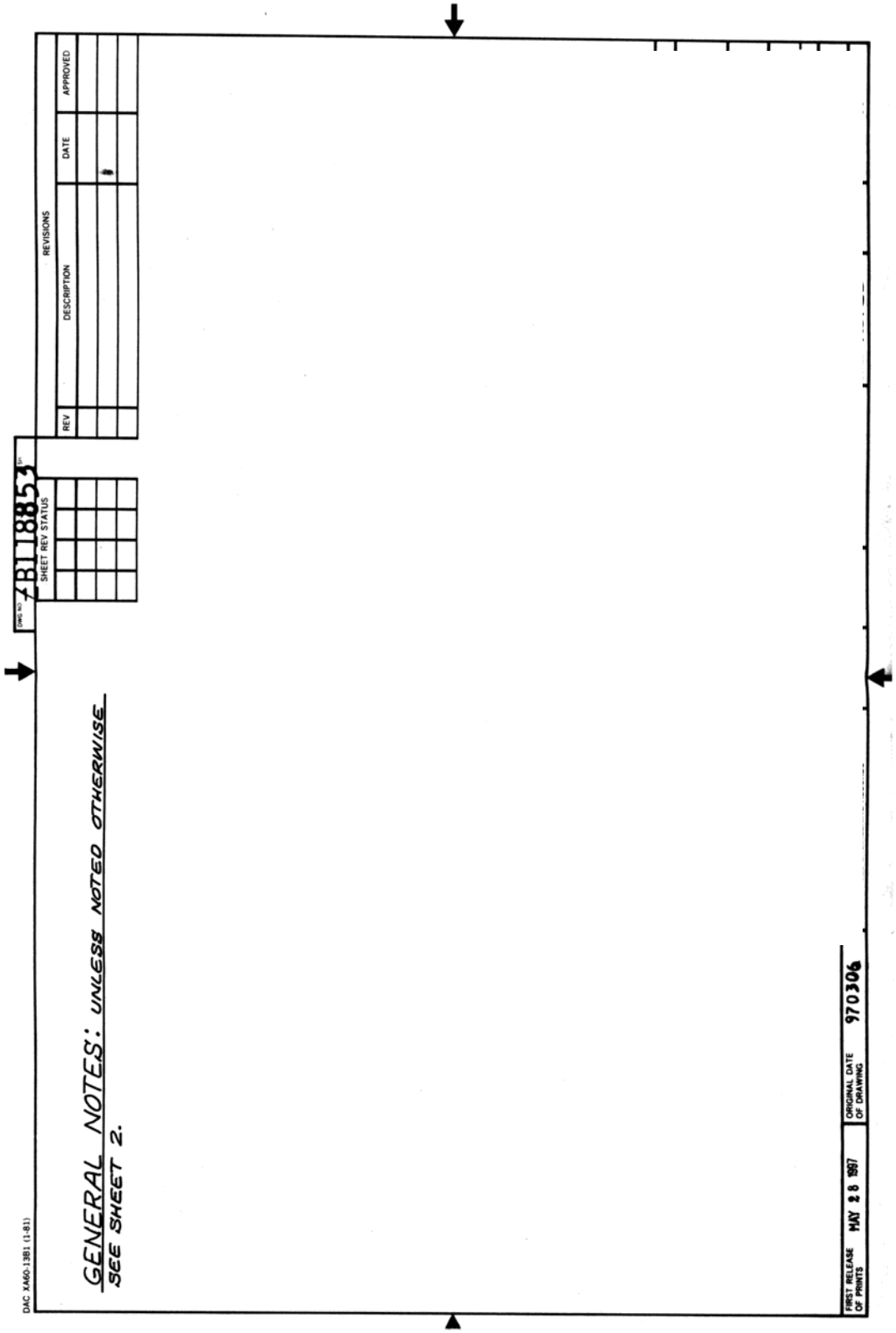


FIGURE E-1. EQUIVALENT INITIAL FLAW SIZE PANEL ASSEMBLY DRAWINGS

DAC 60-13B2 (REV. 12-88)

DWG NO. ZB118853

GENERAL NOTES: UNLESS NOTED OTHERWISE

CENTERLINES AND/OR SURFACES SHOWN AS PERPENDICULAR OR PARALLEL ARE TO BE SO WITHIN .030 IN WIDTH OR LENGTH OF PART.
SURFACE TEXTURE PER ANSI B46.1-1978.
FABRICATION STANDARDS PER DPS 4.710.
ASSEMBLY SHOP PRACTICE PER DPS 2.70-2.
IDENTIFY PER DPS 3.02.
HOLES PER DPS 3.67-22.
INSTALL RIVETS PER S5076260 IN -1, -503 AND -505 ASSEMBLIES.
INSTALL RIVETS PER ENGINEERING INSTRUCTIONS IN -501 ASSEMBLY ONLY.
INSTALL HI-LOK PINS PER S7933654 AND LOCKBOLTS PER S7933655.
STANDARD INTERFERENCE FITS APPLY UNLESS OTHERWISE INDICATED BY SYMBOL DESIGNATION.
INSTALL STRAIN GAGES PER DPS 1.999.
MS20470AD5 RIVETS INDICATED THUS: BJ|5
MS20470AD6 RIVETS INDICATED THUS: BJ|6
NAS1097AD6 RIVETS INDICATED THUS: LZ|6

S4932868-06 LOCKBOLTS AND NAS1080-06 COLLARS INDICATED THUS: XFK|6
S4931919-6 HI-LOK PINS, NAS1252-10L WASHERS AND MS21042-3 NUTS INDICATED THUS: XES|6
METALBOND -27, -29, -33 AND -35 DOUBLERS WITH DMS 2169 PER DPS 1.950.
ALL DETAIL PARTS SHALL BE CC OR MC COATED PER DPS 9.45 AND FR PRIMED WITH DMS 1786 PER DPS 4.50-36. SEE DRAWING ASSEMBLY -1, -501, -503 AND -505 FOR DIMENSIONAL LIMITS OF COATINGS ON SKINS.
SEAL FAYING SURFACES ON -1 AND -505 ASSEMBLIES USING DPM 2292-6 (IF ASSEMBLED WITHIN 6 HOURS) OR DPM 2082 (IF ASSEMBLED WITHIN 2 HOURS) PER DPS 2.590-2 (REF. FIG. 4.2.12).
FILL GAP IN SKINS ON -505 ASSEMBLY WITH DMS 1819.
SEAL FAYING SURFACES ON -501 WITH DPM 2013 CLASS A48 PER DPS 2.50.
SEAL FAYING SURFACES ON -503 WITH DPM 5896-3 (IF ASSEMBLED WITHIN 96 HOURS) PER DPS 2.590-2 (REF. FIG. 4.1).
FILL GAP IN SKINS WITH DPM 2082.

FIGURE E-1. EQUIVALENT INITIAL FLAW SIZE PANEL ASSEMBLY DRAWINGS
(Continued)

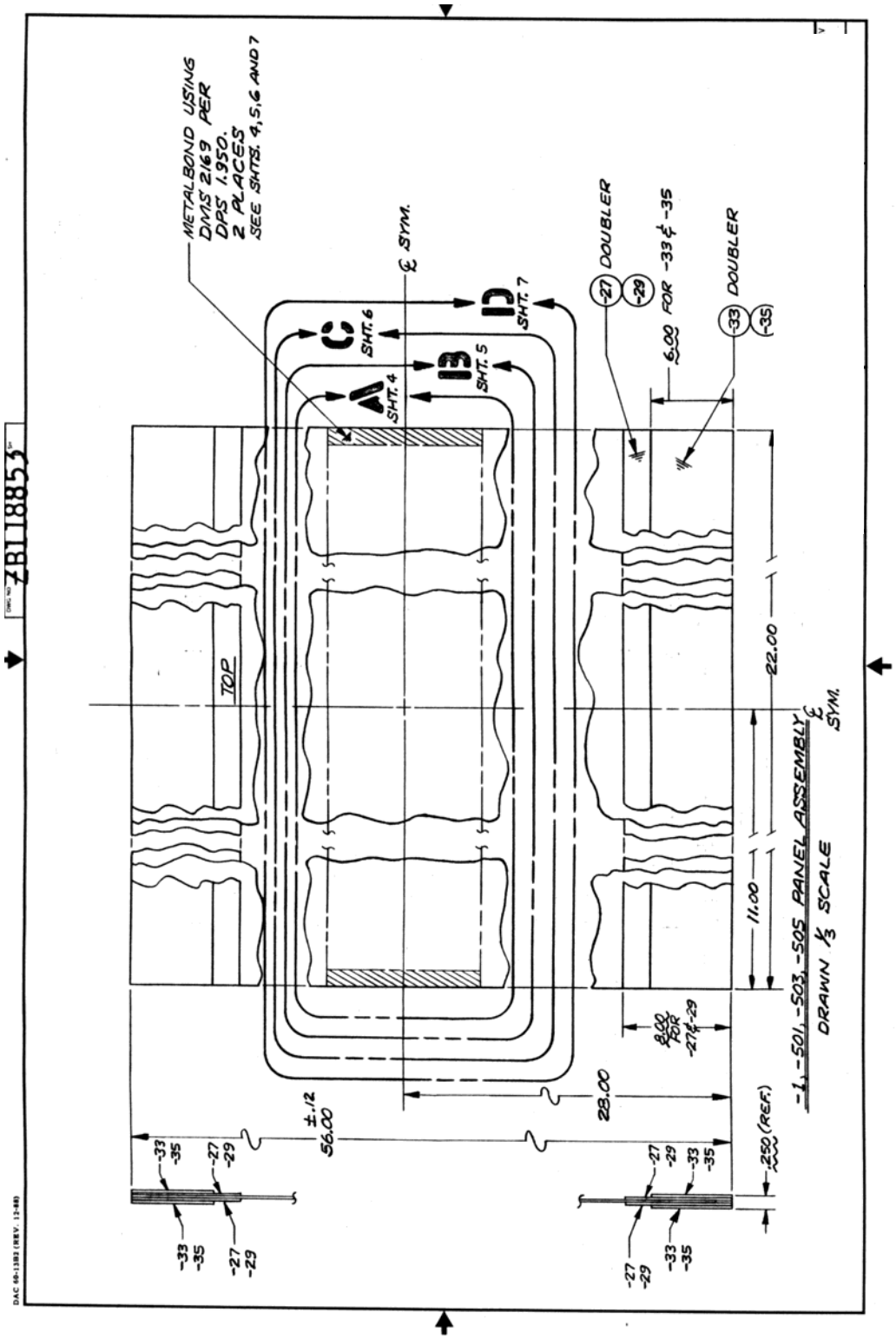


FIGURE E-1. EQUIVALENT INITIAL FLAW SIZE PANEL ASSEMBLY DRAWINGS (Continued)

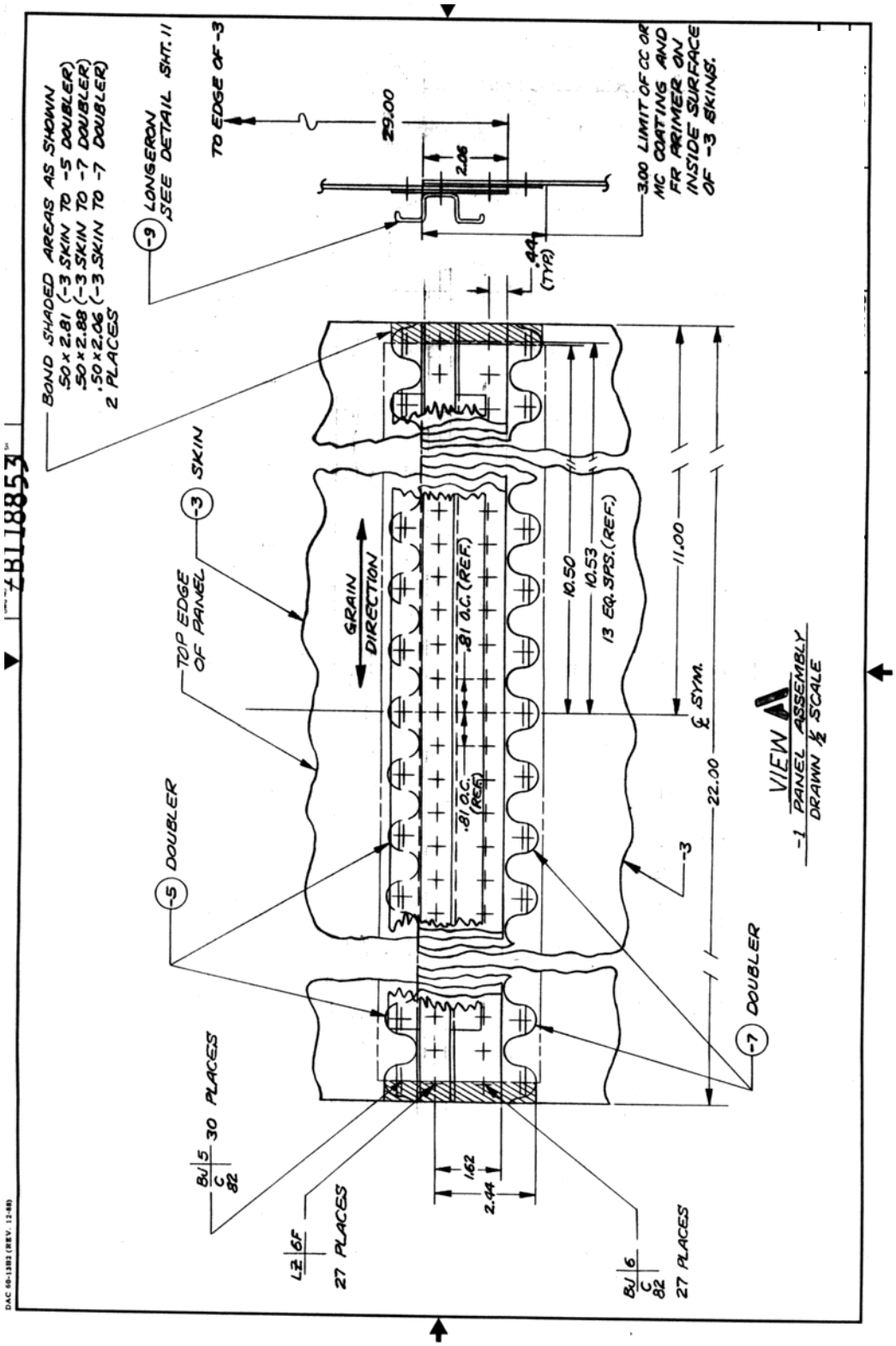


FIGURE E-1. EQUIVALENT INITIAL FLAW SIZE PANEL ASSEMBLY DRAWINGS (Continued)

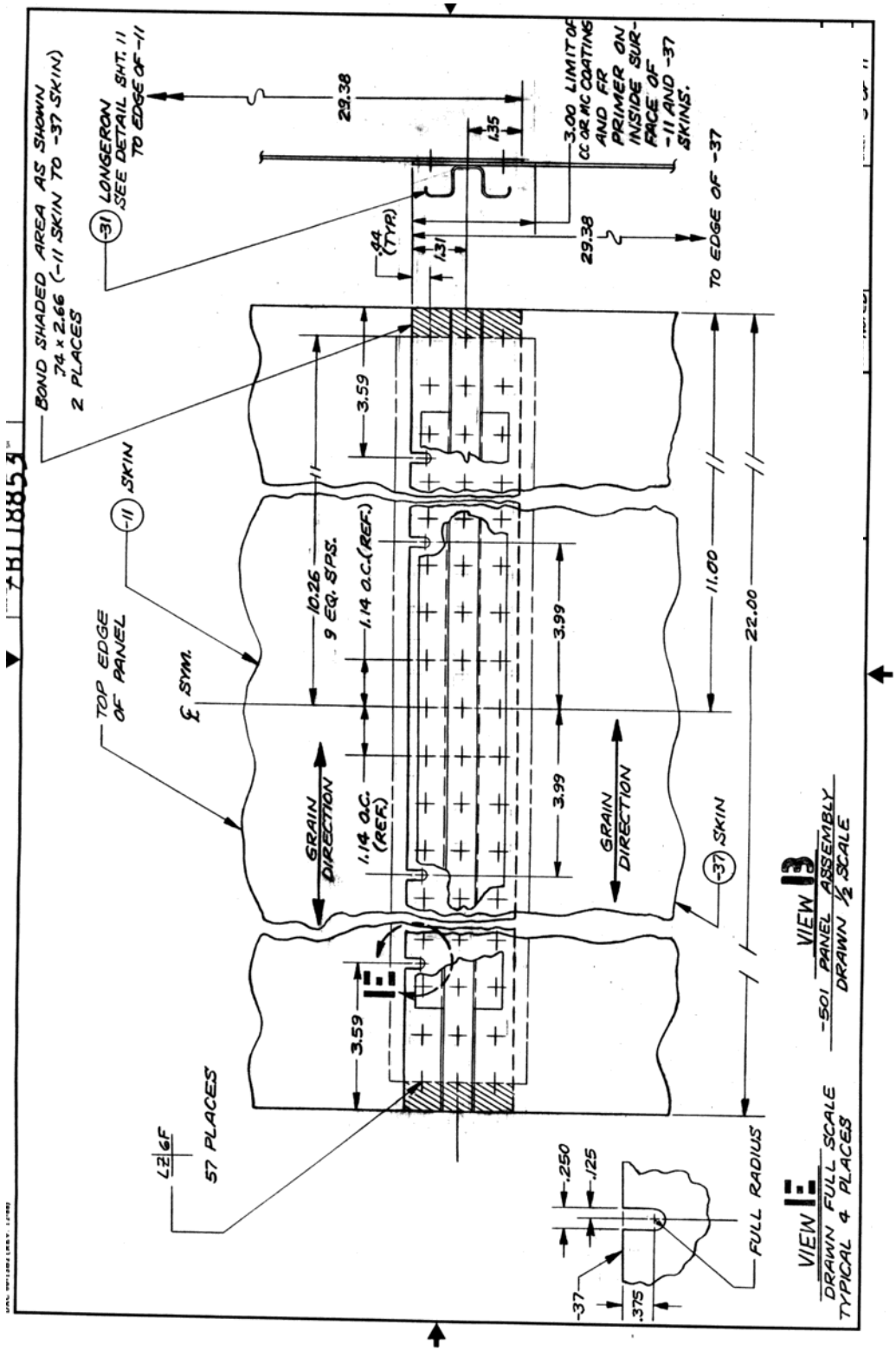


FIGURE E-1. EQUIVALENT INITIAL FLAW SIZE PANEL ASSEMBLY DRAWINGS
(Continued)

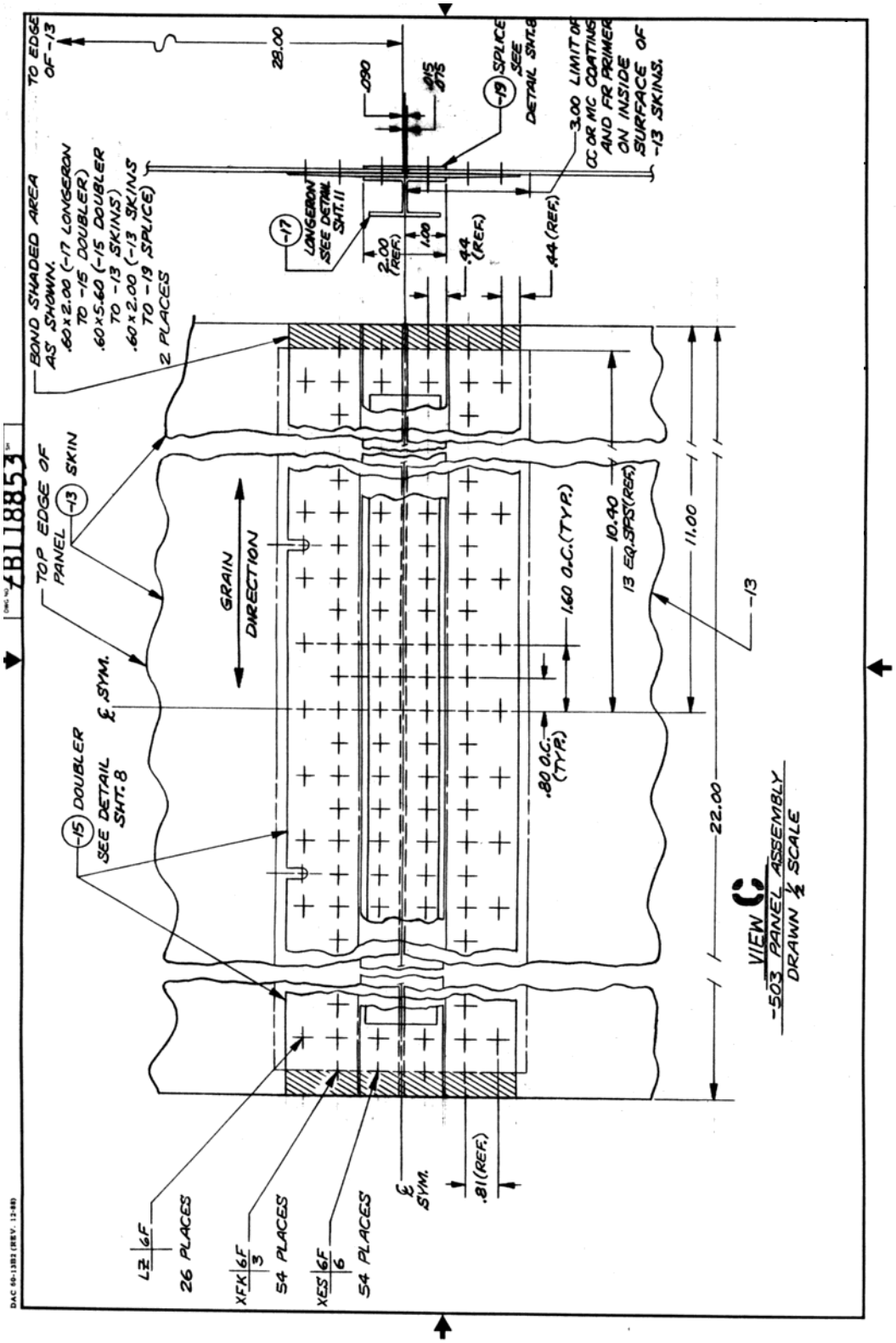


FIGURE E-1. EQUIVALENT INITIAL FLAW SIZE PANEL ASSEMBLY DRAWINGS (Continued)

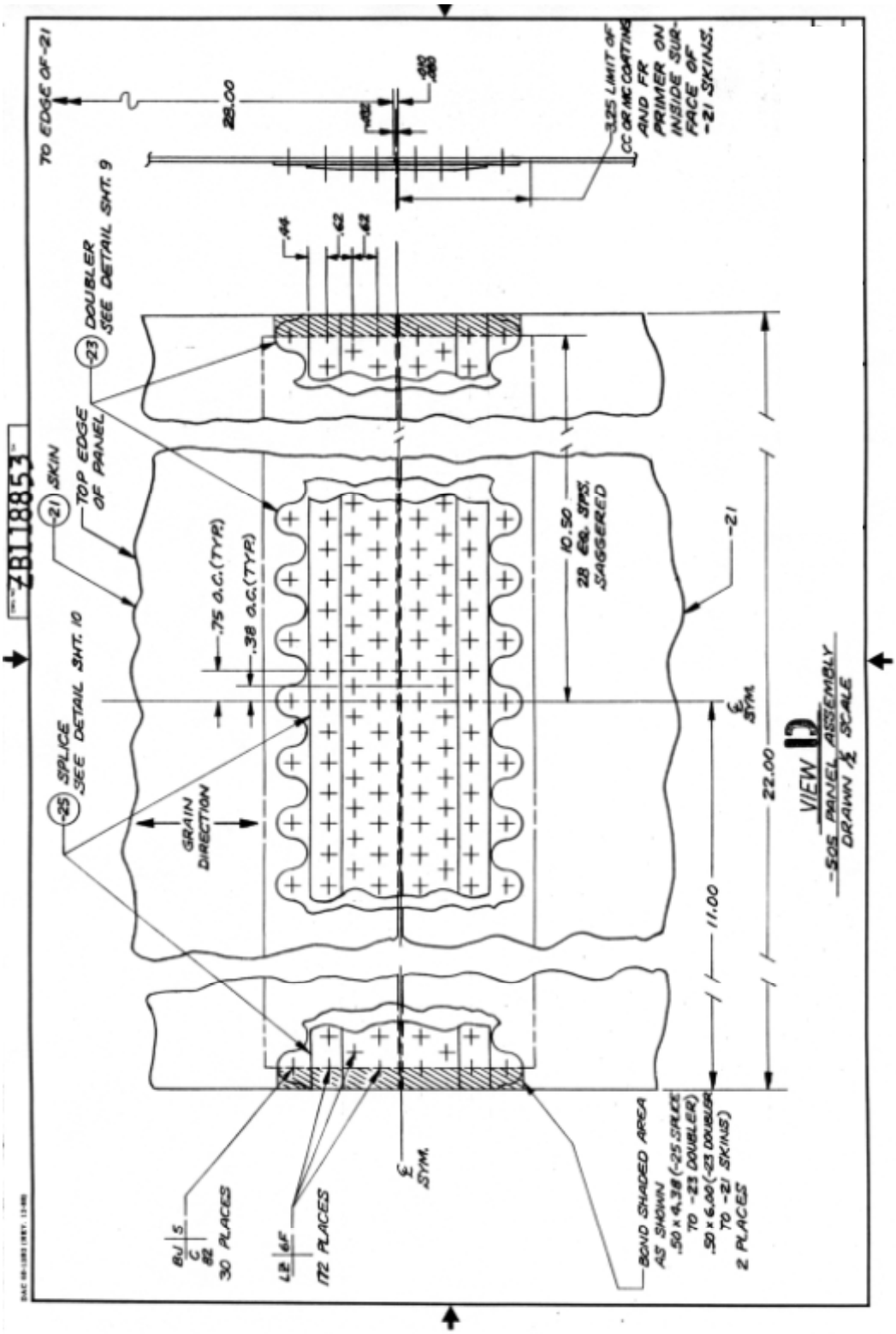


FIGURE E-1. EQUIVALENT INITIAL FLAW SIZE PANEL ASSEMBLY DRAWINGS (Continued)

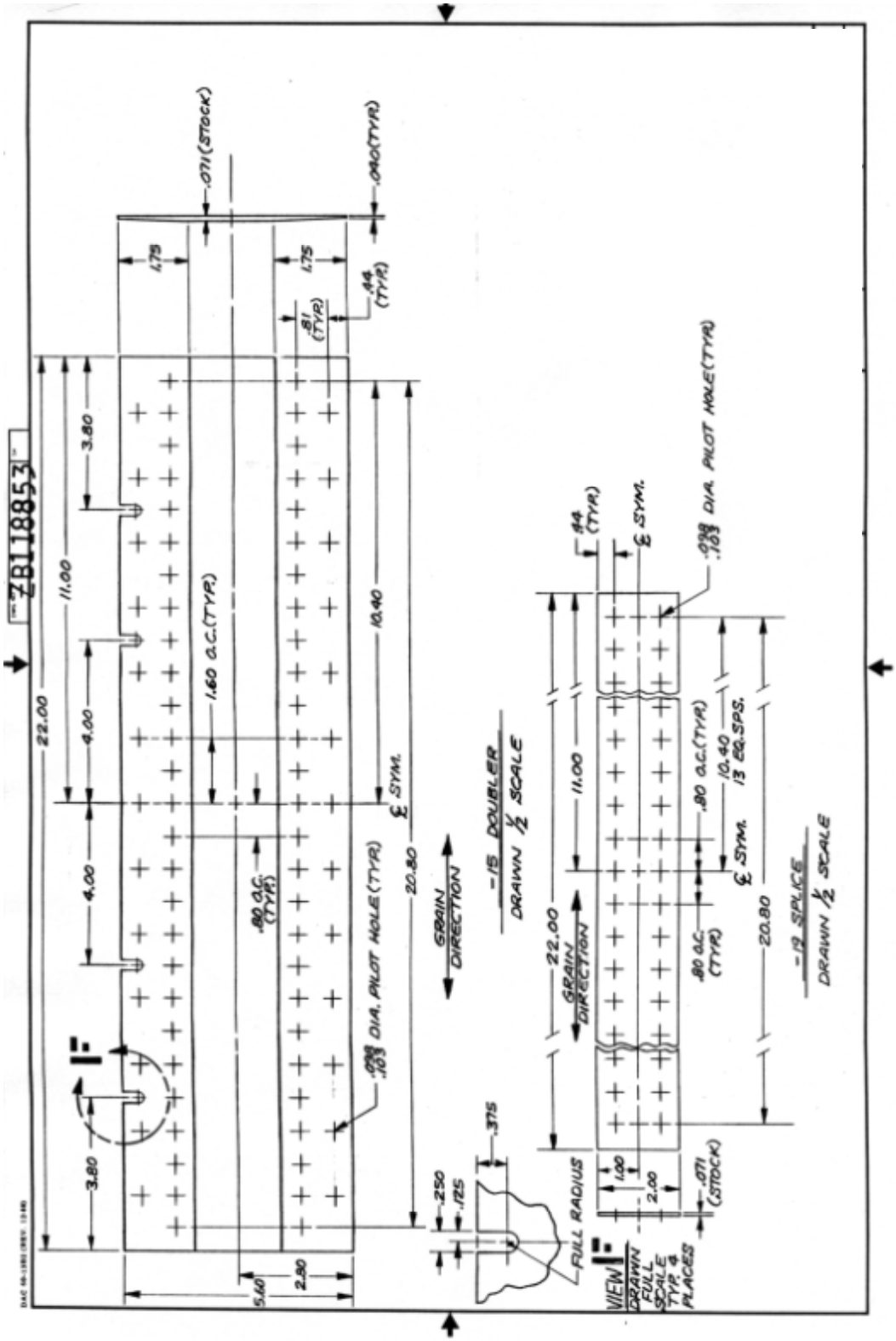


FIGURE E-1. EQUIVALENT INITIAL FLAW SIZE PANEL ASSEMBLY DRAWINGS (Continued)

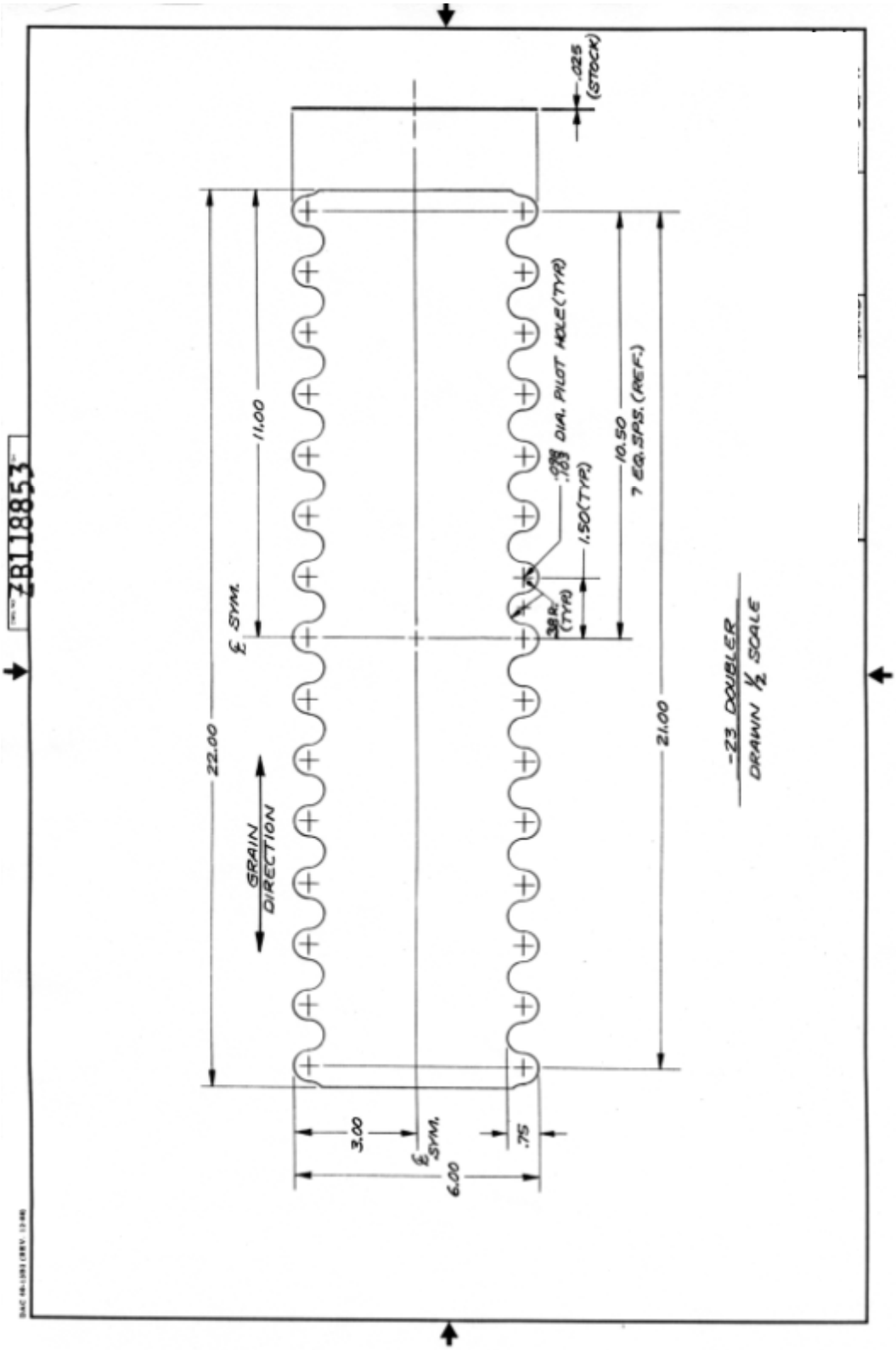


FIGURE E-1. EQUIVALENT INITIAL FLAW SIZE PANEL ASSEMBLY DRAWINGS (Continued)

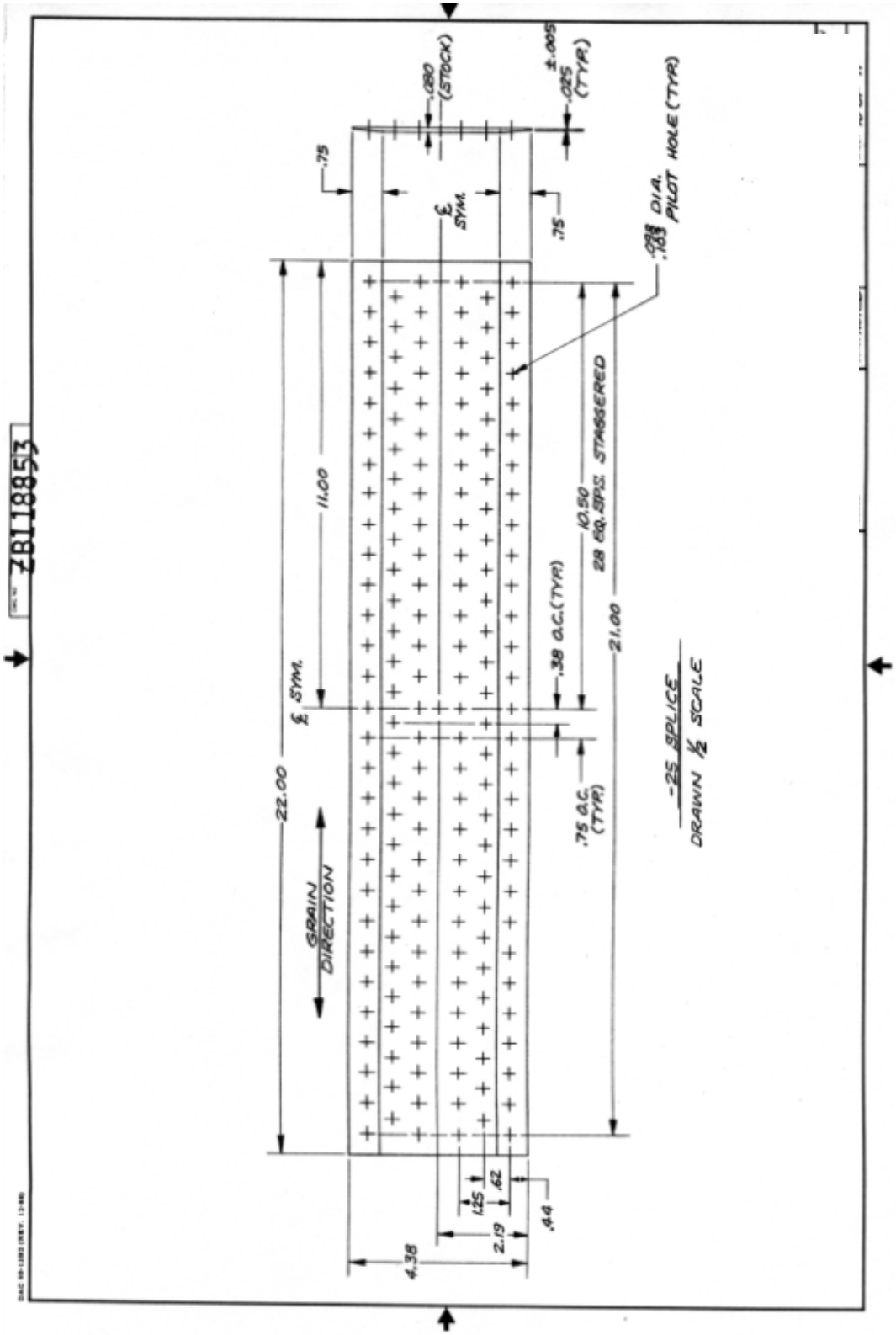


FIGURE E-1. EQUIVALENT INITIAL FLAW SIZE PANEL ASSEMBLY DRAWINGS (Continued)

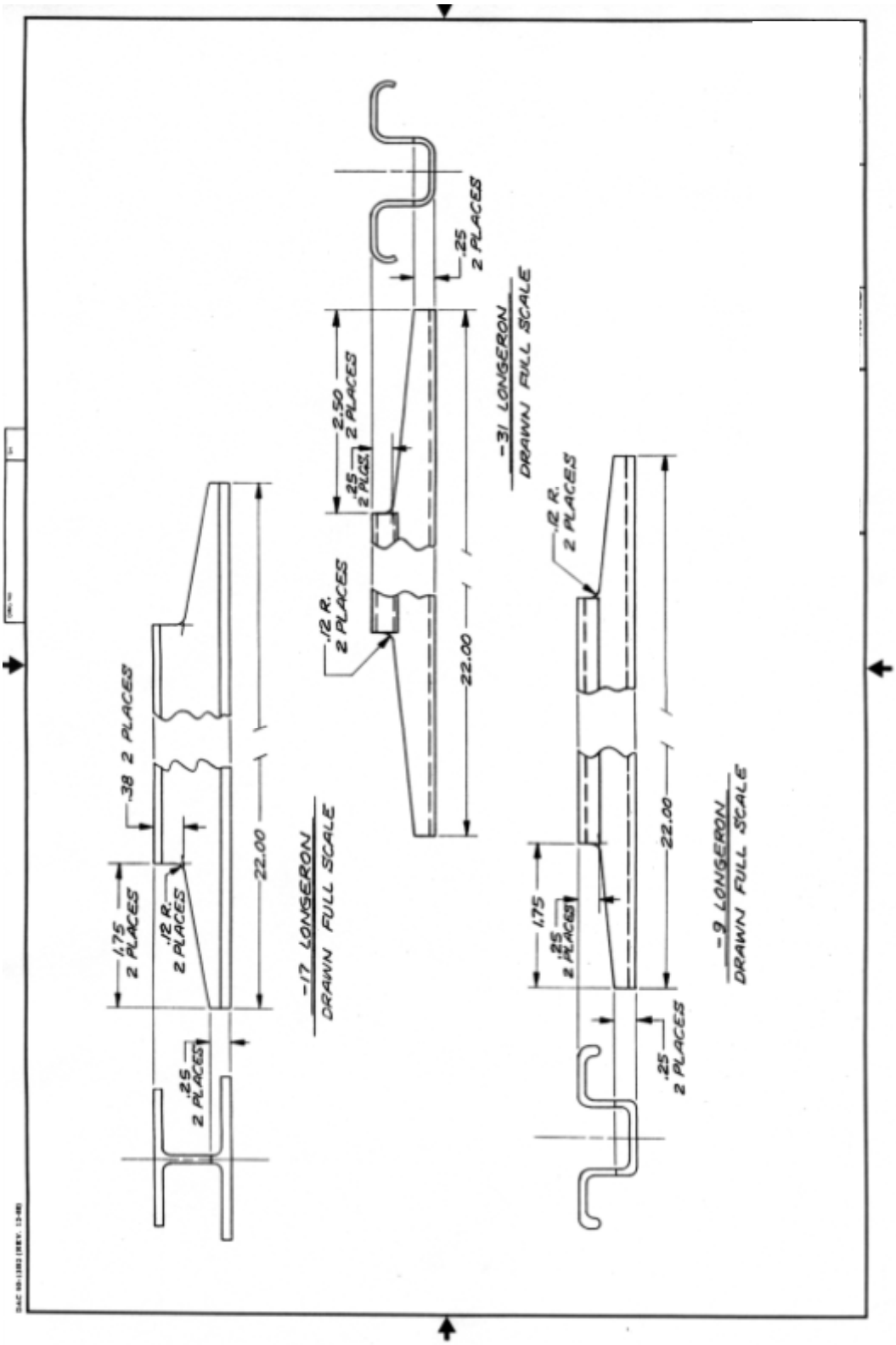


FIGURE E-1. EQUIVALENT INITIAL FLAW SIZE PANEL ASSEMBLY DRAWINGS (Continued)

DRAWING PARTS LIST DOUGLAS AIRCRAFT COMPANY MCDONNELL DOUGLAS CAGE CODE 88277

DAC 25-460B-4D (REV 2-93)

QUANTITY REQUIRED PER NOTED DASH NUMBER

NOTE: DRAWING CONFIGURATIONS ARE INDICATED THUS* OTHER DASH NUMBERS ASSEMBLE INTO DRAWING CONFIGURATIONS AS NOTED

C/C CONTROL CODE

B	BULK MATL	P1	PURCH DAC PART–SUP MATL
C	CUST FURN CUST INSTL	P2	PURCH DAC PART–DAC MATL
D	CUST FURN DAC INSTL	R	REWORK OR REPAIR PART
F	CUST FURN INSTL CHECK	S	DAC STANDARD PART
G	GOVT OR IND STANDARD	V	SUPPLIER ITEM–SPEC CONT
L	COMML SHELF ITEM	X	PROCESS REQD BY SCN
M	MAKE FROM ITEM	Z	REF DOCUMENT
M–	MAKE FROM DAC ITEM	–	DAC DRAWING NOT STD PART

CONTRACT NUMBER

DWG SIZE B DWG NO. PLZB118853 REV

TITLE (NOUN PHRASE) PANEL ASSEMBLY

SHEET 1 OF 3

ENGINEER/DRAFTSMAN E.L. HAYMAN DATE 1-27-97

DESIGN GROUP ATAS D&DT

IPRSX	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17		PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	CAGE NO.	C/C	STOCK SIZE	PARTS LIST CODE OR (MATERIAL DESCRIPTION)	MATERIAL SPECIFICATION (AND/OR SUPPLIER)	NOTES	ITEM FIND NO.	ZONE	IPRSX
														-505	-503	-501	-1												
																	2	1	-3	SKIN			.063×22×29 GR. XWISE.	AL SHEET CLAD 2024-T3	QQ-A-250/5 TEMP T3				
																	1	2	-5	DOUBLER			MAKE FROM S00056-3-3000						
																	1	3	-7	DOUBLER			MAKE FROM S00056-10-3000						
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17													
																	1	4	-9	LONGERON			MAKE FROM S00067-2200						
															1			5	-11	SKIN			.063×22×30 GR. XWISE.	AL SHEET CLAD 2024-T3	QQ-A-250/5 TEMP T3				
														2				6	-13	SKIN			.090×22×28 GR. XWISE.	AL SHEET CLAD 2024-T3	QQ-A-250/5 TEMP T3				
														1				7	-15	DOUBLER			.071×6×22 GR. LONG.	AL SHEET CLAD 2024-T3	QQ-A-250/5 TEMP T3				
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17													
														1				8	-17	LONGERON			MAKE FROM 1D0514T (22.00 LONG)						
														1				9	-19	SPLICE			.071×2×22 GR. LONG	AL SHEET CLAD 2024-T3	QQ-A-250/5 TEMP T3				
													2					10	-21	SKIN			.063×22×28 GR. LONG.	AL SHEET CLAD 2024-T3	QQ-A-250/5 TEMP T3				
													1					11	-23	DOUBLER			.025×6×22 GR. LONG.	AL SHEET CLAD 7075-T6	QQ-A-250/13 TEMP T6				
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17													
													1					12	-25	SPLICE			.080×5×22 GR. LONG.	AL SHEET CLAD 7075-T6	QQ-A-250/13 TEMP T6				

FIGURE E-1. EQUIVALENT INITIAL FLAW SIZE PANEL ASSEMBLY DRAWINGS (Continued)

DRAWING PARTS LIST DOUGLAS AIRCRAFT COMPANY / MCDONNELL DOUGLAS / CAGE CODE 88277

DAC 25-460B-4D (REV. 2-93)

QUANTITY REQUIRED PER NOTED DASH NUMBER

NOTE: DRAWING CONFIGURATIONS ARE INDICATED THUS* OTHER DASH NUMBERS ASSEMBLE INTO DRAWING CONFIGURATIONS AS NOTED.

C/C CONTROL CODE

B	BULK MATL	P1	PURCH DAC PART–SUP MATL
C	CUST FURN CUST INSTL	P2	PURCH DAC PART–DAC MATL
D	CUST FURN DAC INSTL	R	REWORK OR REPAIR PART
F	CUST FURN INSTL CHECK	S	DAC STANDARD PART
G	GOVT OR IND STANDARD	V	SUPPLIER ITEM–SPEC CONT
L	COMM. SHELF ITEM	X	PROCESS REQD BY SCN
M	'MAKE FROM' ITEM	Z	REF DOCUMENT
M–	'MAKE FROM' DAC ITEM	–	DAC DRAWING NOT STD PART

CONTRACT NUMBER _____ DWG SIZE B DWG NO. PLZB118853 REV _____

TITLE (NOUN PHRASE) PANEL ASSEMBLY SHEET 2 OF 3

ENGINEER/DRAFTSMAN E.L. HAYMAN DATE 1-27-97

DESIGN GROUP ATAS D&DT

IPRSX	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17		PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	CAGE NO.	C/C	STOCK SIZE	PARTS LIST CODE OR (MATERIAL DESCRIPTION)	MATERIAL SPECIFICATION (AND/OR SUPPLIER)	NOTES	ITEM FIND NO.	ZONE	IPRSX
														1505	1503	1501	1												
															4			1	-27	DOUBLER			.040×8×22 GR. LONG.	AL SHEET CLAD 2024-T3	QQ-A-250/5 TEMP T3				
														4		4	4	2	-29	DOUBLER			.050×8×22 GR. LONG.	AL SHEET CLAD 2024-T3	QQ-A-250/5 TEMP T3				
																1		3	-31	LONGERON			MAKE	FROM S2777922-6-2200					
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17												
															4			4	-33	DOUBLER			.040×6×22 GR. LONG.	AL SHEET CLAD 2024-T3	QQ-A-250/5 TEMP T3				
														4		4	4	5	-35	DOUBLER			.050×6×22 GR. LONG.	AL SHEET CLAD 2024-T3	QQ-A-250/5 TEMP T3				
																1		6	-37	SKIN			.063×22×30 GR. XWISE	AL SHEET CLAD 2024-T3	QQ-A-250/5 TEMP T3				
																		7											
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	8											
																		9											
																		10											
																		11											
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	12											

FIGURE E-1. EQUIVALENT INITIAL FLAW SIZE PANEL ASSEMBLY DRAWINGS (Continued)

DRAWING PARTS LIST

DAC 25-460B-4D (REV 2-93)

DOUGLAS AIRCRAFT COMPANY
MCDONNELL DOUGLAS
CAGE CODE 80277

QUANTITY REQUIRED PER NOTED DASH NUMBER

NOTE: DRAWING CONFIGURATIONS ARE INDICATED THUS* OTHER DASH NUMBERS ASSEMBLE INTO DRAWING CONFIGURATIONS AS NOTED.

C/C CONTROL CODE

B	BULK MATL	P1	PURCH DAC PART–SUP MATL
C	CUST FURN CUST INSTL	P2	PURCH DAC PART–DAC MATL
D	CUST FURN DAC INSTL	R	REWORK OR REPAIR PART
F	CUST FURN INSTL CHECK	S	DAC STANDARD PART
G	GOVT OR IND STANDARD	V	SUPPLIER ITEM–SPEC CONT
L	COMMIL SHELF ITEM	X	PROCESS REQD BY SCN
M	'MAKE FROM' ITEM	Z	REF DOCUMENT
M–	'MAKE FROM' DAC ITEM	–	DAC DRAWING NOT STD PART

CONTRACT NUMBER _____ DWG SIZE B DWG NO. PLZB118853 REV _____

TITLE (NOUN PHRASE) PANEL ASSEMBLY SHEET 3 OF 3

ENGINEER/DRAFTSMAN E.L. HAYMAN DATE 1-27-97

DESIGN GROUP ATAS D&DT

IPRSX	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17		PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	CAGE NO.	C/C	STOCK SIZE	PARTS LIST CODE OR (MATERIAL DESCRIPTION)	MATERIAL SPECIFICATION (AND/OR SUPPLIER)	NOTES	ITEM FIND NO.	ZONE	IPRSX
														-505	-503	-501	-1												
														30			30	1	MS20470AD5	RIVET			INDICATED	THUS	BJ 5				
																	27	2	MS20470AD6	RIVET			INDICATED	THUS	BJ 6				
														172	26	57	27	3	NAS1097AD6	RIVET			INDICATED	THUS	LZ 6				
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17												
															54			4	S4932868-06	LOCKBOLT			INDICATED	THUS	XFK 6				
															54			5	NAS1080-06	COLLAR									
															54			6	S4931919-6	PIN			INDICATED	THUS	XES 6				
															54			7	NAS1252-10L	WASHER									
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17												
															54			8	MS21042-3	NUT									
																		9											
																		10											
																		11											
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	12											

FIGURE E-1. EQUIVALENT INITIAL FLAW SIZE PANEL ASSEMBLY DRAWINGS (Continued)

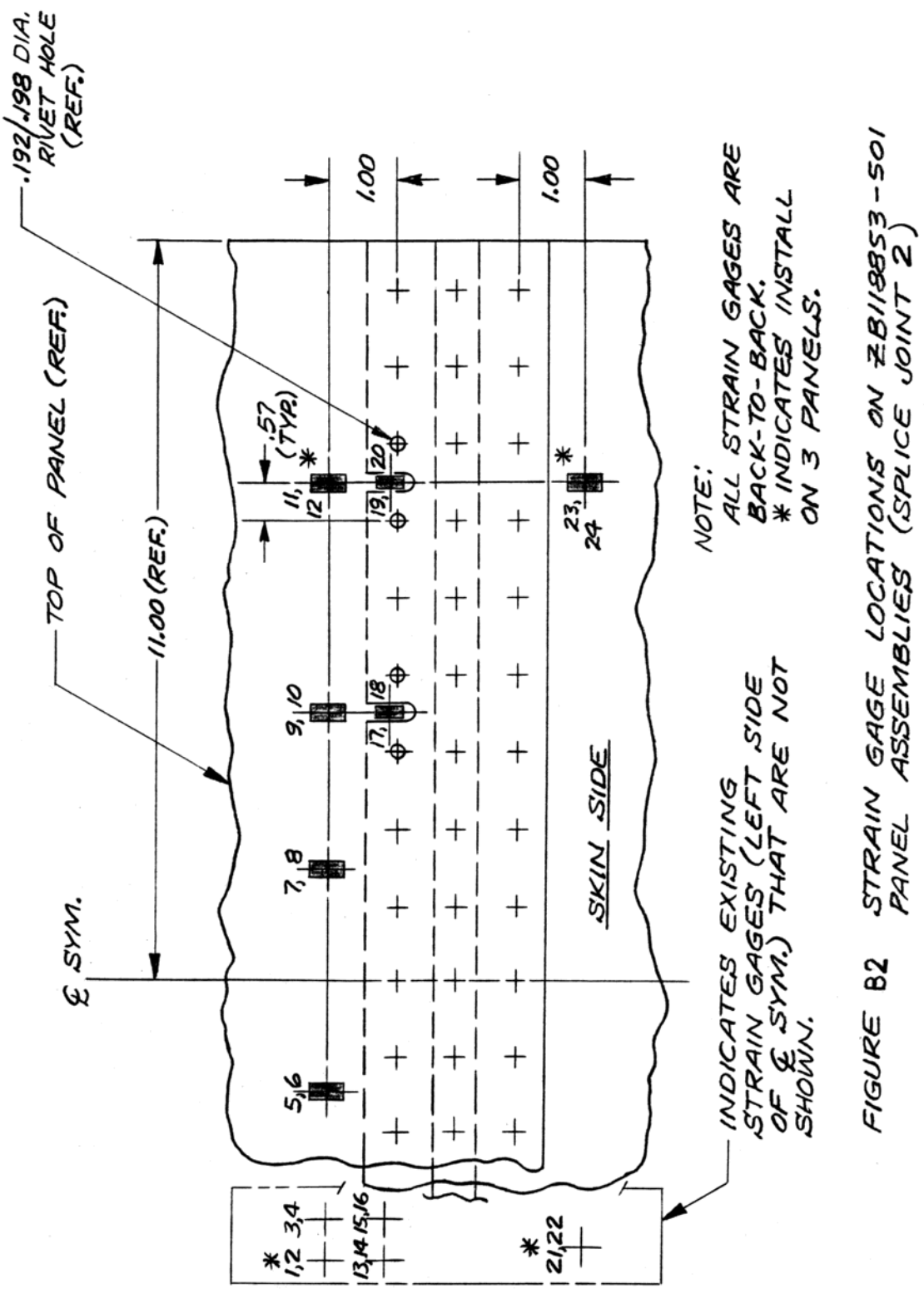


FIGURE E-2. STRAIN GAGE LOCATIONS FOR EIFS PANELS

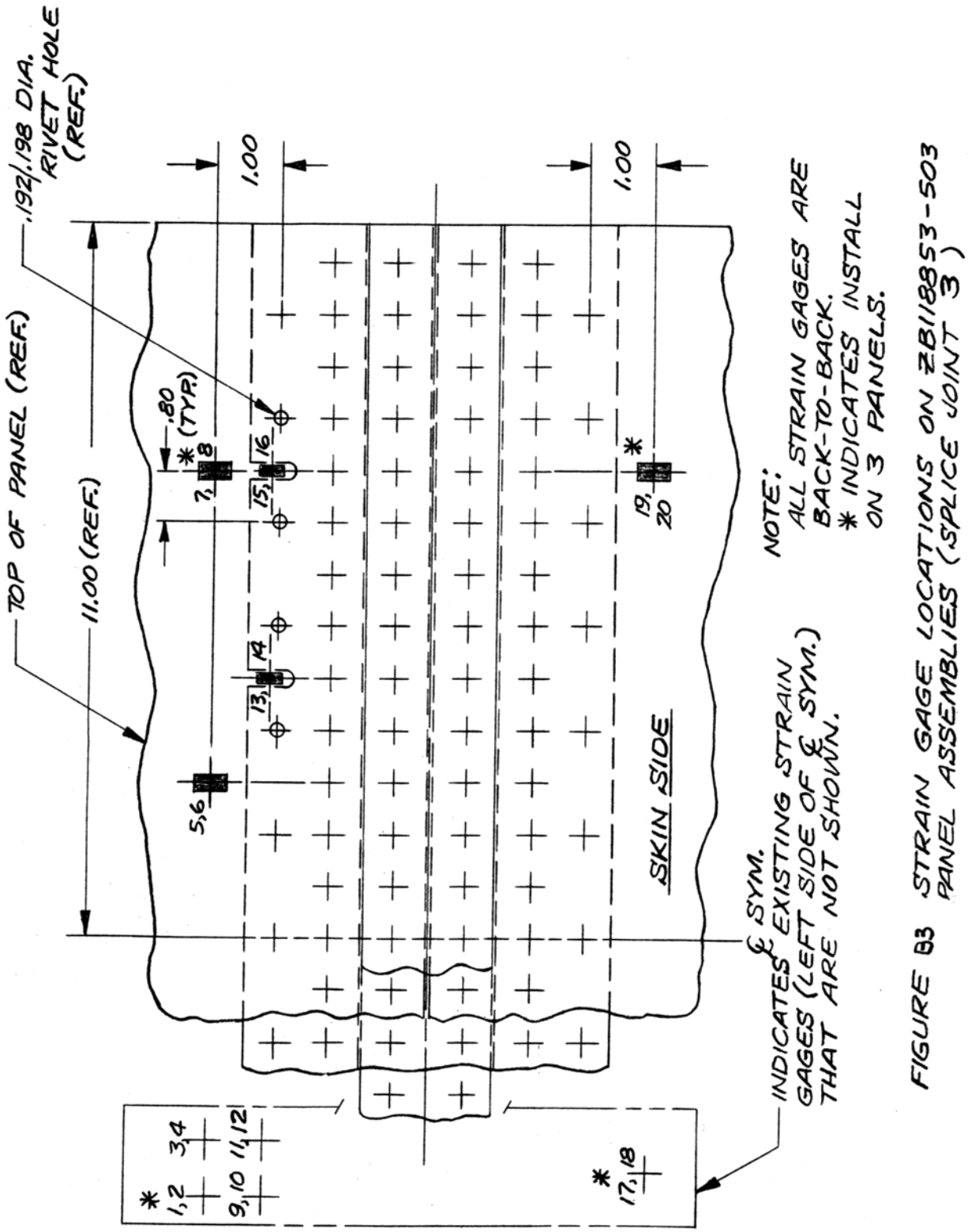


FIGURE B3 STRAIN GAGE LOCATIONS ON ZB118853-503 PANEL ASSEMBLIES (SPLICE JOINT 3)

FIGURE E-2. STRAIN GAGE LOCATIONS FOR EIFS PANELS (Continued)

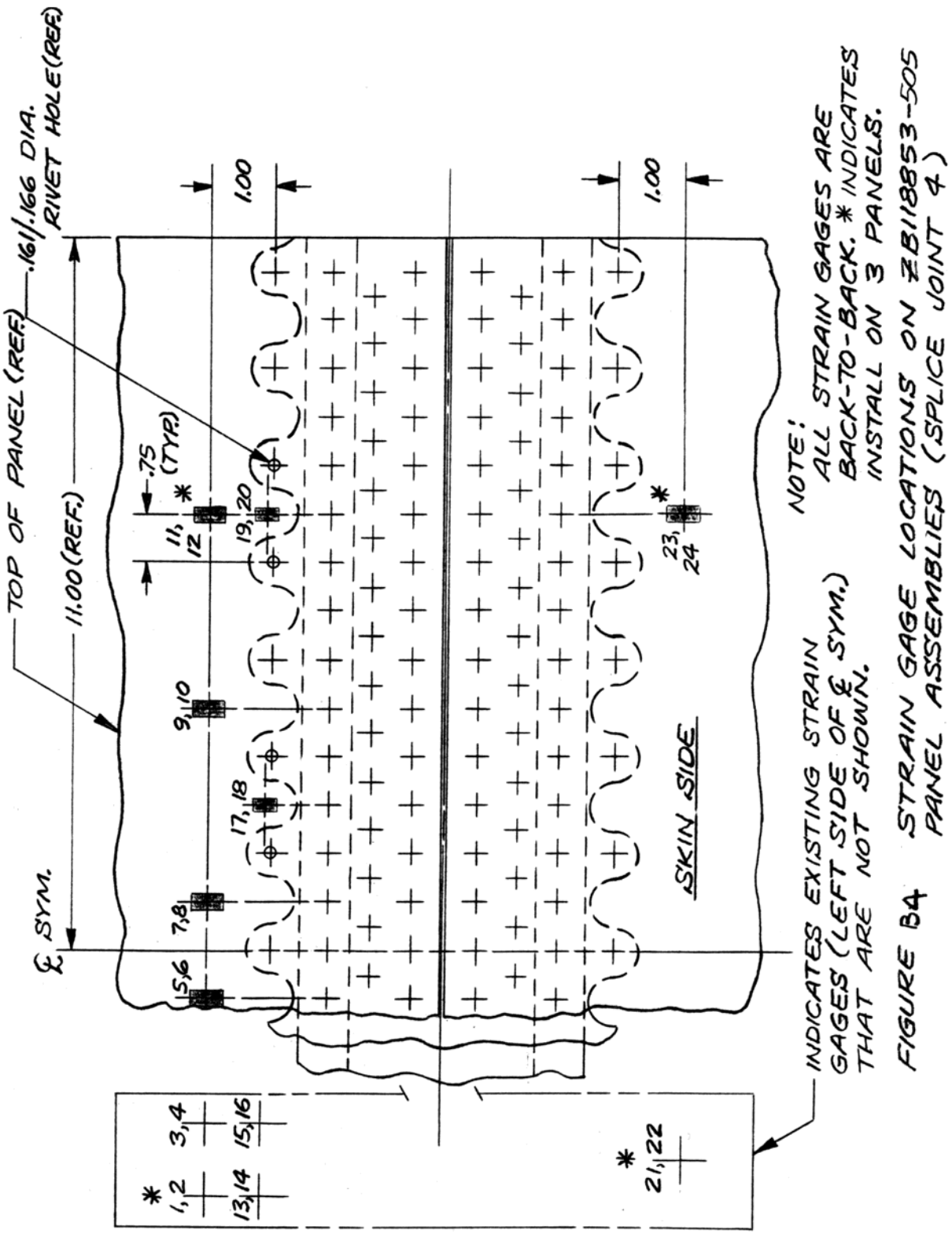


FIGURE E-2. STRAIN GAGE LOCATIONS FOR EIFS PANELS Continued)

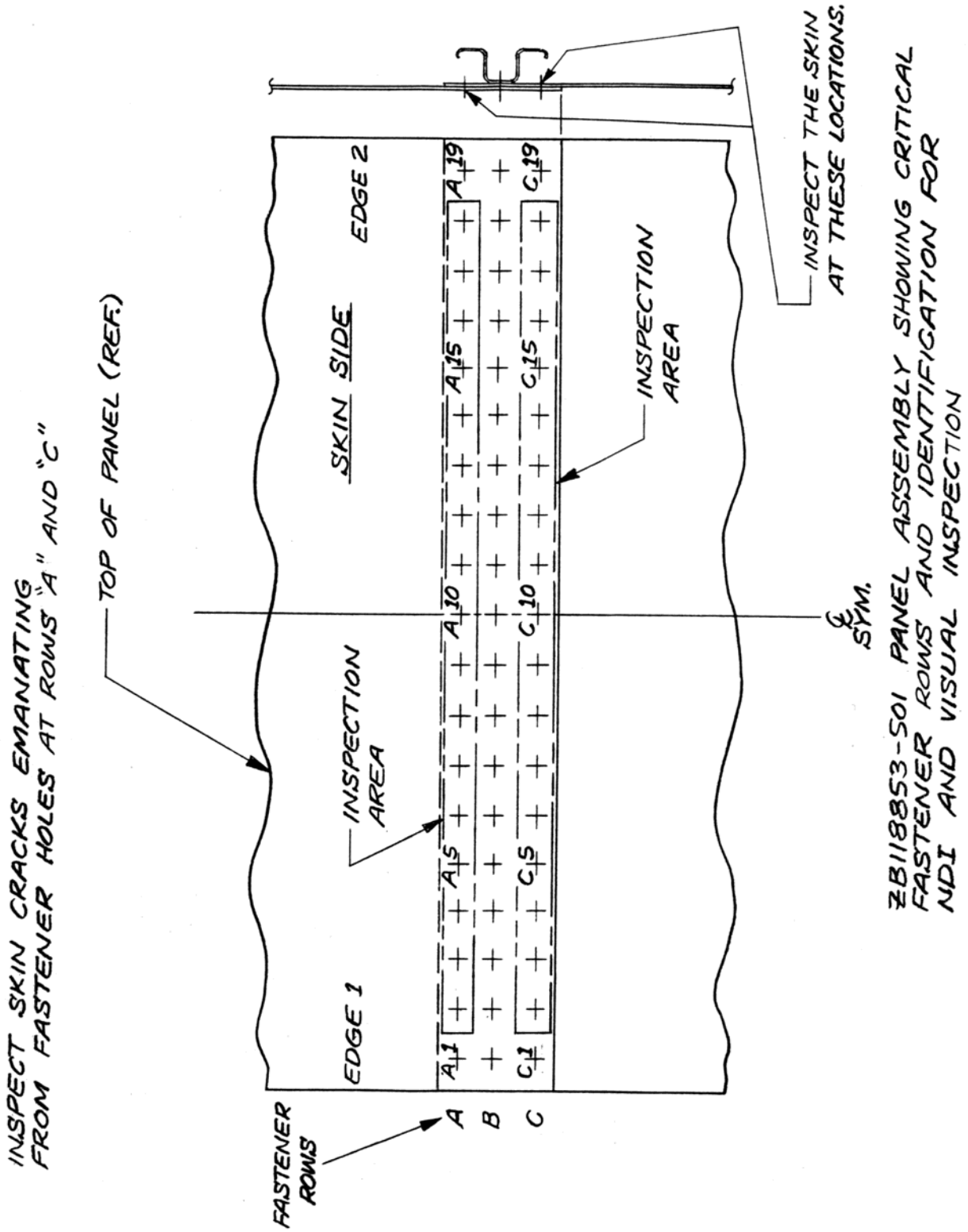


FIGURE E-3. EIFS PANELS INSPECTION AREA AND RIVET NUMBERING

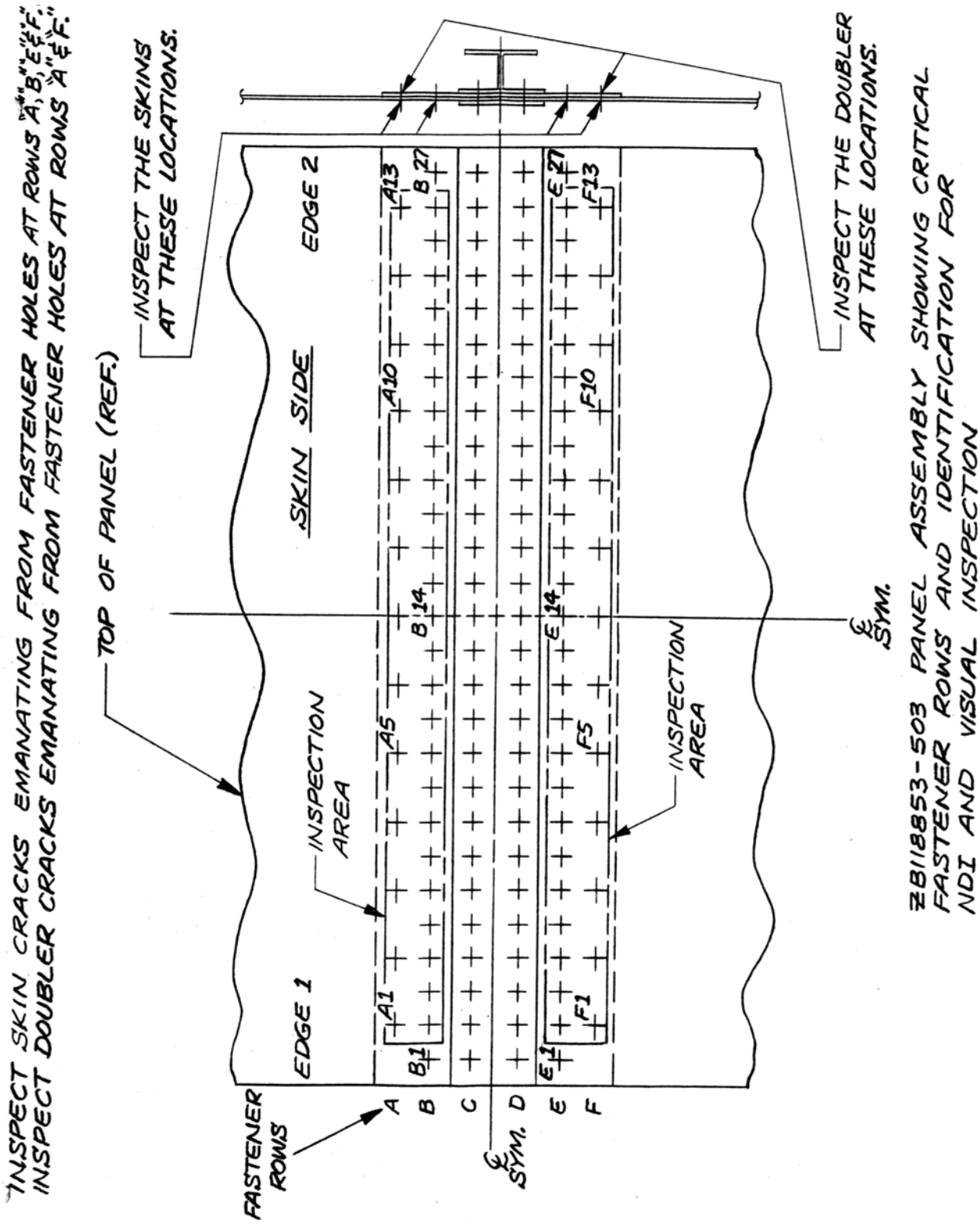


FIGURE E-3. EIFS PANELS INSPECTION AREA AND RIVET NUMBERING (Continued)

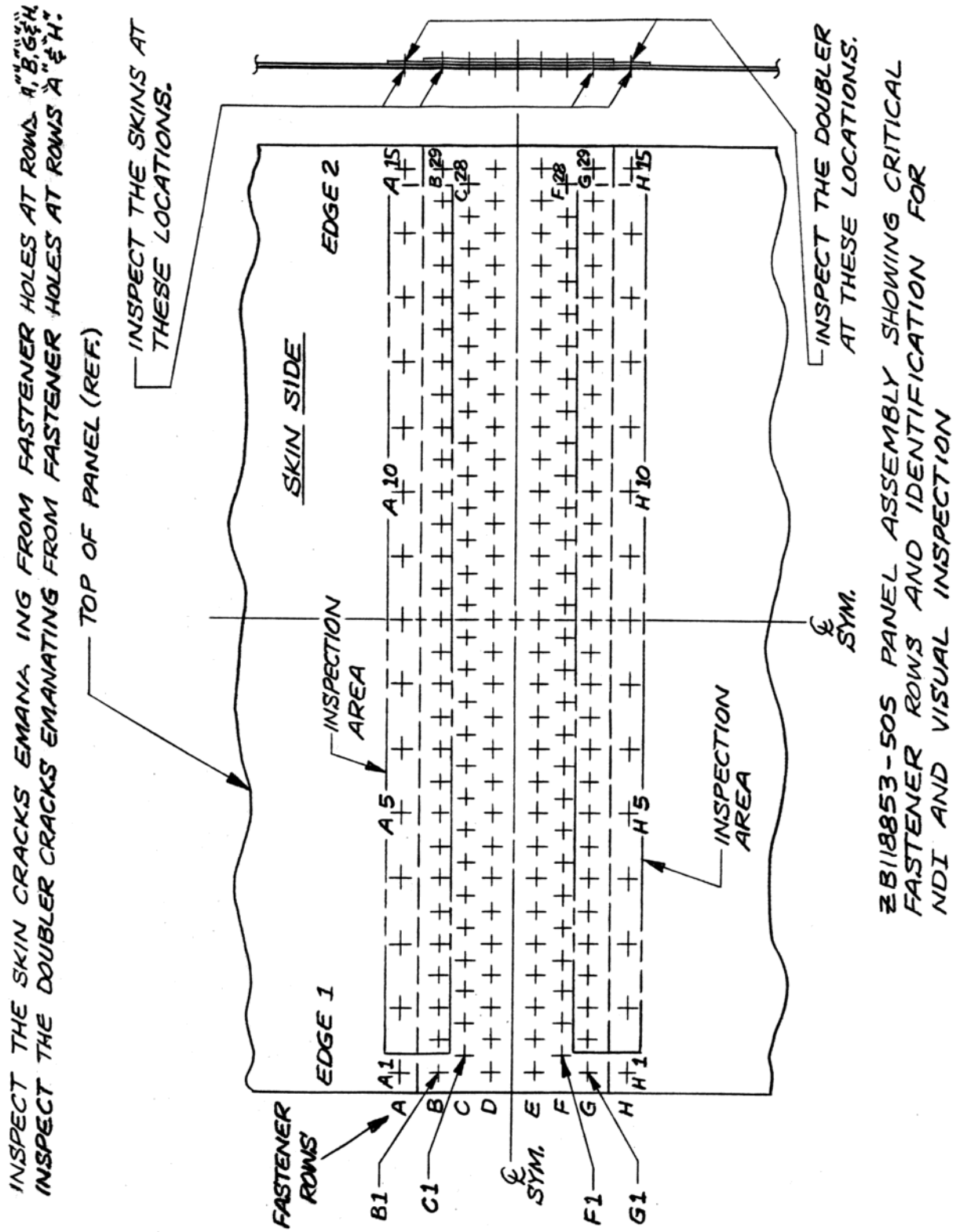


FIGURE E-3. EIFS PANELS INSPECTION AREA AND RIVET NUMBERING (Continued)

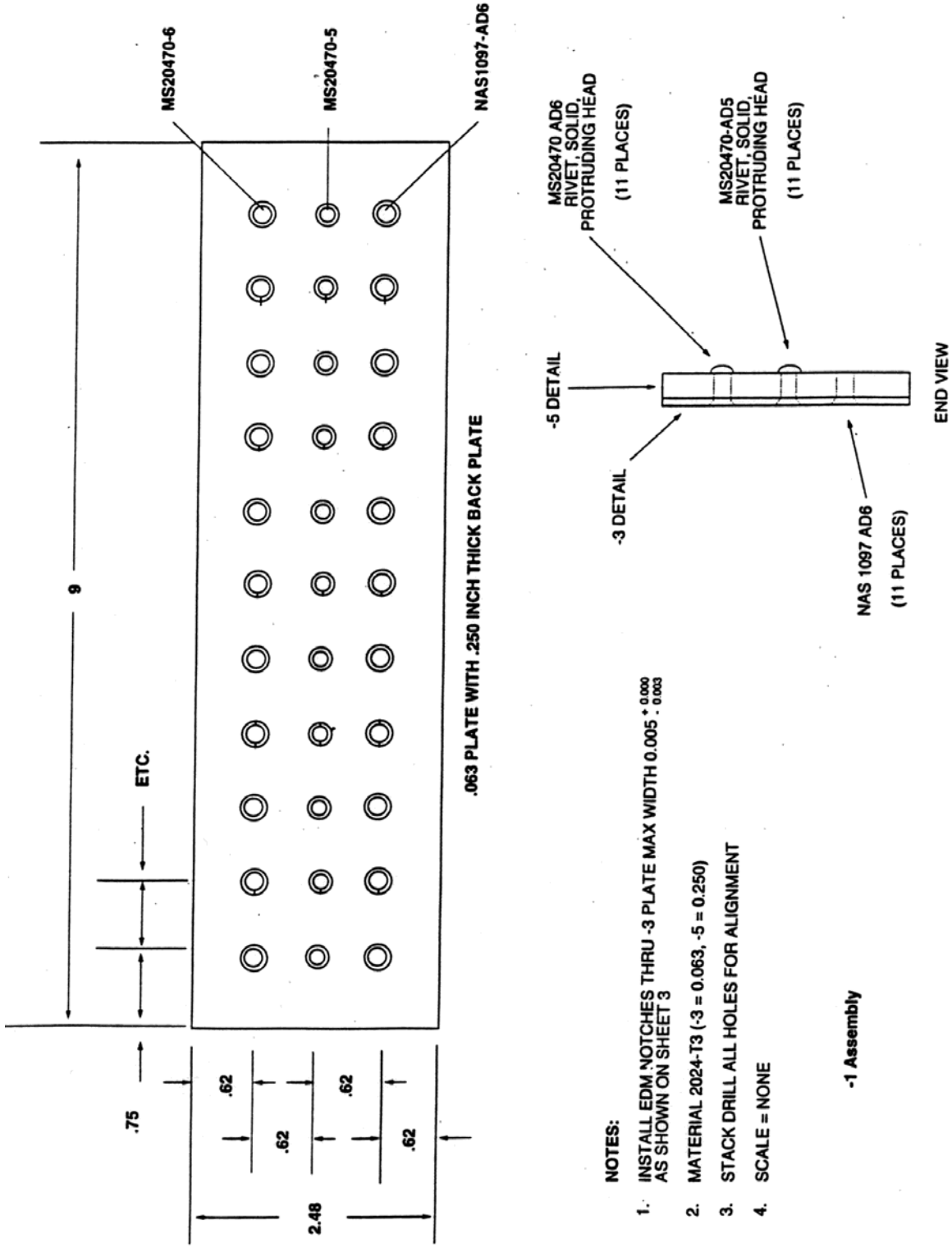


FIGURE E-4. DESCRIPTION OF 0.063-inch SKIN REFERENCE STANDARD

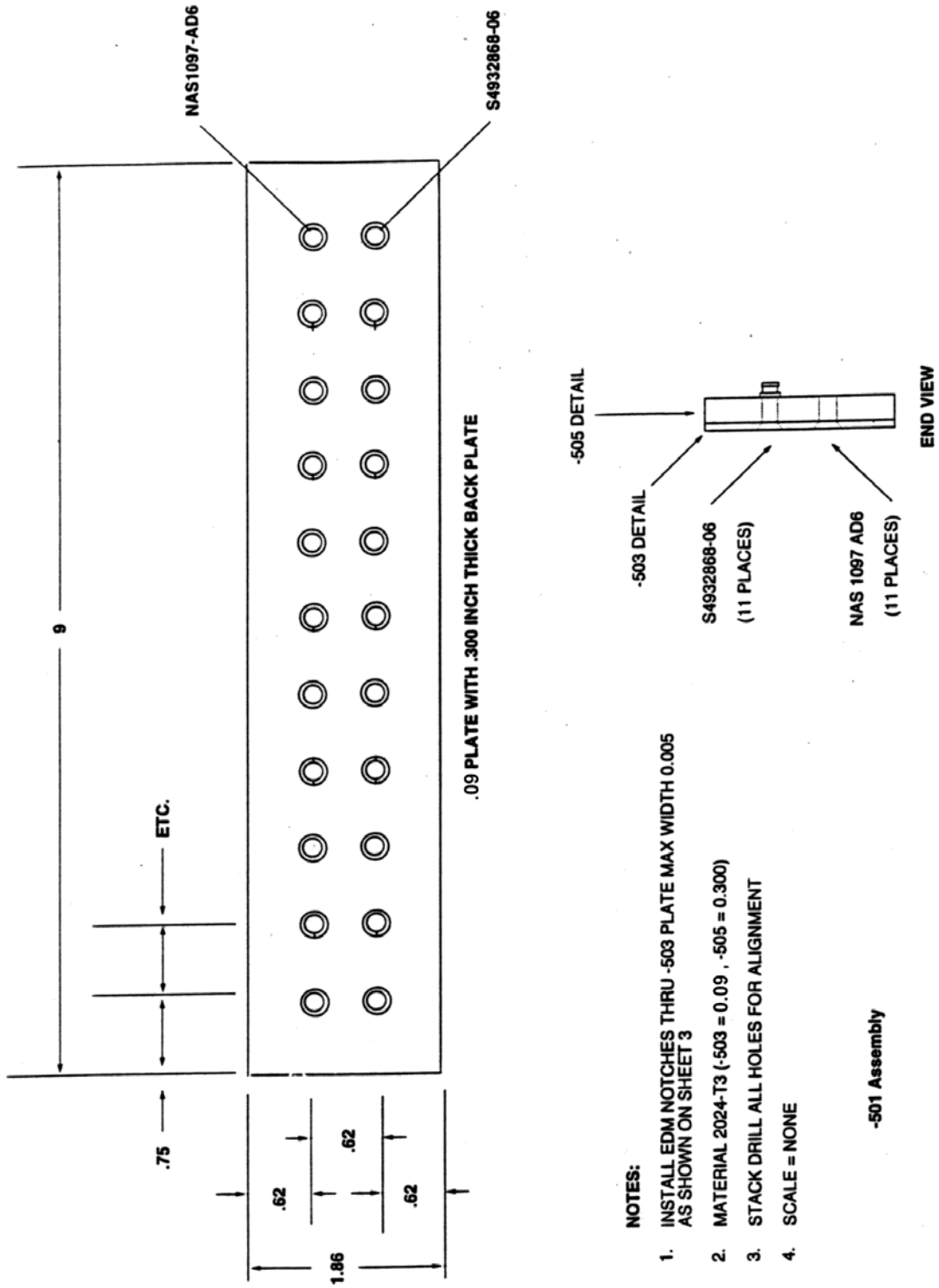
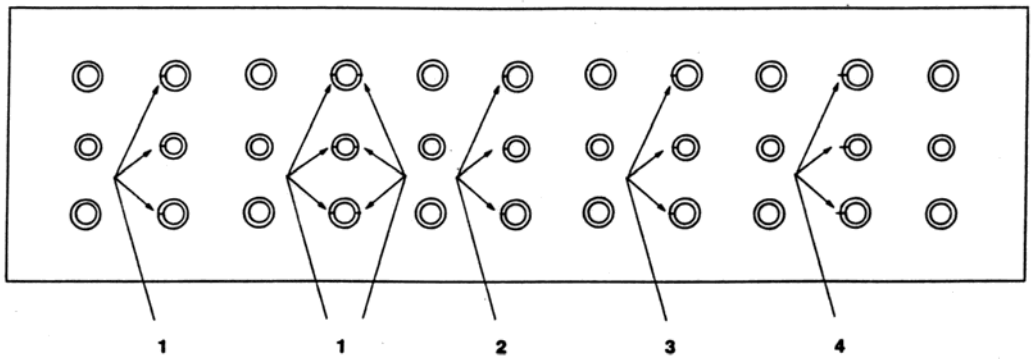


FIGURE E-5. DESCRIPTION OF 0.090-inch SKIN REFERENCE STANDARD



NOTES:

1. INSTALL EDM NOTCH THRU PLATE 0.030 LONG X .005 WIDTH +.000 OR -.003 INCH (9 PLACES)
2. INSTALL EDM NOTCH THRU PLATE 0.040 LONG X .005 WIDTH +.000 OR -.003 INCH (3 PLACES)
3. INSTALL EDM NOTCH THRU PLATE 0.050 LONG X .005 WIDTH +.000 OR -.003 INCH (3 PLACES)
4. INSTALL EDM NOTCH THRU PLATE 0.075 LONG X .005 WIDTH +.000 OR -.003 INCH (3 PLACES)
5. NO SCALE

EDM INSTALLATION

FIGURE E-6. DESCRIPTION OF EDM INSTALLATION FOR (3 ROWS) 0.063-inch SKIN ASSEMBLY

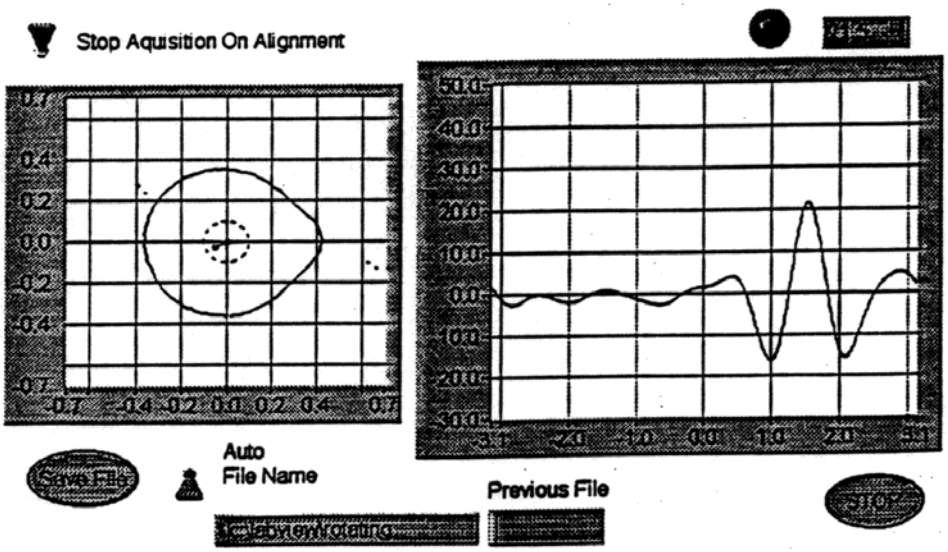


FIGURE E-7. FRONT PANEL OF THE ROTATING PROBE SYSTEM DISPLAY

Figure E-8 contains the data obtained during the SEM fractographic investigation of all EIFS panel fracture surfaces for which marker bands could be detected.

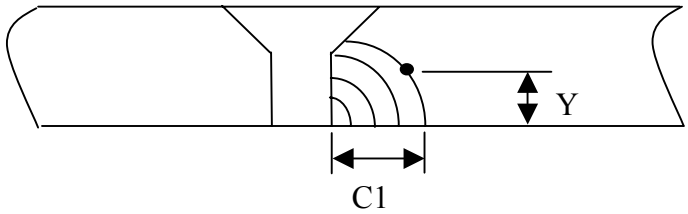
The crack naming convention is as follows:

E.1.1 3C14R

- Hole Side (**L**eft or **R**ight)
- Hole Number (Left to Right)
- Rivet Row
- EIFS Specimen Number

The parameters in the table are:

Groups - Number of marker cycle blocks, either 10, 4, or 6 blocks (see section 6.5)
y - The distance from the faying surface to the crack front in the thickness direction (mm)
c1 - Crack length (mm)



Groups	y	3C14R Cycles	c1
10	0.12	147660	0.16
4	0.19	151420	0.25
6	0.11	154960	0.40
10	0.30	158830	0.42
4	0.16	162590	0.63

Groups	y	3C17R Cycles	c1
10	0.16	116020	0.34
4	0.12	123320	0.43
6	0.15	130950	0.52
10	0.12	138360	0.62
4	0.16	145660	0.69
6	0.19	153290	0.76
10	0.16	160700	0.85
4	0.21	168000	0.94
fracture	0.25	170000	1.01

Groups	y	3D13R Cycles	c1
4	0.155	157860	0.20
6			
10	0.159	165270	0.26
4	0.184	169030	0.31
fracture		170000	0.32

Groups	y	3D15L Cycles	c1
10	0.16	91810	0.27
4	0.23	95570	0.33
6	0.26	99110	0.43
10	0.28	102980	0.51
4	0.29	106740	0.58
6	0.26	110280	0.67
10	0.26	114150	0.76
4	0.26	117910	0.86
6	0.34	121450	0.93
10	0.32	125320	1.04
4	0.39	129080	1.13
6	0.32	132620	1.25
10	0.31	136490	1.40
4	0.33	140250	1.53
6	0.37	143790	1.69
10	0.35	147660	1.88
4	0.41	151420	2.12
6	0.42	154960	2.37
4	0.17	162590	2.80
10	0.32	170000	3.33

FIGURE E-8. EIFS PANELS SEM CRACK GROWTH DATA

Groups	y	3D15L Cycles	c1
10	0.105	98290	0.298
4		102050	
6		105590	
10	0.277	109460	0.420
4	0.194	113220	0.536
6	0.248	116760	0.598
10	0.336	120630	0.677
4	0.238	124390	0.792
6	0.326	127930	0.865
10	0.388	131800	0.955
4	0.255	135560	1.109
6	0.438	139100	1.178
10	0.401	142970	1.325
4	0.402	146730	1.493
6	0.505	150270	1.631
10	0.476	154140	1.809
4	0.413	157900	2.049
6	0.410	161440	2.328
10	0.354	165310	2.731
4	0.308	169070	3.297
fracture		170000	3.458

Groups	y	4C9R Cycles	c1
4	0.06	138250	0.057
6?	0.07	141790	0.134
10	0.10	145660	0.171
4	0.17	149420	0.245
6	0.15	152960	0.311
10	0.22	156830	0.431
4	0.24	160590	0.502
6	0.22	164130	0.606
10	0.30	168000	0.706
fracture	0.37	170000	0.874

Groups	y	4C10R Cycles	c1
10?	0.21	-18,470	0.249
4?	0.15	-14,710	0.351
6	0.23	-11,170	0.375
10	0.28	-7,300	0.435
4	0.24	-3,540	0.535
fracture	0.26	170,000	0.656

Groups	y	4C11R Cycles	c1
10	0.16	127020	0.065
10	0.20	135190	0.093
10	0.23	143360	0.120
10	0.29	151530	0.216
4	0.20	155290	0.225
6	0.19	158830	0.278
10	0.07	162700	0.411
4	0.17	166460	0.447
6	0.16	170000	0.481

Groups	y	4C12R Cycles	c1
4	0.16	145,660	0.160
6	0.24	149,200	0.195
10	0.25	153,070	0.300
4	0.18	156,830	0.413
6	0.25	160,370	0.460
10	0.22	164,240	0.593
4	0.28	168,000	0.660
fracture	0.29	170,000	0.706

FIGURE E-8. EIFS PANELS SEM CRACK GROWTH DATA (Continued)

Groups	y	7A6L Cycles	c1
6	0.34	80200	0.67
10	0.45	82070	0.73
4			
6	0.46	85370	0.84
10	0.43	87240	0.87
4	0.35	89000	0.90
6	0.26	90540	0.91
10	0.28	92410	0.93
4			
6	0.35	95710	1.00
10	0.58	97580	1.02
4	0.71	99340	1.10
6	0.60	100880	1.16
10	0.70	102750	1.21
4	0.52	104510	1.30
6	0.32	106050	1.36
10	0.49	107920	1.44
4	0.33	109680	1.50
6	0.51	111220	1.52
10	0.52	113090	1.57
4	0.45	114850	1.64
6	0.48	116390	1.69
10	0.47	118260	1.74
4	0.54	120020	1.79
6	0.54	121560	1.83
10	0.54	123430	1.90
4	0.56	125190	1.96
6	0.23	126730	2.06
10	0.28	128600	2.12
4	0.37	130360	2.18
6	0.57	131900	2.23
10	0.55	133770	2.31
4	0.58	135530	2.38
6	0.39	137070	2.47
10	0.37	138940	2.56
4	0.27	140700	2.65
6	0.30	142240	2.75
10	0.19	144110	2.91
4	0.23	145870	3.00
6	0.27	147410	3.12

Groups	y	7A6R Cycles	c1
10	0.23	28500	0.09
4	0.20	30260	0.14
6	0.22	31800	0.16
10	0.19	33670	0.21
4			
6	0.22	36970	0.26
10	0.20	38840	0.32
4			
6	0.24	42140	0.37
10	0.22	44010	0.41
4	0.25	45770	0.44
6			
10	0.10	49180	0.34
4	0.05	50940	0.38
6	0.09	52480	0.41
10	0.10	54350	0.45
4	0.12	56110	0.49
6	0.05	57650	0.54
10			
4			
6	0.09	62820	0.64
10	0.10	64690	0.68
4			
6	0.09	67990	0.74
10	0.11	69860	0.77
4	0.10	71620	0.80
6	0.15	73160	0.86
10	0.23	75030	0.94
4	0.23	76790	0.99
6	0.29	78330	1.05
10	0.09	80200	1.09
4	0.08	81960	1.13
6	0.08	83500	1.18
10	0.13	85370	1.22
4			
6	0.18	88670	1.28
10	0.19	90540	1.32
4	0.25	92300	1.34
6	0.30	93840	1.37
10	0.34	95710	1.39
4	0.38	97470	1.41
10			
4	0.37	100880	1.49
6			

FIGURE E-8. EIFS PANELS SEM CRACK GROWTH DATA (Continued)

7A7L			
Groups	y	Cycles	c1
6	0.28	93840	1.06
10	0.24	95710	1.10
4			
6	0.18	99010	1.16
10	0.07	100880	1.21
4			
6	0.28	104180	1.31
10	0.36	106050	1.37
4	0.37	107810	1.42
6			
10	0.40	111220	1.50
4	0.47	112980	1.53
6	0.50	114520	1.57
10	0.47	116390	1.60
4			
6	0.52	119690	1.65
10	0.31	121560	1.70
4	0.37	123320	1.71
6	0.39	124860	1.75
10	0.42	126730	1.79
4	0.46	128490	1.82
6	0.37	130030	1.82
10	0.40	131900	1.86
4	0.39	133660	1.91
6	0.28	135200	1.96
10	0.34	137070	2.01
4	0.34	138830	2.06
6	0.38	140370	2.11
10	0.38	142240	2.16
4	0.40	144000	2.20
6	0.39	145540	2.26
10	0.38	147410	2.33

7A6R (cont.)			
Groups	y	Cycles	c1
10	0.46	104180	1.53
4	0.46	106050	1.56
6	0.45	107810	1.59
10	0.54	109350	1.63
4	0.53	111220	1.67
6	0.55	112980	1.7
10	0.50	114520	1.75
4	0.48	116390	1.78
6			
10	0.41	119690	1.91
4	0.47	121560	1.93
6	0.43	123320	2.01
10	0.36	124860	2.07
4	0.30	126730	2.14
6	0.32	128490	2.19
10	0.35	130030	2.24
4	0.33	131900	2.29
6	0.36	133660	2.33
10	0.35	135200	2.4
4	0.30	137070	2.49
6	0.26	138830	2.57
10	0.19	140370	2.65
4	0.26	142240	2.74
6	0.24	144000	2.83
10	0.35	145540	2.89
4	0.55	147410	3.01

FIGURE E-8. EIFS PANELS SEM CRACK GROWTH DATA (Continued)

Groups	y	7A7R Cycles	c1
4	0.18	71730	0.23
6			
10	0.19	75030	0.28
4	0.25	76900	0.31
6			
10	0.26	80200	0.38
4			
6	0.25	83830	0.46
10	0.22	85370	0.49
4	0.21	87240	0.53
6	0.21	89000	0.56
10	0.21	90540	0.59
4	0.22	92410	0.62
6	0.20	94170	0.66
10			
4			
6	0.21	99340	0.71
10	0.13	100880	0.74
4	0.15	102750	0.78
6	0.13	104510	0.82
10	0.18	106050	0.87
4	0.22	107920	0.91
6			
10			
4			
6	0.21	114850	0.99
10	0.36	116390	1.02
4			
6	0.35	120020	1.09
10	0.35	121560	1.12
4	0.26	123430	1.13
6	0.29	125190	1.15
10	0.32	126730	1.22
4	0.35	128600	1.24
6	0.38	130360	1.27
10	0.39	131900	1.29
4	0.43	133770	1.29
6	0.42	135530	1.34
10	0.44	137070	1.36
4	0.45	138940	1.41
6	0.38	140700	1.45
10	0.31	142240	1.43
4	0.33	144110	1.58
6	0.25	145870	1.63
10	0.33	147410	1.70

Groups	y	7A8L Cycles	c1
10	0.54	126730	0.38
4			
6	0.57	130360	0.46
10	0.51	131900	0.52
4			
6	0.46	135530	0.58
10	0.47	137070	0.62
4			
6	0.13	140700	0.68
10	0.18	142240	0.71
4	0.16	144110	0.74
6	0.13	145870	0.77
10	0.08	147410	0.81

FIGURE E-8. EIFS PANELS SEM CRACK GROWTH DATA (Continued)

Groups	y	7A12R Cycles	c1	Groups	y	7A13R Cycles	c1
6	0.25	57760	0.23	10	0.03	57650	0.18
10	0.19	59520	0.29	4	0.08	59520	0.22
4	0.22	61390	0.34	6	0.06	61060	0.25
6	0.24	62930	0.37	10	0.07	62820	0.29
10	0.25	64690	0.41	4	0.04	64690	0.31
4	0.24	66560	0.44	6	0.04	66230	0.34
6	0.24	68100	0.47	10	0.07	67990	0.39
10	0.24	69860	0.49	4	0.08	69860	0.42
4	0.24	71730	0.52	6	0.07	71400	0.44
6	0.20	73270	0.56	10	0.08	73160	0.48
10	0.26	75030	0.58	4			
4				6			
6	0.25	78440	0.63	10	0.06	78330	0.51
10	0.28	80200	0.65	4	0.08	80200	0.52
4	0.28	82070	0.69	6			
6	0.28	83610	0.72	10	0.13	83500	0.58
10	0.31	85370	0.76	4	0.11	85370	0.60
4	0.38	87240	0.77	6	0.11	86910	0.62
6	0.40	88780	0.80	10	0.11	88670	0.64
10	0.33	90540	0.84	4			
4				6			
6	0.34	93950	0.90	10	0.11	93840	0.69
10	0.33	95710	0.94	4	0.14	95710	0.74
4	0.36	97580	0.97	6	0.14	97250	0.78
6				10	0.13	99010	0.82
10	0.40	100880	1.02	4	0.13	100880	0.85
4	0.38	102750	1.06	6			
6	0.38	104290	1.10	10	0.14	104180	0.90
10	0.33	106050	1.19	4			
4	0.28	107920	1.26	6	0.12	107590	0.94
6	0.30	109460	1.29	10	0.12	109350	0.96
10	0.34	111220	1.32	4	0.11	111220	0.98
4	0.33	113090	1.38	6	0.12	112760	1.01
6	0.36	114630	1.42	10	0.14	114520	1.04
10	0.36	116390	1.47	4	0.13	116390	1.07
4	0.33	118260	1.54	6	0.13	117930	1.10
6	0.38	119800	1.58	10	0.12	119690	1.13
10	0.43	121560	1.64	4	0.13	121560	1.16
4	0.54	123430	1.67	6			
6	0.58	124970	1.72	10	0.13	124860	1.22
10	0.63	126730	1.79	4	0.13	126730	1.26
4	0.64	128600	1.88	6			
6	0.70	130140	1.96	10	0.04	130030	1.35
10	0.77	131900	2.05	4	0.01	131900	1.43
4	0.80	133770	2.17	6			
6	0.91	135310	2.22	10	0.01	135200	1.52
10	0.97	137070	2.36	4			
4	0.68	138940	2.32	6	0.05	138610	1.61
6	0.59	140480	2.37	10	0.07	140370	1.67
10	0.58	142240	2.37	4	0.09	142240	1.73
4	0.66	144110	2.68	6	0.07	143780	1.83
6	0.65	145650	2.92	10	0.09	145540	1.99
10	0.34	147410	3.28	4	0.02	147410	2.21

FIGURE E-8. EIFS PANELS SEM CRACK GROWTH DATA (Continued)

Groups	y	7A14L Cycles	c1
4	0.58	66560	0.83
6	0.58	68100	0.89
10	0.75	69860	0.94
4			
6			
10			
4			
6	0.75	78440	1.07
10	0.75	80200	1.14
4			
6			
10	0.80	85370	1.26
4			
6	0.84	88780	1.32
10	0.82	90540	1.38
4			
6	0.72	93950	1.45
10	0.72	95710	1.49
4			
6	0.68	99120	1.61
10	0.50	100880	1.64
4	0.45	102750	1.72
6	0.45	104290	1.74
10	0.47	106050	1.78
4	0.50	107920	1.81
6			
10	0.60	111220	1.88
4	0.63	113090	1.92
6	0.61	114630	1.97
10	0.64	116390	2.03
4	0.68	118260	2.07
6	0.72	119800	2.11
10	0.70	121560	2.18
4	0.72	123430	2.24
6	0.71	124970	2.32
10	0.66	126730	2.41
4	0.59	128600	2.51
6	0.77	130140	2.53
10	0.74	131900	2.63
4	0.69	133770	2.74
6	0.84	135310	2.77
10	0.89	137070	2.86
4	0.90	138940	2.97
6	0.85	140480	3.12
10	0.84	142240	3.26
4	0.84	144110	3.40
6	0.83	145650	3.58
10	0.85	147410	3.79

Groups	y	7A14R Cycles	c1
4	0.07	40710	0.12
6	0.07	42250	0.13
10	0.07	44010	0.15
4			
6			
10			
4	0.12	51050	0.20
6	0.12	52590	0.22
10	0.17	54350	0.25
4	0.15	56220	0.28
6			
10	0.18	59520	0.34
4			
6	0.19	62930	0.42
10	0.22	64690	0.45
4	0.2	66560	0.49
6	0.23	68100	0.52
10	0.22	69860	0.56
4			
6	0.13	73270	0.67
10	0.16	75030	0.71
4	0.15	76900	0.74
6	0.12	78440	0.79
10	0.12	80200	0.83
4	0.1	82070	0.88
6	0.12	83610	0.92
10	0.07	85370	0.98
4			
6	0.1	88780	1.05
10	0.1	90540	1.09
4	0.12	92410	1.13
6	0.1	93950	1.17
10	0.12	95710	1.20
4	0.11	97580	1.26
6	0.06	99120	1.31
10	0.08	100880	1.34
4	0.09	102750	1.38
6	0.09	104290	1.43
10	0.11	106050	1.48
4	0.099	107920	1.52
6	0.12	109460	1.56
10	0.08	111220	1.60
4	0.07	113090	1.65
6	0.07	114630	1.68
10	0.15	116390	1.72
4	0.16	118260	1.77
6	0.22	119800	1.82
10	0.24	121560	1.87
4			
6	0.26	124970	1.96
10	0.3	126730	1.99
4	0.21	128600	2.08
6	0.26	130140	2.15
10	0.26	131900	2.22
4	0.25	133770	2.28
6	0.2	135310	2.37
10	0.27	137070	2.43
4	0.27	138940	2.52
6	0.32	140480	2.60
10	0.25	142240	2.72
4	0.28	144110	2.86
6	0.26	145650	3.03
10	0.26	147410	3.23

FIGURE E-8. EIFS PANELS SEM CRACK GROWTH DATA (Continued)

Groups	y	7A15R Cycles	c1
6	0.05	42250	0.23
10	0.08	44010	0.26
4			
6	0.11	47420	0.30
10	0.10	49180	0.34
4			
6	0.04	52590	0.43
10	0.05	54350	0.41
4	0.10	56220	0.44
6	0.08	57760	0.47
10	0.14	59520	0.49
4	0.12	61390	0.52
6	0.07	62930	0.54
10	0.04	64690	0.56
4	0.01	66560	0.59
6	0.03	68100	0.60
10	0.03	69860	0.62
4	0.02	71730	0.64
6	0.02	73270	0.66
10	0.01	75030	0.69
4	0.01	76900	0.71
6			
10	0.03	80200	0.74
4			
6	0.04	83610	0.77
10	0.10	85370	0.80
4	0.07	87240	0.84
6	0.05	88780	0.85
10	0.02	90540	0.87
4			
6			
10	0.02	95710	0.94
4	0.02	97580	0.97
6			
10	0.02	100880	1.00
4			
6			
10	0.05	106050	1.05
4	0.06	107920	1.09
6			
10	0.10	111220	1.12
4			
6	0.17	114630	1.15
10	0.18	116390	1.17
4			
6	0.26	119800	1.19
10	0.25	121560	1.24
4			
6	0.24	124970	1.29
10	0.23	126730	1.33
4	0.26	128600	1.39
6	0.23	130140	1.45
10	0.23	131900	1.49
4	0.24	133770	1.55
6	0.21	135310	1.60
10	0.21	137070	1.65
4			
6	0.27	140480	1.75
10	0.23	142240	1.84
4	0.20	144110	1.96

Groups	y	7A16L Cycles	c1
10	0.34	75030	0.83
4			
6			
10	0.27	80200	0.89
4			
6			
10	0.23	85370	0.93
4			
6	0.24	88780	0.99
10			
4			
6	0.26	93950	1.08
10	0.20	95710	1.13
4	0.22	97580	1.17
6	0.26	99120	1.19
10	0.20	100880	1.24
4			
6	0.24	104290	1.29
10	0.24	106050	1.33
4			
6	0.19	109460	1.42
10	0.31	111220	1.44
4	0.34	113090	1.51
6	0.33	114630	1.55
10	0.19	116390	1.60
4			
6	0.08	119800	1.71
10	0.03	121560	1.75
4	0.06	123430	1.80
6	0.01	124970	1.85
10	0.06	126730	1.91
4	0.04	128600	1.96
6	0.11	130140	2.01
10	0.08	131900	2.08
4	0.13	133770	2.13
6	0.16	135310	2.19
10	0.13	137070	2.29
4	0.17	138940	2.36
6	0.11	140480	2.45
10	0.10	142240	2.56
4	0.10	144110	2.66

FIGURE E-8. EIFS PANELS SEM CRACK GROWTH DATA (Continued)

Groups	y	7A16R Cycles	c1
6	0.13	104290	0.02
10	0.18	106050	0.05
4			
6			
10	0.14	111220	0.09
4	0.15	113090	0.12
6			
10	0.07	116390	0.17
4	0.11	118260	0.21
6	0.11	119800	0.23
10		121560	0.26
4		123430	0.28
6	0.01	124970	0.31
10		126730	0.34
4	0.01	128600	0.37
6	0.03	130140	0.45
10	0.04	131900	0.48
4			
6	0.04	135310	0.52
10	0.05	137070	0.54
4			
6	0.10	140480	0.57
10	0.05	142240	0.62
4	0.07	144110	0.66

Groups	y	7A17L Cycles	c1
6	0.11	78440	0.32
10			
4	0.18	82070	0.38
6	0.18	83610	0.41
10	0.19	85370	0.44
4	0.20	87240	0.46
6	0.22	88780	0.49
10	0.22	90540	0.53
4	0.22	92410	0.56
6	0.19	93950	0.59
10	0.21	95710	0.64
4	0.22	97580	0.66
6			
10	0.20	100880	0.73
4	0.19	102750	0.75
6	0.23	104290	0.79
10	0.12	106050	0.84
4	0.12	107920	0.87
6	0.12	109460	0.92
10	0.18	111220	0.96
4	0.18	113090	1.02
6	0.16	114630	1.07
10	0.23	116390	1.13
4	0.28	118260	1.19
6	0.22	119800	1.27
10	0.23	121560	1.35
4	0.29	123430	1.43
6	0.35	124970	1.50
10	0.35	126730	1.59
4	0.40	128600	1.67
6	0.35	130140	1.76
10	0.37	131900	1.85
4	0.43	133770	1.95
6	0.32	135310	2.06
10	0.40	137070	2.17
4	0.33	138940	2.28
6	0.43	140480	2.39
10	0.48	142240	2.52
4	0.54	144110	2.66
6	0.52	145650	2.79
10	0.43	147410	2.94

FIGURE E-8. EIFS PANELS SEM CRACK GROWTH DATA (Continued)

Groups	y	7A17R Cycles	c1
10	0.06	23,330	0.14
4			
6			
10	0.06	28,500	0.25
4	0.04	30,370	0.28
6	0.02	31,910	0.31
10	0.03	33,670	0.33
4	0.02	35,540	0.37
6			
10	0.04	38,840	0.42
4	0.01	40,710	0.47
6	0.01	42,250	0.48
10	0.04	44,010	0.50
4			
6	0.08	47,420	0.53
10	0.10	49,180	0.57
4	0.10	51,050	0.60
6	0.10	52,590	0.63
10	0.10	54,350	0.67
4	0.11	56,220	0.69
6	0.11	57,760	0.71
10			
4			
6			
10			
4			
6	0.19	68,100	0.88
10	0.14	69,860	0.91
4			
6			
10	0.20	75,030	0.99
4	0.19	76,900	1.02
6	0.17	78,440	1.05
10	0.23	80,200	1.08
4	0.23	82,070	1.11
6	0.20	83,610	1.13
10	0.19	85,370	1.16
4			
6	0.17	88,780	1.21
10	0.15	90,540	1.24
4			

Groups	y	7A17R (cont.) Cycles	c1
6	0.12	93,950	1.28
10	0.12	95,710	1.31
4	0.12	97,580	1.34
6	0.15	99,120	1.38
10	0.07	100,880	1.40
4			
6	0.01	104,290	1.46
10	0.09	106,050	1.51
4	0.17	107,920	1.56
6	0.07	109,460	1.58
10	0.10	111,220	1.64
4	0.17	113,090	1.68
6	0.07	114,630	1.71
10	0.06	116,390	1.75
4	0.08	118,260	1.79
6	0.08	119,800	1.84
10	0.08	121,560	1.90
4	0.11	123,430	1.98
6	0.18	124,970	2.03
10	0.10	126,730	2.10
4	0.10	128,600	2.17
6		130,140	2.23
10		131,900	2.31
4	0.02	133,770	2.39
6	0.02	135,310	2.47
10	0.03	137,070	2.55
4	0.02	138,940	2.67
6	0.01	140,480	2.77
10	0.01	142,240	2.90
4	0.02	144,110	3.03

FIGURE E-8. EIFS PANELS SEM CRACK GROWTH DATA (Continued)

Groups	y	8A10L Cycles	c1
4	0.206	65340	0.292
6	0.026	67210	0.386
10	0.222	68970	0.38
4	0.036	70510	0.455
6	0.154	72380	0.448
10	0.255	74140	0.441
4		75680	
6		77550	
10	0.298	79310	0.451
4		80850	
6		82720	
10	0.226	84480	0.593
4	0.230	86020	0.604
6	0.345	87890	0.555
10	0.255	89650	0.639
4		91190	
6	0.061	93060	0.723
10	0.408	94820	0.658
4		96360	
6	0.091	98230	0.781
10	0.080	99990	0.816
4		101530	
6	0.076	103400	0.983
10	-0.115	105160	1.078
4		106700	
6	0.276	108570	1.242
10	0.122	110330	1.392
4	0.179	111870	1.487
6	0.081	113740	1.647
10	0.225	115500	1.746
4	0.145	117040	1.893
6	0.285	118910	2.042
10	0.247	120670	2.202
4	0.185	122210	2.419
6	0.055	124080	2.621
10	0.038	125840	2.875
4	0.314	127380	3.206
6	0.322	129250	3.563
fracture		130000	3.962

Groups	y	8A10R Cycles	c1
6	0.286	65340	0.222
10	0.232	67210	0.33
4		68970	
6	0.158	70510	0.407
10	0.149	72380	0.424
4		74140	
6		75680	
10	-0.028	77550	0.518
4	0.120	79310	0.561
6	-0.061	80850	0.594
10		82720	
4		84480	
6	0.201	86020	0.656
10	0.523	87890	0.507
4		89650	
6	0.260	91190	0.789
10	0.313	93060	0.817
4		94820	
6	0.320	96360	0.877
10		98230	
4	0.226	99990	0.977
6	0.118	101530	1.059
10	0.243	103400	1.061
4		105160	
6	0.330	106700	1.199
10	0.341	108570	1.275
4		110330	
6	0.262	111870	1.443
10	0.379	113740	1.491
4		115500	
6	0.515	117040	1.748
10	0.365	118910	1.824
4		120670	
6	0.236	122210	2.074
10	0.101	124080	2.259
4	0.259	125840	2.402
6	0.409	127380	2.658
10	0.341	129250	3.164
fracture		130000	3.936

Groups	y	8A19L Cycles	c1
6	0.070	122210	0.53
10	0.095	124080	0.764
4	0.183	125840	1.033
6	0.122	127380	1.343
10	0.308	129250	1.728
fracture		130000	5.06

FIGURE E-8. EIFS PANELS SEM CRACK GROWTH DATA (Continued)

9A5L			
Groups	y	Cycles	c1
10	0.299	481850	1.116
4	0.296	485610	1.390
6	0.176	489150	1.744
10	0.305	493020	2.211
fracture		498063	3.000
μ =	0.269		
σ =	0.062		

9A5R			
Groups	y	Cycles	c1
6	0.139	468510	0.391
10	0.342	470480	0.347
4		474240	
6	0.303	477780	0.561
10	0.096	479750	0.683
4		483510	
6	0.107	487050	0.810
10	0.125	489020	1.081
4	0.054	492780	1.300
6	0.233	496320	1.661
fracture		498063	1.882

10F5R			
Groups	y	Cycles	c1
10	0.200	119760	0.148
4	0.144	123520	0.225
6	0.134	127060	0.278
10	0.141	130930	0.312
4	0.137	134690	0.358
6	0.178	138230	0.404
10	0.091	142100	0.465
4	0.074	145860	0.527
6	0.173	149400	0.586
10	0.192	153270	0.747
4	0.077	157030	1.079

10F6L			
Groups	y	Cycles	c1
6	0.116	126010	0.321
10	0.167	129880	0.376
4	0.228	133640	0.456
6	0.222	137180	0.548
10	0.201	141050	0.643
4	0.126	144810	0.734
6	0.195	148350	0.835
10	0.226	152220	1.044
4	0.227	155980	1.348
6	0.146	159520	1.777
10	0.241	163390	2.407

10F6R			
Groups	y	Cycles	c1
4	0.099	122470	0.228
6	0.066	126010	0.322
10	0.097	129880	0.413
6	0.112	137180	0.661
10	0.097	141050	0.835
4	0.065	144810	1.006
6	0.063	148350	1.236
10	0.112	152220	1.559
4	0.058	155980	2.024
6	0.186	159520	2.597
10	0.166	163390	3.457

10F7L			
Groups	y	Cycles	c1
10	0.152	129880	0.252
6	0.146	137180	0.389
10	0.125	141050	0.47
4	0.122	144810	0.54
6	0.189	148350	0.655
10	0.182	152220	0.931
4	0.188	155980	1.291
6	0.142	159520	1.843
10	0.218	163390	2.637

FIGURE E-8. EIFS PANELS SEM CRACK GROWTH DATA (Continued)

Groups	y	10F7R Cycles	c1
10	0.211	143950	0.482
4	0.254	147710	0.662
6	0.209	151250	0.931
10	0.208	154220	1.298
4	0.223	157980	2.053

Groups	y	10F8L Cycles	c1
10	0.136	88200	0.145
10	0.136	96370	0.212
4	0.108	100130	0.255
10	0.131	107540	0.330
4	0.113	111300	0.369
6	0.118	114840	0.417
10	0.132	118710	0.445
4	0.139	122470	0.479
6	0.166	126010	0.511
10	0.137	129880	0.571
4	0.179	133640	0.616
6	0.100	137180	0.670
10	0.173	141050	0.728
4	0.087	144810	0.815
6	0.206	148350	0.902
10	0.180	152220	1.012
4	0.186	155980	1.169
6	0.203	159520	1.337
10	0.226	163390	1.711

Groups	y	10F8R Cycles	c1
4	0.135	128350	0.287
6	0.201	131890	0.294
10	0.215	135760	0.346
4	0.344	139520	0.261
6	0.292	143060	0.503
10	0.100	146930	0.759
4	0.323	150690	1.020
6	0.228	154230	1.293
10	0.207	158100	1.680
fracture		165390	1.750

Groups	y	10F10R Cycles	c1
6	0.124	131890	0.517
10	0.088	135760	0.810
4	0.347	139520	1.117
6	0.077	143060	1.393
10	0.195	146930	1.690
4	0.213	150690	1.977
6	0.181	154230	2.288
10	0.125	158100	2.656
fracture		165390	3.071

FIGURE E-8. EIFS PANELS SEM CRACK GROWTH DATA (Continued)

Groups	y	11F6L Cycles	c1
10	0.234	127590	0.527
4		131350	
6	0.731	134890	0.550
10	0.424	138760	1.026
4	0.289	142520	1.361
6	0.219	146060	1.806
10	0.258	149930	2.460
fracture		154827	

Groups	y	11F6R Cycles	c1
10	0.003	106250	0.673
4		110010	
6		113550	
10	0.301	117420	0.827
4		121180	
6	0.294	124720	0.872
10	0.095	128590	1.021
4	0.197	132350	1.127
6	0.559	135890	1.183
10	0.163	139760	1.491
4	0.214	143520	1.929
6	0.375	147060	2.501
fracture		154287	

Groups	y	11F7L Cycles	c1
10	0.377	128590	0.491
4	0.673	132350	0.554
6	0.233	135890	0.954
10	0.263	139760	1.251
4	0.336	143520	1.645
6	0.29	147060	2.185
fracture		154827	2.300

Groups	y	11F7R Cycles	c1
10	0.318	127590	0.483
4	0.341	131350	0.627
6	0.662	134890	0.665
10	0.318	138760	1.081
4	0.634	142520	1.455
6	0.532	146060	1.913
10	0.714	149930	2.622
fracture		154297	3.300

Groups	y	11F8L Cycles	c1	dc1/dN
10	0.217	128590	0.393	2.56E-05
4		132350		
6	0.226	135890	0.580	1.86E-05
10	0.409	139760	0.652	5.98E-05
4	0.269	143520	0.877	7.54E-05
6	0.27	147060	1.144	
fracture		154287		

Groups	y	11F8R Cycles	c1	dc1/dN
10	0.19	127590	0.163	4.23E-05
4	0.283	131350	0.322	6.89E-05
6	0.132	134890	0.566	5.89E-05
10	0.187	138760	0.794	6.33E-05
4	0.354	142520	1.032	7.37E-05
6	0.277	146060	1.293	9.04E-05
10	0.261	149930	1.643	2.23E-05
fracture		154287	1.740	

FIGURE E-8. EIFS PANELS SEM CRACK GROWTH DATA (Continued)

Groups	y	11F9R Cycles	c1
6	0.196	124720	0.584
10	0.29	128590	0.913
4	0.388	132350	1.199
6	0.445	135890	1.504
10	0.844	139760	2.075
4	0.439	143520	2.627
6	0.096	147060	3.185

Groups	y	11F10R Cycles	c1
6	0.178	123720	0.477
10	0.28	127590	0.776
4	0.344	131350	1.067
6	0.142	134890	1.329
10	0.293	138760	1.617
4	0.195	142520	1.888
6	0.217	146060	2.201
10	0.144	149930	2.555
fracture		154827	2.800

Flights	y	15E2R Cycles	c1
20	0.08	171287	0.40
21	0.09	179853	0.57
22	0.18	188419	0.74
23	0.21	196985	0.97
24	0.24	205551	1.26
25	0.29	214117	1.56
25.5	0.00	218484	1.86

Flights	y	15E11R Cycles	c1
18	0.26	154155	0.71
19	0.21	162721	1.06
20	0.15	171287	1.43
21	0.15	179853	1.84
22	0.15	188419	2.26
23	0.18	196985	2.79
24	0.14	205551	3.45
25	0.25	214117	4.30
25.5	0.00	218484	4.75

Flights	y	15E16L Cycles	c1
19	0.27	162721	0.28
20	0.24	171287	0.41
21	0.25	179853	0.56
22	0.31	188419	0.72
23	0.27	196985	0.99
24	0.17	205551	1.27
25	0.05	214117	1.75
25.5	0.00	218484	2.22

Flights	y	15E16R Cycles	c1
13	0.40	111325	0.12
14	0.32	119891	0.26
15	0.31	128457	0.41
16	0.39	137023	0.59
17	0.32	145589	0.82
18	0.43	154155	1.00
19	0.43	162721	1.25
20	0.39	171287	1.58
21	0.21	179853	1.96
22	0.19	188419	2.40
23	0.24	196985	2.98
24	0.20	205551	3.67
25	0.23	214117	4.57
25.5	0.00	218484	5.22

FIGURE E-8. EIFS PANELS SEM CRACK GROWTH DATA (Continued)

15E20L			
Flights	y	Cycles	c1
16	0.28	137023	0.43
18	0.18	154155	0.76
19	0.20	162721	1.05
20	0.38	171287	1.35
21	0.42	179853	1.72
22	0.26	188419	2.29
23	0.26	196985	2.96
24	0.31	205551	3.93
25	0.31	214117	5.33
25.5	0.00	218484	6.33

15E26R			
Flights	y	Cycles	c1
19	0.23	162721	0.65
20	0.23	171287	1.00
21	0.23	179853	1.38
22	0.25	188419	1.88
23	0.25	196985	2.46
24	0.19	205551	3.32
25	0.24	214117	4.23
25.5	0.00	218484	4.87

15E28R			
Flights	y	Cycles	c1
23	0.22	196985	0.44
24	0.18	205551	0.70
25	0.23	214117	1.07
25.5	0.00	218484	1.56

FIGURE E-8. EIFS PANELS SEM CRACK GROWTH DATA (Continued)

Article ID: ZB5118853-1 #1 (EIFS-1) Date: 17-Nov-97

Measurements Taken By: McCann / Grommon

Top Skin Width @ Grips:	22.063	inches
Top Skin Width @ Splice:	22.000	inches
Top Skin Length (Left):	23.219	inches
Top Skin Length (Right):	23.438	inches
Bottom Skin Width @ Grips:	22.063	inches
Bottom Skin Width @ Splice:	22.031	inches
Bottom Skin Length (Left):	23.250	inches
Bottom Skin Length (Right):	23.281	inches
Splice Overlap (Left):	2.072	inches
Splice Overlap (Right):	2.065	inches
A1 - B1 Measurement:	0.811	inches
A15 - B27 Measurement:	0.740	inches
A1 - C1 Measurement:	2.006	inches
A15 - C27 Measurement:	1.950	inches
A1 - D1 Measurement:	2.827	inches
A15 - D15 Measurement:	2.835	inches
B1 - C1 Measurement:	1.207	inches
B27 - C27 Measurement:	1.205	inches

S.G. #1 Above A1 - A15 Line:	0.998	inches	from Panel Center:	6.715	inches
S.G. #2 Above A1 - A15 Line:	0.977	inches	from Panel Center:	*	inches
S.G. #3 Above A1 - A15 Line:	0.993	inches	from Panel Center:	3.729	inches
S.G. #4 Above A1 - A15 Line:	0.977	inches	from Panel Center:	*	inches
S.G. #5 Above A1 - A15 Line:	0.977	inches	from Panel Center:	0.693	inches
S.G. #6 Above A1 - A15 Line:	0.977	inches	from Panel Center:	*	inches
S.G. #7 Above A1 - A15 Line:	0.977	inches	from Panel Center:	0.793	inches
S.G. #8 Above A1 - A15 Line:	0.983	inches	from Panel Center:	*	inches
S.G. #9 Above A1 - A15 Line:	0.980	inches	from Panel Center:	3.803	inches
S.G. #10 Above A1 - A15 Line:	0.993	inches	from Panel Center:	*	inches
S.G. #11 Above A1 - A15 Line:	0.979	inches	from Panel Center:	6.768	inches
S.G. #12 Above A1 - A15 Line:	0.999	inches	from Panel Center:	*	inches
S.G. #13 Above A1 - A15 Line:	0.064	inches	from Panel Center:	6.717	inches
S.G. #14 Above A1 - A15 Line:	0.120	inches	from Panel Center:	*	inches
S.G. #15 Above A1 - A15 Line:	0.059	inches	from Panel Center:	2.182	inches
S.G. #16 Above A1 - A15 Line:	0.111	inches	from Panel Center:	*	inches
S.G. #17 Above A1 - A15 Line:	0.070	inches	from Panel Center:	2.261	inches
S.G. #18 Above A1 - A15 Line:	0.095	inches	from Panel Center:	*	inches
S.G. #19 Above A1 - A15 Line:	0.072	inches	from Panel Center:	6.774	inches
S.G. #20 Above A1 - A15 Line:	0.105	inches	from Panel Center:	*	inches
S.G. #21 Below D1 - D15 Line:	0.975	inches	from Panel Center:	5.299	inches
S.G. #22 Below D1 - D15 Line:	1.000	inches	from Panel Center:	*	inches
S.G. #23 Below D1 - D15 Line:	0.973	inches	from Panel Center:	5.208	inches
S.G. #24 Below D1 - D15 Line:	0.993	inches	from Panel Center:	*	inches

* Inaccessable on back of panel in test fixture.

FIGURE E-9. MEASURED EIFS SPECIMEN DIMENSIONS

Article ID: ZB5118853-1 #1 (EIFS-2) Date: 20-Nov-97

Measurements Taken By: McCann / Grommon

Top Skin Width @ Grips:	22.063	inches			
Top Skin Width @ Splice:	22.063	inches			
Top Skin Length (Left):	23.375	inches			
Top Skin Length (Right):	23.375	inches			
Bottom Skin Width @ Grips:	22.031	inches			
Bottom Skin Width @ Splice:	22.000	inches			
Bottom Skin Length (Left):	23.281	inches			
Bottom Skin Length (Right):	23.344	inches			
Splice Overlap (Left):	2.078	inches			
Splice Overlap (Right):	2.068	inches			
A1 - B1 Measurement:	0.812	inches			
A15 - B27 Measurement:	0.800	inches			
A1 - C1 Measurement:	1.995	inches			
A15 - C27 Measurement:	1.991	inches			
A1 - D1 Measurement:	2.834	inches			
A15 - D15 Measurement:	2.820	inches			
B1 - C1 Measurement:	1.205	inches			
B27 - C27 Measurement:	1.205	inches			
S.G. #1 Above A1 - A15 Line:	0.995	inches	from Panel Center:	6.769	inches
S.G. #2 Above A1 - A15 Line:	0.998	inches	from Panel Center:	6.773	inches
S.G. #3 Above A1 - A15 Line:		inches	from Panel Center:		inches
S.G. #4 Above A1 - A15 Line:		inches	from Panel Center:		inches
S.G. #5 Above A1 - A15 Line:		inches	from Panel Center:		inches
S.G. #6 Above A1 - A15 Line:		inches	from Panel Center:		inches
S.G. #7 Above A1 - A15 Line:		inches	from Panel Center:		inches
S.G. #8 Above A1 - A15 Line:		inches	from Panel Center:		inches
S.G. #9 Above A1 - A15 Line:		inches	from Panel Center:		inches
S.G. #10 Above A1 - A15 Line:		inches	from Panel Center:		inches
S.G. #11 Above A1 - A15 Line:	1.028	inches	from Panel Center:	6.691	inches
S.G. #12 Above A1 - A15 Line:	0.977	inches	from Panel Center:	6.719	inches
S.G. #13 Above A1 - A15 Line:		inches	from Panel Center:		inches
S.G. #14 Above A1 - A15 Line:		inches	from Panel Center:		inches
S.G. #15 Above A1 - A15 Line:		inches	from Panel Center:		inches
S.G. #16 Above A1 - A15 Line:		inches	from Panel Center:		inches
S.G. #17 Above A1 - A15 Line:		inches	from Panel Center:		inches
S.G. #18 Above A1 - A15 Line:		inches	from Panel Center:		inches
S.G. #19 Above A1 - A15 Line:		inches	from Panel Center:		inches
S.G. #20 Above A1 - A15 Line:		inches	from Panel Center:		inches
S.G. #21 Below D1 - D15 Line:	1.020	inches	from Panel Center:	6.783	inches
S.G. #22 Below D1 - D15 Line:	1.046	inches	from Panel Center:	6.786	inches
S.G. #23 Below D1 - D15 Line:	1.008	inches	from Panel Center:	6.671	inches
S.G. #24 Below D1 - D15 Line:	1.016	inches	from Panel Center:	6.695	inches

FIGURE E-9. MEASURED EIFS SPECIMEN DIMENSIONS (Continued)

Article ID: ZB5118853-1 #1 (EIFS-3) Date: 01-Dec-97

Measurements Taken By: MCCann / Grommon

Top Skin Width @ Grips:	22.063	inches			
Top Skin Width @ Splice:	22.063	inches			
Top Skin Length (Left):	23.281	inches			
Top Skin Length (Right):	23.313	inches			
Bottom Skin Width @ Grips:	22.094	inches			
Bottom Skin Width @ Splice:	22.063	inches			
Bottom Skin Length (Left):	23.250	inches			
Bottom Skin Length (Right):	23.344	inches			
Splice Overlap (Left):	2.060	inches			
Splice Overlap (Right):	2.071	inches			
A1 - B1 Measurement:	0.801	inches			
A15 - B27 Measurement:	0.844	inches			
A1 - C1 Measurement:	1.979	inches			
A15 - C27 Measurement:	2.026	inches			
A1 - D1 Measurement:	1.817	inches			
A15 - D15 Measurement:	2.864	inches			
B1 - C1 Measurement:	1.209	inches			
B27 - C27 Measurement:	1.211	inches			
S.G. #1 Above A1 - A15 Line:	1.047	inches	from Panel Center:	6.801	inches
S.G. #2 Above A1 - A15 Line:	1.020	inches	from Panel Center:	6.788	inches
S.G. #3 Above A1 - A15 Line:		inches	from Panel Center:		inches
S.G. #4 Above A1 - A15 Line:		inches	from Panel Center:		inches
S.G. #5 Above A1 - A15 Line:		inches	from Panel Center:		inches
S.G. #6 Above A1 - A15 Line:		inches	from Panel Center:		inches
S.G. #7 Above A1 - A15 Line:		inches	from Panel Center:		inches
S.G. #8 Above A1 - A15 Line:		inches	from Panel Center:		inches
S.G. #9 Above A1 - A15 Line:		inches	from Panel Center:		inches
S.G. #10 Above A1 - A15 Line:		inches	from Panel Center:		inches
S.G. #11 Above A1 - A15 Line:	1.024	inches	from Panel Center:	6.750	inches
S.G. #12 Above A1 - A15 Line:	1.018	inches	from Panel Center:	6.734	inches
S.G. #13 Above A1 - A15 Line:		inches	from Panel Center:		inches
S.G. #14 Above A1 - A15 Line:		inches	from Panel Center:		inches
S.G. #15 Above A1 - A15 Line:		inches	from Panel Center:		inches
S.G. #16 Above A1 - A15 Line:		inches	from Panel Center:		inches
S.G. #17 Above A1 - A15 Line:		inches	from Panel Center:		inches
S.G. #18 Above A1 - A15 Line:		inches	from Panel Center:		inches
S.G. #19 Above A1 - A15 Line:		inches	from Panel Center:		inches
S.G. #20 Above A1 - A15 Line:		inches	from Panel Center:		inches
S.G. #21 Below D1 - D15 Line:	1.024	inches	from Panel Center:	6.787	inches
S.G. #22 Below D1 - D15 Line:	0.993	inches	from Panel Center:	6.768	inches
S.G. #23 Below D1 - D15 Line:	0.984	inches	from Panel Center:	6.764	inches
S.G. #24 Below D1 - D15 Line:	1.009	inches	from Panel Center:	6.748	inches

FIGURE E-9. MEASURED EIFS SPECIMEN DIMENSIONS (Continued)

Article ID: ZB5118853-1 #4 (EIFS-4) Date: 13-Jan-98

Measurements Taken By: McCann & Grommon

Top Skin Width @ Grips:	22.125	inches			
Top Skin Width @ Splice:	22.031	inches			
Top Skin Length (Left):	23.313	inches			
Top Skin Length (Right):	23.313	inches			
Bottom Skin Width @ Grips:	22.125	inches			
Bottom Skin Width @ Splice:	22.063	inches			
Bottom Skin Length (Left):	23.188	inches			
Bottom Skin Length (Right):	23.188	inches			
Splice Overlap (Left):	2.680	inches			
Splice Overlap (Right):	2.530	inches			
A1 - B1 Measurement:	0.800	inches			
A15 - B27 Measurement:	0.807	inches			
A1 - C1 Measurement:	1.963	inches			
A15 - C27 Measurement:	2.005	inches			
A1 - D1 Measurement:	2.804	inches			
A15 - D15 Measurement:	1.869	inches			
B1 - C1 Measurement:	1.170	inches			
B27 - C27 Measurement:	1.185	inches			
S.G. #1 Above A1 - A15 Line:	1.004	inches	from Panel Center:	6.807	inches
S.G. #2 Above A1 - A15 Line:	0.983	inches	from Panel Center:	6.734	inches
S.G. #3 Above A1 - A15 Line:		inches	from Panel Center:		inches
S.G. #4 Above A1 - A15 Line:		inches	from Panel Center:		inches
S.G. #5 Above A1 - A15 Line:		inches	from Panel Center:		inches
S.G. #6 Above A1 - A15 Line:		inches	from Panel Center:		inches
S.G. #7 Above A1 - A15 Line:		inches	from Panel Center:		inches
S.G. #8 Above A1 - A15 Line:		inches	from Panel Center:		inches
S.G. #9 Above A1 - A15 Line:		inches	from Panel Center:		inches
S.G. #10 Above A1 - A15 Line:		inches	from Panel Center:		inches
S.G. #11 Above A1 - A15 Line:	0.977	inches	from Panel Center:	6.767	inches
S.G. #12 Above A1 - A15 Line:	0.989	inches	from Panel Center:	6.821	inches
S.G. #13 Above A1 - A15 Line:		inches	from Panel Center:		inches
S.G. #14 Above A1 - A15 Line:		inches	from Panel Center:		inches
S.G. #15 Above A1 - A15 Line:		inches	from Panel Center:		inches
S.G. #16 Above A1 - A15 Line:		inches	from Panel Center:		inches
S.G. #17 Above A1 - A15 Line:		inches	from Panel Center:		inches
S.G. #18 Above A1 - A15 Line:		inches	from Panel Center:		inches
S.G. #19 Above A1 - A15 Line:		inches	from Panel Center:		inches
S.G. #20 Above A1 - A15 Line:		inches	from Panel Center:		inches
S.G. #21 Below D1 - D15 Line:	0.983	inches	from Panel Center:	6.813	inches
S.G. #22 Below D1 - D15 Line:	0.983	inches	from Panel Center:	6.756	inches
S.G. #23 Below D1 - D15 Line:	0.981	inches	from Panel Center:	6.761	inches
S.G. #24 Below D1 - D15 Line:	1.001	inches	from Panel Center:	6.788	inches

FIGURE E-9. MEASURED EIFS SPECIMEN DIMENSIONS (Continued)

Article ID: ZB5118853-1 #1 (EIFS-5) Date: 05-Nov-97

Measurements Taken By: Sean Coghlan

Top Panel Width @ Grips:		inches
Top Skin Width @ Splice:		inches
Top Skin Length (Left):		inches
Top Skin Length (Right):		inches
Bottom Skin Width @ Grips:		inches
Bottom Skin Width @ Splice:		inches
Bottom Skin Length (Left):		inches
Bottom Skin Length (Right):		inches
A2 - C2 Measurement:	1.669	inches
A1 - C1 Measurement:	1.672	inches
A18 - C18 Measurement:	1.637	inches
A19-C19 Measurement:	1.650	inches
S.G. #1 Above A1 - A19 Line:		inches
S.G. #2 Above A1 - A19 Line:		inches
S.G. #3 Above A1 - A19 Line:		inches
S.G. #4 Above A1 - A19 Line:		inches
S.G. #5 Above A1 - A19 Line:		inches
S.G. #6 Above A1 - A19 Line:		inches
S.G. #7 Above A1 - A19 Line:		inches
S.G. #8 Above A1 - A19 Line:		inches
S.G. #9 Above A1 - A19 Line:		inches
S.G. #10 Above A1 - A19 Line:		inches
S.G. #11 Above A1 - A19 Line:		inches
S.G. #12 Above A1 - A19 Line:		inches
S.G. #13 Above A1 - A19 Line:		inches
S.G. #14 Above A1 - A19 Line:		inches
S.G. #15 Above A1 - A19 Line:		inches
S.G. #16 Above A1 - A19 Line:		inches
S.G. #17 Above A1 - A19 Line:		inches
S.G. #18 Above A1 - A19 Line:		inches
S.G. #19 Above A1 - A19 Line:		inches
S.G. #20 Above A1 - A19 Line:		inches
S.G. #21 Below C1 - C19 Line:		inches
S.G. #22 Below C1 - C19 Line:		inches
S.G. #23 Below C1 - C19 Line:		inches
S.G. #24 Below C1 - C19 Line:		inches

FIGURE E-9. MEASURED EIFS SPECIMEN DIMENSIONS (Continued)

Article ID: ZB5118853-1 #1 (EIFS-6) Date: 05-Nov-97

Measurements Taken By: Sean Coghlan

Top Panel Width @ Grips:		inches
Top Skin Width @ Splice:		inches
Top Skin Length (Left):		inches
Top Skin Length (Right):		inches
Bottom Skin Width @ Grips:		inches
Bottom Skin Width @ Splice:		inches
Bottom Skin Length (Left):		inches
Bottom Skin Length (Right):		inches
A1 - C1 Measurement:	1.676	inches
A2 - C2 Measurement:	1.687	inches
A18 - C18 Measurement:	1.617	inches
A19 - C19 Measurement:	1.644	inches
S.G. #1 Above A1 - A19 Line:		inches
S.G. #2 Above A1 - A19 Line:		inches
S.G. #3 Above A1 - A19 Line:		inches
S.G. #4 Above A1 - A19 Line:		inches
S.G. #5 Above A1 - A19 Line:		inches
S.G. #6 Above A1 - A19 Line:		inches
S.G. #7 Above A1 - A19 Line:		inches
S.G. #8 Above A1 - A19 Line:		inches
S.G. #9 Above A1 - A19 Line:		inches
S.G. #10 Above A1 - A19 Line:		inches
S.G. #11 Above A1 - A19 Line:		inches
S.G. #12 Above A1 - A19 Line:		inches
S.G. #13 Above A1 - A19 Line:		inches
S.G. #14 Above A1 - A19 Line:		inches
S.G. #15 Above A1 - A19 Line:		inches
S.G. #16 Above A1 - A19 Line:		inches
S.G. #17 Above A1 - A19 Line:		inches
S.G. #18 Above A1 - A19 Line:		inches
S.G. #19 Above A1 - A19 Line:		inches
S.G. #20 Above A1 - A19 Line:		inches
S.G. #21 Below C1 - C19 Line:		inches
S.G. #22 Below C1 - C19 Line:	1.008	inches
S.G. #23 Below C1 - C19 Line:		inches
S.G. #24 Below C1 - C19 Line:	0.970	inches

FIGURE E-9. MEASURED EIFS SPECIMEN DIMENSIONS (Continued)

Article ID: ZB5118853-1 #1 (EIFS-7) Date: 31-Oct-97

Measurements Taken By: Anselmo, McCann, Smith

Top Panel Width @ Grips:		inches
Top Skin Width @ Splice:		inches
Top Skin Length (Left):		inches
Top Skin Length (Right):		inches
Bottom Skin Width @ Grips:		inches
Bottom Skin Width @ Splice:		inches
Bottom Skin Length (Left):		inches
Bottom Skin Length (Right):		inches
A2 - C2 Measurement:	1.675	inches
A18 - C18 Measurement:	1.637	inches
S.G. #1 Above A1 - A19 Line:	1.010	inches
S.G. #2 Above A1 - A19 Line:	1.025	inches
S.G. #3 Above A1 - A19 Line:		inches
S.G. #4 Above A1 - A19 Line:		inches
S.G. #5 Above A1 - A19 Line:		inches
S.G. #6 Above A1 - A19 Line:		inches
S.G. #7 Above A1 - A19 Line:		inches
S.G. #8 Above A1 - A19 Line:		inches
S.G. #9 Above A1 - A19 Line:		inches
S.G. #10 Above A1 - A19 Line:		inches
S.G. #11 Above A1 - A19 Line:	0.973	inches
S.G. #12 Above A1 - A19 Line:	1.011	inches
S.G. #13 Above A1 - A19 Line:		inches
S.G. #14 Above A1 - A19 Line:		inches
S.G. #15 Above A1 - A19 Line:		inches
S.G. #16 Above A1 - A19 Line:		inches
S.G. #17 Above A1 - A19 Line:		inches
S.G. #18 Above A1 - A19 Line:		inches
S.G. #19 Above A1 - A19 Line:		inches
S.G. #20 Above A1 - A19 Line:		inches
S.G. #21 Below C1 - C19 Line:	0.977	inches
S.G. #22 Below C1 - C19 Line:	1.016	inches
S.G. #23 Below C1 - C19 Line:		inches
S.G. #24 Below C1 - C19 Line:		inches

FIGURE E-9. MEASURED EIFS SPECIMEN DIMENSIONS (Continued)

Article ID: ZB5118853-1 #4 (EIFS-8) Date: 12-Feb-98

Measurements Taken By: Larry Mack, Jeff Vannorsdall

Top Panel Width @ Grips:	21.934	inches	
Top Skin Width @ Splice:	21.973	inches	
Top Skin Length (Left):	24.125	inches	
Top Skin Length (Right):	24.187	inches	
Bottom Skin Width @ Grips:	21.930	inches	
Bottom Skin Width @ Splice:	21.971	inches	
Bottom Skin Length (Left):	24.062	inches	
Bottom Skin Length (Right):	24.125	inches	
A2 - C2 Measurement:	1.655	inches	
A18 - C18 Measurement:	1.653	inches	
S.G. #1 Above A1 - A19 Line:	0.987	inches	
S.G. #2 Above A1 - A19 Line:	1.014	inches	
S.G. #3 Above A1 - A19 Line:		inches	
S.G. #4 Above A1 - A19 Line:		inches	
S.G. #5 Above A1 - A19 Line:		inches	
S.G. #6 Above A1 - A19 Line:		inches	
S.G. #7 Above A1 - A19 Line:		inches	
S.G. #8 Above A1 - A19 Line:		inches	
S.G. #9 Above A1 - A19 Line:		inches	
S.G. #10 Above A1 - A19 Line:		inches	
S.G. #11 Above A1 - A19 Line:	0.983	inches	
S.G. #12 Above A1 - A19 Line:	1.032	inches	
S.G. #13 Above A1 - A19 Line:		inches	
S.G. #14 Above A1 - A19 Line:		inches	
S.G. #15 Above A1 - A19 Line:		inches	
S.G. #16 Above A1 - A19 Line:		inches	
S.G. #17 Above A1 - A19 Line:		inches	
S.G. #18 Above A1 - A19 Line:		inches	
S.G. #19 Above A1 - A19 Line:		inches	
S.G. #20 Above A1 - A19 Line:		inches	
S.G. #21 Below C1 - C19 Line:	0.987	inches	26.073
S.G. #22 Below C1 - C19 Line:	1.000	inches	26.060
S.G. #23 Below C1 - C19 Line:	0.973	inches	26.087
S.G. #24 Below C1 - C19 Line:	0.986	inches	26.074

FIGURE E-9. MEASURED EIFS SPECIMEN DIMENSIONS (Continued)

Article ID: ZB5118853-503 #1 (EIFS-9) Date: 14-Jan-98

Measurements Taken By: McCann / Grommon

Top Skin Width @ Grips:	22.063	inches			
Top Skin Width @ Splice:	21.875	inches			
Top Skin Length (Left):	22.100	inches			
Top Skin Length (Right):	22.150	inches			
Bottom Skin Width @ Grips:	22.063	inches			
Bottom Skin Width @ Splice:	22.031	inches			
Bottom Skin Length (Left):	22.150	inches			
Bottom Skin Length (Right):	22.080	inches			
Splice Overlap (Left):		inches			
Splice Overlap (Right):		inches			
A1 - B2 Measurement:	0.803	inches	A1 - F1 Measurement:	4.732	inches
A13 - B26 Measurement:	0.779	inches	A13 - F13 Measurement:	4.681	inches
A1 - C2 Measurement:	1.744	inches			
A13 - C26 Measurement:	1.726	inches			
A1 - D2 Measurement:	2.914	inches			
A13 - D26 Measurement:	2.880	inches			
A1 - E2 Measurement:	3.885	inches			
A13 - E26 Measurement:	3.859	inches			
S.G. #1 Above A1 - A13 Line:	0.968	inches	from Panel Center:	7.275	inches
S.G. #2 Above A1 - A13 Line:	1.007	inches	from Panel Center:	7.250	inches
S.G. #3 Above A1 - A13 Line:	1.007	inches	from Panel Center:	4.096	inches
S.G. #4 Above A1 - A13 Line:	1.003	inches	from Panel Center:	2.472	inches
S.G. #5 Above A1 - A13 Line:	0.994	inches	from Panel Center:	2.430	inches
S.G. #6 Above A1 - A13 Line:	1.003	inches	from Panel Center:	2.472	inches
S.G. #7 Above A1 - A13 Line:	1.009	inches	from Panel Center:	7.181	inches
S.G. #8 Above A1 - A13 Line:	1.003	inches	from Panel Center:	7.218	inches
S.G. #9 Above A1 - A13 Line:	0.127	inches	from Panel Center:	2.275	inches
S.G. #10 Above A1 - A13 Line:	0.150	inches	from Panel Center:	2.250	inches
S.G. #11 Above A1 - A13 Line:	0.121	inches	from Panel Center:	4.093	inches
S.G. #12 Above A1 - A13 Line:	0.152	inches	from Panel Center:	4.045	inches
S.G. #13 Above A1 - A13 Line:	0.125	inches	from Panel Center:	3.977	inches
S.G. #14 Above A1 - A13 Line:	0.165	inches	from Panel Center:	3.986	inches
S.G. #15 Above A1 - A13 Line:	0.125	inches	from Panel Center:	7.181	inches
S.G. #16 Above A1 - A13 Line:	0.971	inches	from Panel Center:	7.218	inches
S.G. #17 Above A1 - A13 Line:	1.003	inches	from Panel Center:	7.308	inches
S.G. #18 Above F1 - F13 Line:	1.003	inches	from Panel Center:	7.224	inches
S.G. #19 Above F1 - F13 Line:	1.020	inches	from Panel Center:	7.235	inches
S.G. #20 Above F1 - F13 Line:		inches	from Panel Center:	7.164	inches

FIGURE E-9. MEASURED EIFS SPECIMEN DIMENSIONS (Continued)

Article ID: ZB5118853-503 #2 (EIFS-10) Date: 02-Mar-98

Measurements Taken By: Jeff Vannorsdall / Larry Mack

Top Skin Width @ Grips:	22.090	inches			
Top Skin Width @ Splice:	22.065	inches			
Top Skin Length (Left):	22.140	inches			
Top Skin Length (Right):	22.150	inches			
Bottom Skin Width @ Grips:	22.025	inches			
Bottom Skin Width @ Splice:	22.045	inches			
Bottom Skin Length (Left):	22.070	inches			
Bottom Skin Length (Right):	22.060	inches			
Splice Overlap (Left):		inches			
Splice Overlap (Right):		inches			
A1 - B2 Measurement:	0.815	inches	A1 - F1 Measurement:	4.730	inches
A13 - B26 Measurement:	0.825	inches	A13 - F13 Measurement:	4.792	inches
A1 - C2 Measurement:	1.777	inches			
A13 - C26 Measurement:	1.820	inches			
A1 - D2 Measurement:	2.884	inches			
A13 - D26 Measurement:	2.923	inches			
A1 - E2 Measurement:	3.895	inches			
A13 - E26 Measurement:	3.938	inches			
S.G. #1 Above A1 - A13 Line:	1.000	inches	from Panel Center:	7.210	inches
S.G. #2 Above A1 - A13 Line:	1.011	inches	from Panel Center:	7.265	inches
S.G. #3 Above A1 - A13 Line:		inches	from Panel Center:		inches
S.G. #4 Above A1 - A13 Line:		inches	from Panel Center:		inches
S.G. #5 Above A1 - A13 Line:		inches	from Panel Center:		inches
S.G. #6 Above A1 - A13 Line:		inches	from Panel Center:		inches
S.G. #7 Above A1 - A13 Line:	1.000	inches	from Panel Center:	7.110	inches
S.G. #8 Above A1 - A13 Line:	1.011	inches	from Panel Center:	7.155	inches
S.G. #9 Above A1 - A13 Line:		inches	from Panel Center:		inches
S.G. #10 Above A1 - A13 Line:		inches	from Panel Center:		inches
S.G. #11 Above A1 - A13 Line:		inches	from Panel Center:		inches
S.G. #12 Above A1 - A13 Line:		inches	from Panel Center:		inches
S.G. #13 Above A1 - A13 Line:		inches	from Panel Center:		inches
S.G. #14 Above A1 - A13 Line:		inches	from Panel Center:		inches
S.G. #15 Above A1 - A13 Line:		inches	from Panel Center:		inches
S.G. #16 Above A1 - A13 Line:		inches	from Panel Center:		inches
S.G. #17 Above A1 - A13 Line:	0.982	inches	from Panel Center:	7.210	inches
S.G. #18 Above F1 - F13 Line:	1.000	inches	from Panel Center:	7.233	inches
S.G. #19 Above F1 - F13 Line:	0.984	inches	from Panel Center:	7.130	inches
S.G. #20 Above F1 - F13 Line:	1.000	inches	from Panel Center:	7.135	inches

FIGURE E-9. MEASURED EIFS SPECIMEN DIMENSIONS (Continued)

Article ID: ZB5118853-503 #3 (EIFS-11) Date: 02-Mar-98

Measurements Taken By: J. Vannorsdall / L. Mack

Top Skin Width @ Grips:	22.059	inches			
Top Skin Width @ Splice:	22.018	inches			
Top Skin Length (Left):	22.100	inches			
Top Skin Length (Right):	22.130	inches			
Bottom Skin Width @ Grips:	22.043	inches			
Bottom Skin Width @ Splice:	22.028	inches			
Bottom Skin Length (Left):	22.000	inches			
Bottom Skin Length (Right):	22.020	inches			
Splice Overlap (Left):		inches			
Splice Overlap (Right):		inches			
A1 - B2 Measurement:	0.800	inches	A1 - F1 Measurement:	4.723	inches
A13 - B26 Measurement:	0.775	inches	A13 - F13 Measurement:	4.684	inches
A1 - C2 Measurement:	1.789	inches			
A13 - C26 Measurement:	1.815	inches			
A1 - D2 Measurement:	2.944	inches			
A13 - D26 Measurement:	2.954	inches			
A1 - E2 Measurement:	3.915	inches			
A13 - E26 Measurement:	3.873	inches			
S.G. #1 Above A1 - A13 Line:	0.995	inches	from Panel Center:	7.210	inches
S.G. #2 Above A1 - A13 Line:	1.006	inches	from Panel Center:	7.255	inches
S.G. #3 Above A1 - A13 Line:		inches	from Panel Center:		inches
S.G. #4 Above A1 - A13 Line:		inches	from Panel Center:		inches
S.G. #5 Above A1 - A13 Line:		inches	from Panel Center:		inches
S.G. #6 Above A1 - A13 Line:		inches	from Panel Center:		inches
S.G. #7 Above A1 - A13 Line:	0.995	inches	from Panel Center:	7.130	inches
S.G. #8 Above A1 - A13 Line:	1.021	inches	from Panel Center:	7.140	inches
S.G. #9 Above A1 - A13 Line:		inches	from Panel Center:		inches
S.G. #10 Above A1 - A13 Line:		inches	from Panel Center:		inches
S.G. #11 Above A1 - A13 Line:		inches	from Panel Center:		inches
S.G. #12 Above A1 - A13 Line:		inches	from Panel Center:		inches
S.G. #13 Above A1 - A13 Line:		inches	from Panel Center:		inches
S.G. #14 Above A1 - A13 Line:		inches	from Panel Center:		inches
S.G. #15 Above A1 - A13 Line:		inches	from Panel Center:		inches
S.G. #16 Above A1 - A13 Line:		inches	from Panel Center:		inches
S.G. #17 Above A1 - A13 Line:	0.991	inches	from Panel Center:	7.220	inches
S.G. #18 Above F1 - F13 Line:	0.988	inches	from Panel Center:	7.185	inches
S.G. #19 Above F1 - F13 Line:	1.003	inches	from Panel Center:	7.040	inches
S.G. #20 Above F1 - F13 Line:	0.971	inches	from Panel Center:	7.220	inches

FIGURE E-9. MEASURED EIFS SPECIMEN DIMENSIONS (Continued)

Article ID: ZB5118853-503 #4 (EIFS-12) Date: 01-Apr-98

Measurements Taken By: J. Vannorsdall/L. Mack

Top Skin Width @ Grips:	22.067	inches			
Top Skin Width @ Splice:	22.126	inches			
Top Skin Length (Left):	22.060	inches			
Top Skin Length (Right):	22.130	inches			
Bottom Skin Width @ Grips:	22.083	inches			
Bottom Skin Width @ Splice:	22.045	inches			
Bottom Skin Length (Left):	22.240	inches			
Bottom Skin Length (Right):	22.160	inches			
Splice Overlap (Left):		inches			
Splice Overlap (Right):		inches			
A1 - B2 Measurement:	0.782	inches	A1 - F1 Measurement:	4.696	inches
A13 - B26 Measurement:	0.775	inches	A13 - F13 Measurement:	4.696	inches
A1 - C2 Measurement:	1.725	inches			
A13 - C26 Measurement:	1.800	inches			
A1 - D2 Measurement:	2.863	inches			
A13 - D26 Measurement:	2.951	inches			
A1 - E2 Measurement:	3.869	inches			
A13 - E26 Measurement:	3.902	inches			
S.G. #1 Above A1 - A13 Line:	1.023	inches	from Panel Center:	7.185	inches
S.G. #2 Above A1 - A13 Line:	1.018	inches	from Panel Center:	7.210	inches
S.G. #3 Above A1 - A13 Line:		inches	from Panel Center:		inches
S.G. #4 Above A1 - A13 Line:		inches	from Panel Center:		inches
S.G. #5 Above A1 - A13 Line:		inches	from Panel Center:		inches
S.G. #6 Above A1 - A13 Line:		inches	from Panel Center:		inches
S.G. #7 Above A1 - A13 Line:	0.997	inches	from Panel Center:	7.210	inches
S.G. #8 Above A1 - A13 Line:	1.024	inches	from Panel Center:	7.220	inches
S.G. #9 Above A1 - A13 Line:		inches	from Panel Center:		inches
S.G. #10 Above A1 - A13 Line:		inches	from Panel Center:		inches
S.G. #11 Above A1 - A13 Line:		inches	from Panel Center:		inches
S.G. #12 Above A1 - A13 Line:		inches	from Panel Center:		inches
S.G. #13 Above A1 - A13 Line:		inches	from Panel Center:		inches
S.G. #14 Above A1 - A13 Line:		inches	from Panel Center:		inches
S.G. #15 Above A1 - A13 Line:		inches	from Panel Center:		inches
S.G. #16 Above A1 - A13 Line:		inches	from Panel Center:		inches
S.G. #17 Above A1 - A13 Line:	1.004	inches	from Panel Center:	7.240	inches
S.G. #18 Above F1 - F13 Line:	1.015	inches	from Panel Center:	7.130	inches
S.G. #19 Above F1 - F13 Line:	0.996	inches	from Panel Center:	7.270	inches
S.G. #20 Above F1 - F13 Line:	1.024	inches	from Panel Center:	7.140	inches

FIGURE E-9. MEASURED EIFS SPECIMEN DIMENSIONS (Continued)

Article ID: ZB5118853-505 #1 (EIFS-13) Date: 01-Apr-98

Measurements Taken By: Jeff Vannorsdall

Top Skin Width @ Grips:	22.027	inches			
Top Skin Width @ Splice:	22.057	inches			
Top Skin Length (Left):	22.200	inches			
Top Skin Length (Right):	22.140	inches			
Bottom Skin Width @ Grips:	22.025	inches			
Bottom Skin Width @ Splice:	22.047	inches			
Bottom Skin Length (Left):	22.160	inches			
Bottom Skin Length (Right):	22.200	inches			
A1 - B1 Measurement:	0.855	inches	A1 - F1 Measurement:	3.714	inches
A15 - B29 Measurement:	0.907	inches	A15 - F28 Measurement:	3.772	inches
A1 - C1 Measurement:	1.490	inches	A1 - G1 Measurement:	4.365	inches
A15 - C28 Measurement:	1.542	inches	IA15 - G29 Measurement:	4.425	inches
A1 - D1 Measurement:	2.102	inches	A1 - H1 Measurement:	5.248	inches
A15 - D29 Measurement:	2.144	inches	A15 - H15 Measurement:	5.310	inches
A1 - E1 Measurement:	3.092	inches			
A15 - E29 Measurement:	3.169	inches			
S.G. #1 Above A1 - A15 Line:	1.000	inches	from Panel Center:	6.800	inches
S.G. #2 Above A1 - A15 Line:	0.982	inches	from Panel Center:	6.800	inches
S.G. #3 Above A1 - A15 Line:	1.000	inches	from Panel Center:	3.820	inches
S.G. #4 Above A1 - A15 Line:	0.965	inches	from Panel Center:	3.840	inches
S.G. #5 Above A1 - A15 Line:	1.000	inches	from Panel Center:	0.820	inches
S.G. #6 Above A1 - A15 Line:	0.975	inches	from Panel Center:	0.800	inches
S.G. #7 Above A1 - A15 Line:	1.000	inches	from Panel Center:	0.700	inches
S.G. #8 Above A1 - A15 Line:	0.990	inches	from Panel Center:	0.700	inches
S.G. #9 Above A1 - A15 Line:	1.000	inches	from Panel Center:	3.640	inches
S.G. #10 Above A1 - A15 Line:	0.964	inches	from Panel Center:	3.680	inches
S.G. #11 Above A1 - A15 Line:	1.000	inches	from Panel Center:	6.640	inches
S.G. #12 Above A1 - A15 Line:	0.971	inches	from Panel Center:	6.680	inches
S.G. #13 Above A1 - A15 Line:	0.075	inches	from Panel Center:	6.840	inches
S.G. #14 Above A1 - A15 Line:	c/l	inches	from Panel Center:	6.800	inches
S.G. #15 Above A1 - A15 Line:	0.065	inches	from Panel Center:	2.340	inches
S.G. #16 Above A1 - A15 Line:	c/l	inches	from Panel Center:	2.320	inches
S.G. #17 Above A1 - A15 Line:	0.035	inches	from Panel Center:	2.260	inches
S.G. #18 Above A1 - A15 Line:	c/l	inches	from Panel Center:	2.200	inches
S.G. #19 Above A1 - A15 Line:	0.018	inches	from Panel Center:	6.620	inches
S.G. #20 Above A1 - A15 Line:	c/l	inches	from Panel Center:	6.700	inches
S.G. #21 Below H1 - H15 Line:	1.000	inches	from Panel Center:	6.780	inches
S.G. #22 Below H1 - H15 Line:	0.995	inches	from Panel Center:	6.760	inches
S.G. #23 Below H1 - H15 Line:	1.000	inches	from Panel Center:	6.700	inches
S.G. #24 Below H1 - H15 Line:	1.000	inches	from Panel Center:	6.720	inches

FIGURE E-9. MEASURED EIFS SPECIMEN DIMENSIONS (Continued)

Article ID: ZB5118853-505 #2 (EIFS-14) Date: 09-Apr-98

Measurements Taken By: J. Vannorsdall & L. Mack

Top Skin Width @ Grips:	22.035	inches			
Top Skin Width @ Splice:	22.055	inches			
Top Skin Length (Left):		inches			
Top Skin Length (Right):		inches			
Bottom Skin Width @ Grips:	22.008	inches			
Bottom Skin Width @ Splice:	22.035	inches			
Bottom Skin Length (Left):		inches			
Bottom Skin Length (Right):		inches			
A1 - B1 Measurement:	0.870	inches	A1 - F1 Measurement:	3.735	inches
A15 - B29 Measurement:	0.823	inches	A15 - F28 Measurement:	3.717	inches
A1 - C1 Measurement:	1.492	inches	A1 - G1 Measurement:	4.359	inches
A15 - C28 Measurement:	1.463	inches	IA15 - G29 Measurement:	4.337	inches
A1 - D1 Measurement:	2.103	inches	A1 - H1 Measurement:	5.250	inches
A15 - D29 Measurement:	2.078	inches	A15 - H15 Measurement:	5.182	inches
A1 - E1 Measurement:	3.128	inches			
A15 - E29 Measurement:	3.081	inches			
S.G. #1 Above A1 - A15 Line:	1.000	inches	from Panel Center:	6.735	inches
S.G. #2 Above A1 - A15 Line:	0.970	inches	from Panel Center:	6.700	inches
S.G. #3 Above A1 - A15 Line:		inches	from Panel Center:		inches
S.G. #4 Above A1 - A15 Line:		inches	from Panel Center:		inches
S.G. #5 Above A1 - A15 Line:		inches	from Panel Center:		inches
S.G. #6 Above A1 - A15 Line:		inches	from Panel Center:		inches
S.G. #7 Above A1 - A15 Line:		inches	from Panel Center:		inches
S.G. #8 Above A1 - A15 Line:		inches	from Panel Center:		inches
S.G. #9 Above A1 - A15 Line:		inches	from Panel Center:		inches
S.G. #10 Above A1 - A15 Line:		inches	from Panel Center:		inches
S.G. #11 Above A1 - A15 Line:	1.020	inches	from Panel Center:	6.760	inches
S.G. #12 Above A1 - A15 Line:	1.039	inches	from Panel Center:	6.775	inches
S.G. #13 Above A1 - A15 Line:		inches	from Panel Center:		inches
S.G. #14 Above A1 - A15 Line:		inches	from Panel Center:		inches
S.G. #15 Above A1 - A15 Line:		inches	from Panel Center:		inches
S.G. #16 Above A1 - A15 Line:		inches	from Panel Center:		inches
S.G. #17 Above A1 - A15 Line:		inches	from Panel Center:		inches
S.G. #18 Above A1 - A15 Line:		inches	from Panel Center:		inches
S.G. #19 Above A1 - A15 Line:		inches	from Panel Center:		inches
S.G. #20 Above A1 - A15 Line:		inches	from Panel Center:		inches
S.G. #21 Below H1 - H15 Line:	1.000	inches	from Panel Center:	6.735	inches
S.G. #22 Below H1 - H15 Line:	0.972	inches	from Panel Center:	6.700	inches
S.G. #23 Below H1 - H15 Line:	1.000	inches	from Panel Center:	6.770	inches
S.G. #24 Below H1 - H15 Line:	1.000	inches	from Panel Center:	6.775	inches

FIGURE E-9. MEASURED EIFS SPECIMEN DIMENSIONS (Continued)

Article ID: ZB5118853-505 #3 (EIFS-15) Date: 09-Apr-98

Measurements Taken By: J. Vannorsdall & L. Mack

Top Skin Width @ Grips:	22.035	inches			
Top Skin Width @ Splice:	22.055	inches			
Top Skin Length (Left):	22.100	inches			
Top Skin Length (Right):	22.100	inches			
Bottom Skin Width @ Grips:	22.020	inches			
Bottom Skin Width @ Splice:	22.006	inches			
Bottom Skin Length (Left):	22.240	inches			
Bottom Skin Length (Right):	22.300	inches			
A1 - B1 Measurement:	0.847	inches	A1 - F1 Measurement:	3.746	inches
A15 - B29 Measurement:	0.925	inches	A15 - F28 Measurement:	3.775	inches
A1 - C1 Measurement:	1.470	inches	A1 - G1 Measurement:	4.333	inches
A15 - C28 Measurement:	1.546	inches	IA15 - G29 Measurement:	4.400	inches
A1 - D1 Measurement:	2.095	inches	A1 - H1 Measurement:	5.217	inches
A15 - D29 Measurement:	2.160	inches	A15 - H15 Measurement:	5.230	inches
A1 - E1 Measurement:	3.090	inches			
A15 - E29 Measurement:	3.150	inches			
S.G. #1 Above A1 - A15 Line:	0.960	inches	from Panel Center:	2.750	inches
S.G. #2 Above A1 - A15 Line:	1.000	inches	from Panel Center:	6.720	inches
S.G. #3 Above A1 - A15 Line:		inches	from Panel Center:		inches
S.G. #4 Above A1 - A15 Line:		inches	from Panel Center:		inches
S.G. #5 Above A1 - A15 Line:		inches	from Panel Center:		inches
S.G. #6 Above A1 - A15 Line:		inches	from Panel Center:		inches
S.G. #7 Above A1 - A15 Line:		inches	from Panel Center:		inches
S.G. #8 Above A1 - A15 Line:		inches	from Panel Center:		inches
S.G. #9 Above A1 - A15 Line:		inches	from Panel Center:		inches
S.G. #10 Above A1 - A15 Line:		inches	from Panel Center:		inches
S.G. #11 Above A1 - A15 Line:	0.926	inches	from Panel Center:	6.740	inches
S.G. #12 Above A1 - A15 Line:	0.957	inches	from Panel Center:	6.700	inches
S.G. #13 Above A1 - A15 Line:		inches	from Panel Center:		inches
S.G. #14 Above A1 - A15 Line:		inches	from Panel Center:		inches
S.G. #15 Above A1 - A15 Line:		inches	from Panel Center:		inches
S.G. #16 Above A1 - A15 Line:		inches	from Panel Center:		inches
S.G. #17 Above A1 - A15 Line:		inches	from Panel Center:		inches
S.G. #18 Above A1 - A15 Line:		inches	from Panel Center:		inches
S.G. #19 Above A1 - A15 Line:		inches	from Panel Center:		inches
S.G. #20 Above A1 - A15 Line:		inches	from Panel Center:		inches
S.G. #21 Below H1 - H15 Line:	1.019	inches	from Panel Center:	6.780	inches
S.G. #22 Below H1 - H15 Line:	1.080	inches	from Panel Center:	6.735	inches
S.G. #23 Below H1 - H15 Line:	1.059	inches	from Panel Center:	6.750	inches
S.G. #24 Below H1 - H15 Line:	1.021	inches	from Panel Center:	6.730	inches

FIGURE E-9. MEASURED EIFS SPECIMEN DIMENSIONS (Continued)

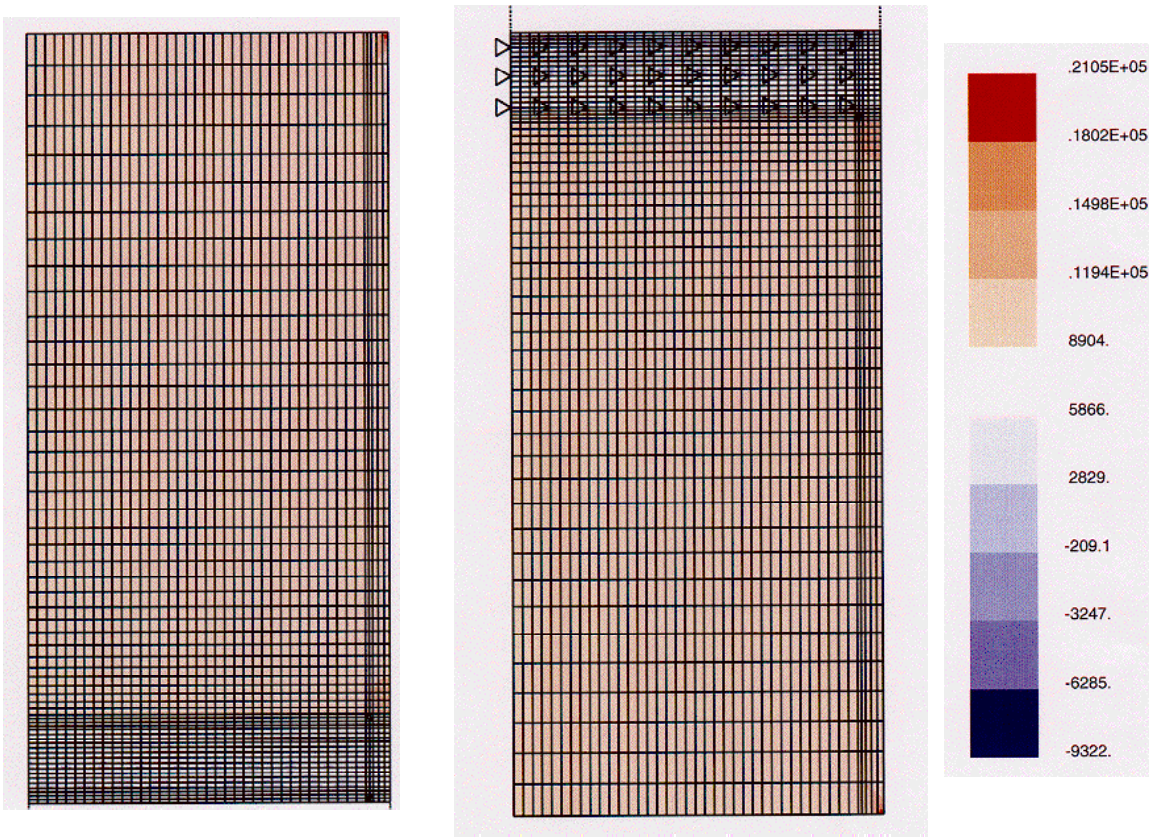
Article ID: ZB5118853-505 #4 (EIFS-16) Date: 09-Apr-98

Measurements Taken By: J. Vannorsdall

Top Skin Width @ Grips:	22.000	inches			
Top Skin Width @ Splice:	22.010	inches			
Top Skin Length (Left):	22.200	inches			
Top Skin Length (Right):	22.140	inches			
Bottom Skin Width @ Grips:	22.029	inches			
Bottom Skin Width @ Splice:	22.050	inches			
Bottom Skin Length (Left):	22.100	inches			
Bottom Skin Length (Right):	22.140	inches			
A1 - B1 Measurement:	0.875	inches	A1 - F1 Measurement:	3.750	inches
A15 - B29 Measurement:	0.860	inches	A15 - F28 Measurement:	3.740	inches
A1 - C1 Measurement:	1.500	inches	A1 - G1 Measurement:	4.491	inches
A15 - C28 Measurement:	1.480	inches	A15 - G29 Measurement:	4.385	inches
A1 - D1 Measurement:	2.150	inches	A1 - H1 Measurement:	5.265	inches
A15 - D29 Measurement:	2.120	inches	A15 - H15 Measurement:	5.250	inches
A1 - E1 Measurement:	3.150	inches			
A15 - E29 Measurement:	3.110	inches			
S.G. #1 Above A1 - A15 Line:	0.975	inches	from Panel Center:	6.760	inches
S.G. #2 Above A1 - A15 Line:	1.000	inches	from Panel Center:	6.800	inches
S.G. #3 Above A1 - A15 Line:		inches	from Panel Center:		inches
S.G. #4 Above A1 - A15 Line:		inches	from Panel Center:		inches
S.G. #5 Above A1 - A15 Line:		inches	from Panel Center:		inches
S.G. #6 Above A1 - A15 Line:		inches	from Panel Center:		inches
S.G. #7 Above A1 - A15 Line:		inches	from Panel Center:		inches
S.G. #8 Above A1 - A15 Line:		inches	from Panel Center:		inches
S.G. #9 Above A1 - A15 Line:		inches	from Panel Center:		inches
S.G. #10 Above A1 - A15 Line:		inches	from Panel Center:		inches
S.G. #11 Above A1 - A15 Line:	1.038	inches	from Panel Center:	6.700	inches
S.G. #12 Above A1 - A15 Line:	1.000	inches	from Panel Center:	6.780	inches
S.G. #13 Above A1 - A15 Line:		inches	from Panel Center:		inches
S.G. #14 Above A1 - A15 Line:		inches	from Panel Center:		inches
S.G. #15 Above A1 - A15 Line:		inches	from Panel Center:		inches
S.G. #16 Above A1 - A15 Line:		inches	from Panel Center:		inches
S.G. #17 Above A1 - A15 Line:		inches	from Panel Center:		inches
S.G. #18 Above A1 - A15 Line:		inches	from Panel Center:		inches
S.G. #19 Above A1 - A15 Line:		inches	from Panel Center:		inches
S.G. #20 Above A1 - A15 Line:		inches	from Panel Center:		inches
S.G. #21 Below H1 - H15 Line:	1.030	inches	from Panel Center:	6.780	inches
S.G. #22 Below H1 - H15 Line:	0.970	inches	from Panel Center:	6.780	inches
S.G. #23 Below H1 - H15 Line:	0.975	inches	from Panel Center:	6.730	inches
S.G. #24 Below H1 - H15 Line:	1.000	inches	from Panel Center:	6.780	inches

FIGURE E-9. MEASURED EIFS SPECIMEN DIMENSIONS (Continued)

The following pages contain the stress fringe plots for the EIFS finite element models, which are detailed in section 6.10.4.



Upper Skin Skin

FIGURE E-10. STRESS DISTRIBUTION FOR SKIN, 10 ksi—TYPE 2 EIFS TEST SPECIMEN

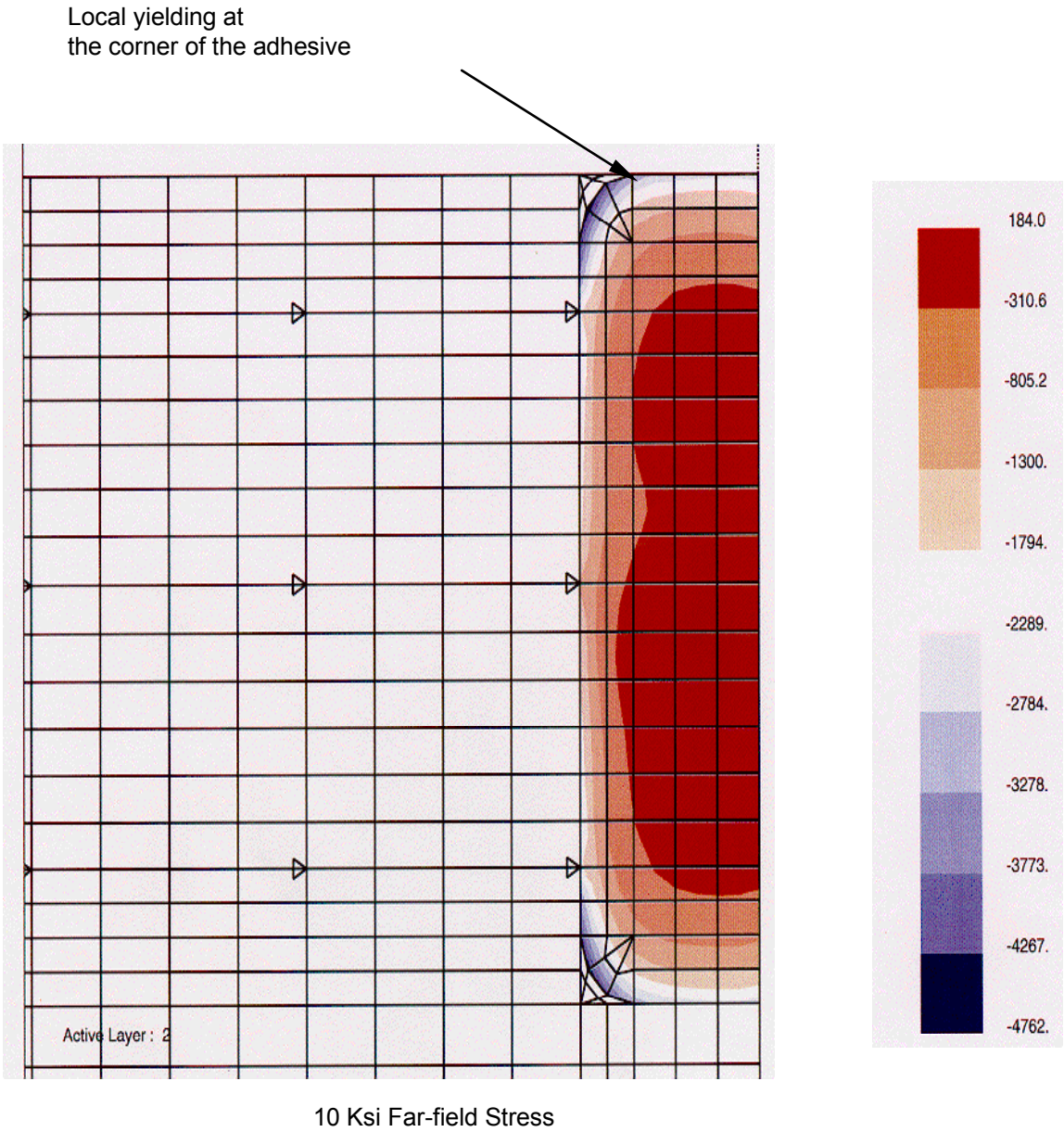


FIGURE E-11. STRESS DISTRIBUTION FOR SKIN, WITH EDGE BOUNDING, 10 ksi—
TYPE 2 EIFS TEST SPECIMEN

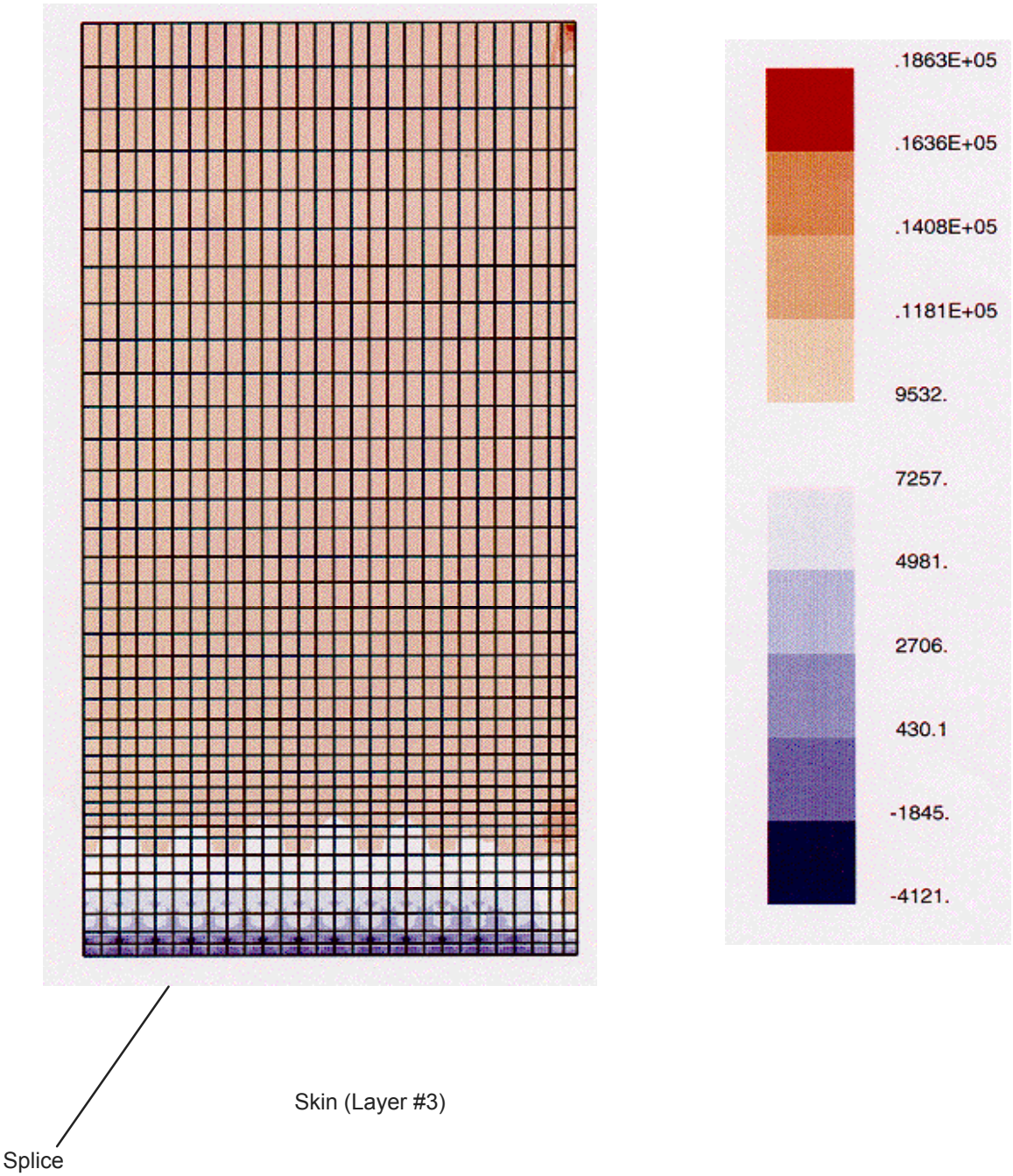


FIGURE E-12. STRESS DISTRIBUTION FOR SKIN, WITH EDGE BOUNDING, 10 ksi—TYPE 3 EIFS TEST SPECIMEN

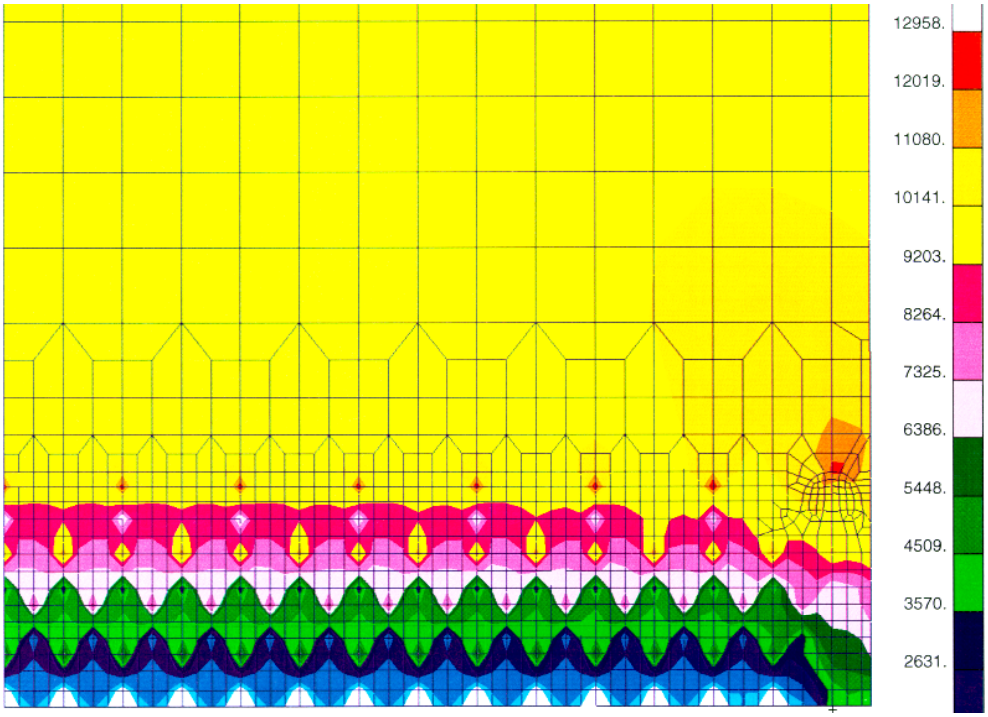


FIGURE E-13. STRESS DISTRIBUTION FOR SKIN, 10 ksi—TYPE 4 EIFS TEST SPECIMEN

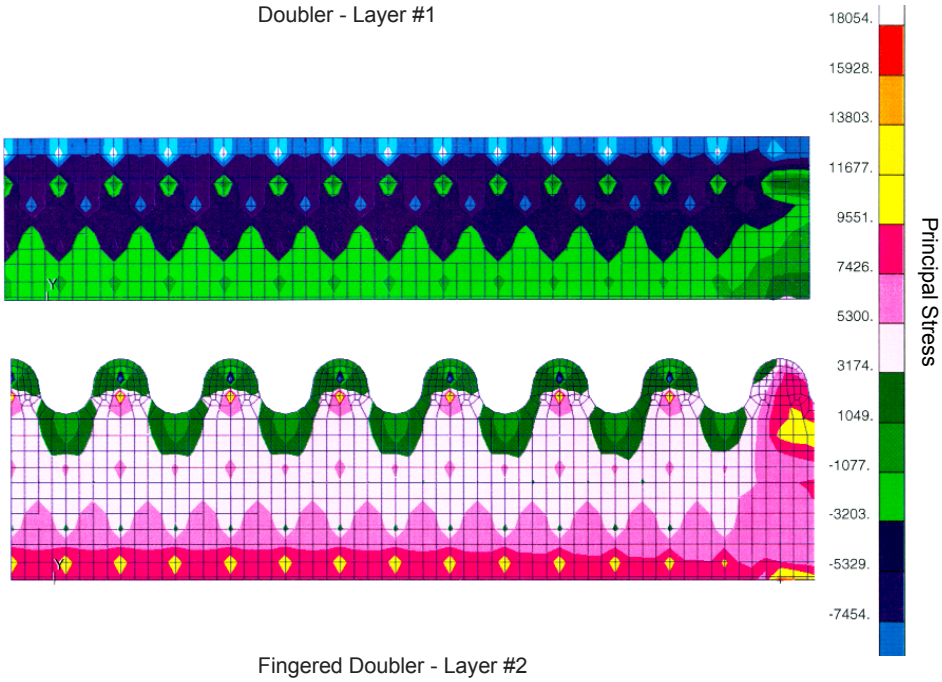


FIGURE E-14. STRESS DISTRIBUTION FOR DOUBLERS, 10 ksi—TYPE 4 EIFS TEST SPECIMEN

The following pages contain the strain predictions and measured results for the EIFS panels, which are detailed in section 6.10.4.

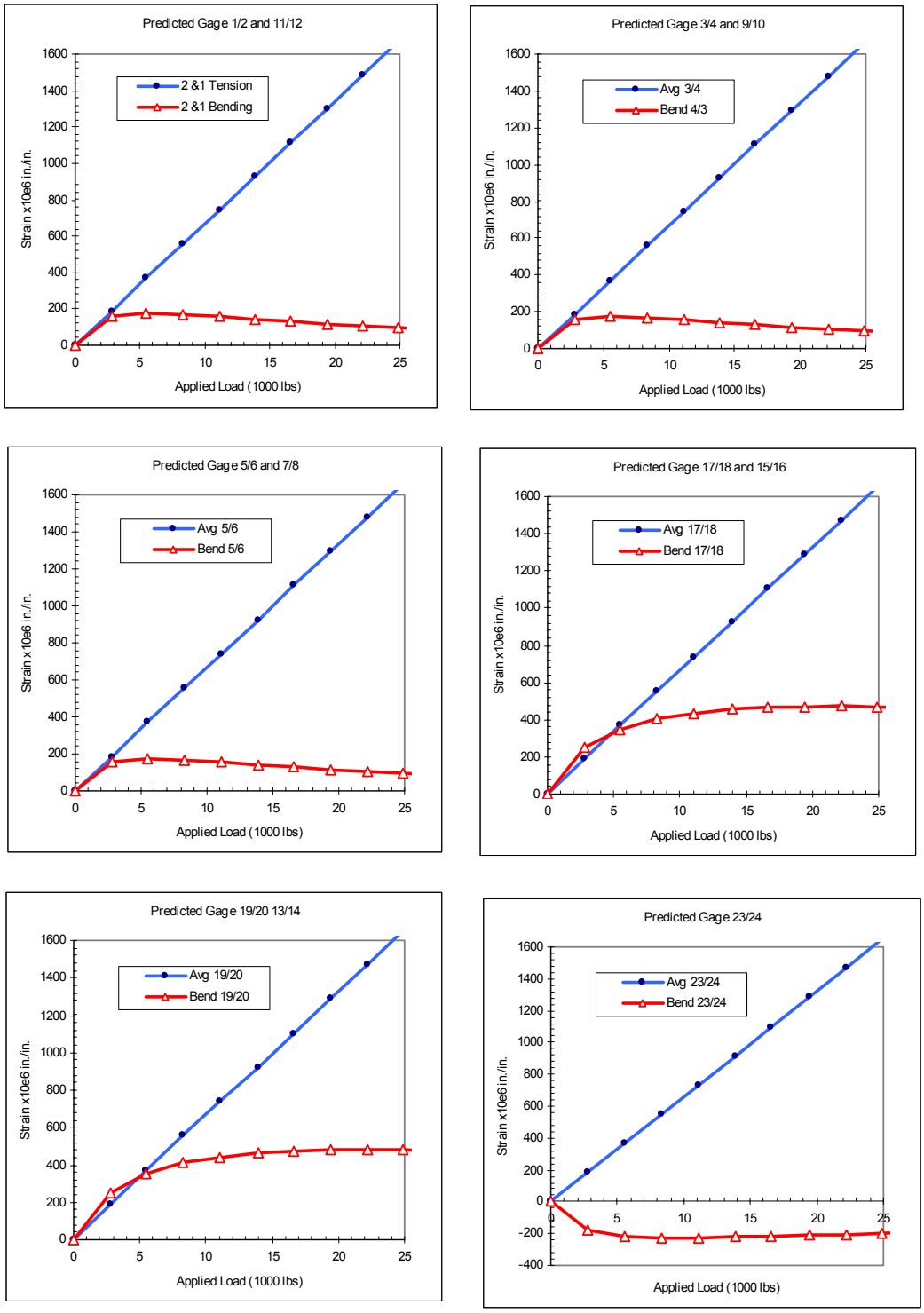


FIGURE E-15. PREDICTED STRAIN FOR EIFS TYPE 1 EIFS PANELS

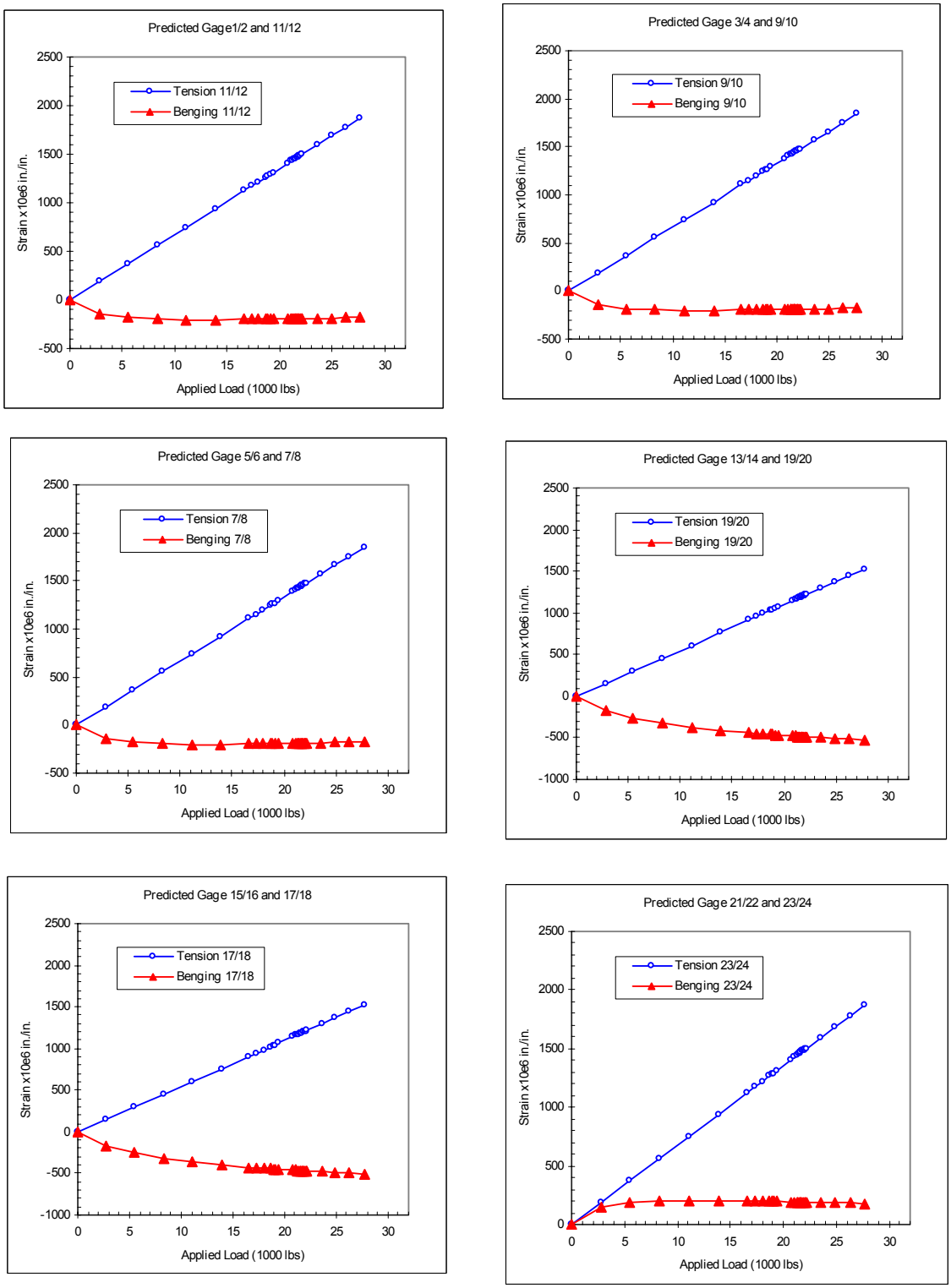
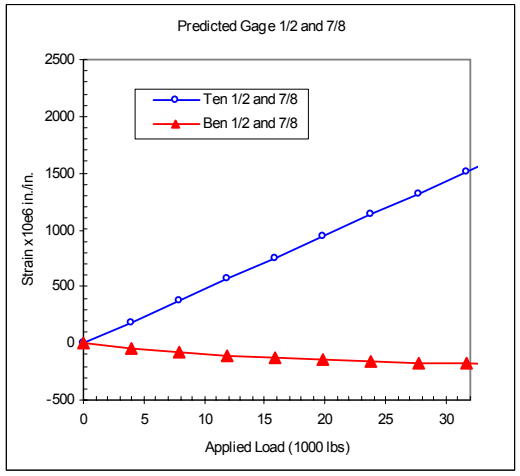
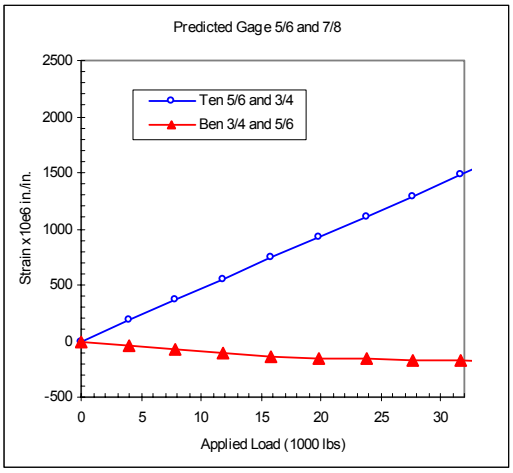
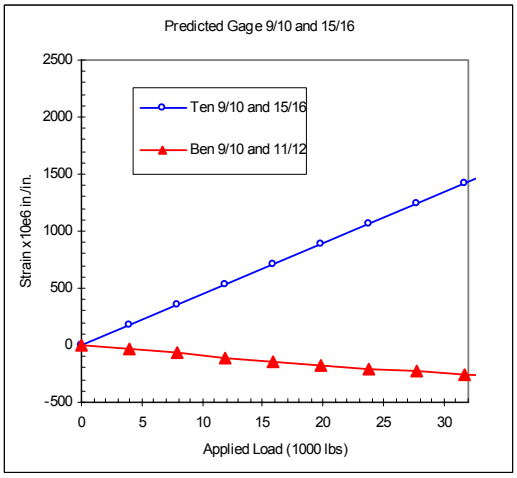
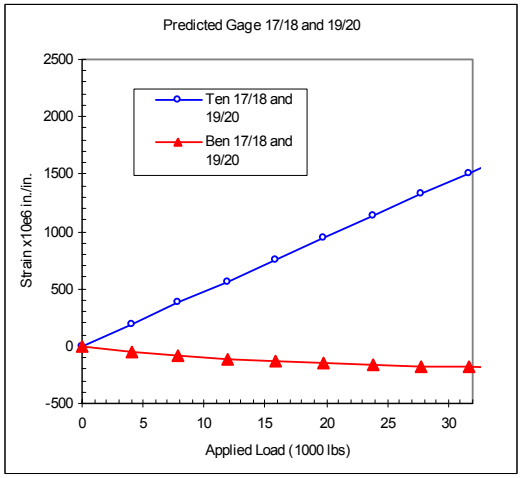


FIGURE E-16. PREDICTED STRAIN FOR EIFS TYPE 2 EIFS PANELS









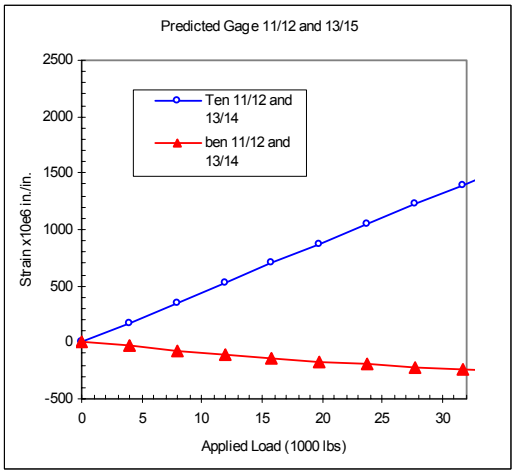


FIGURE E-17. PREDICTED STRAIN FOR EIFS TYPE 3 EIFS PANELS

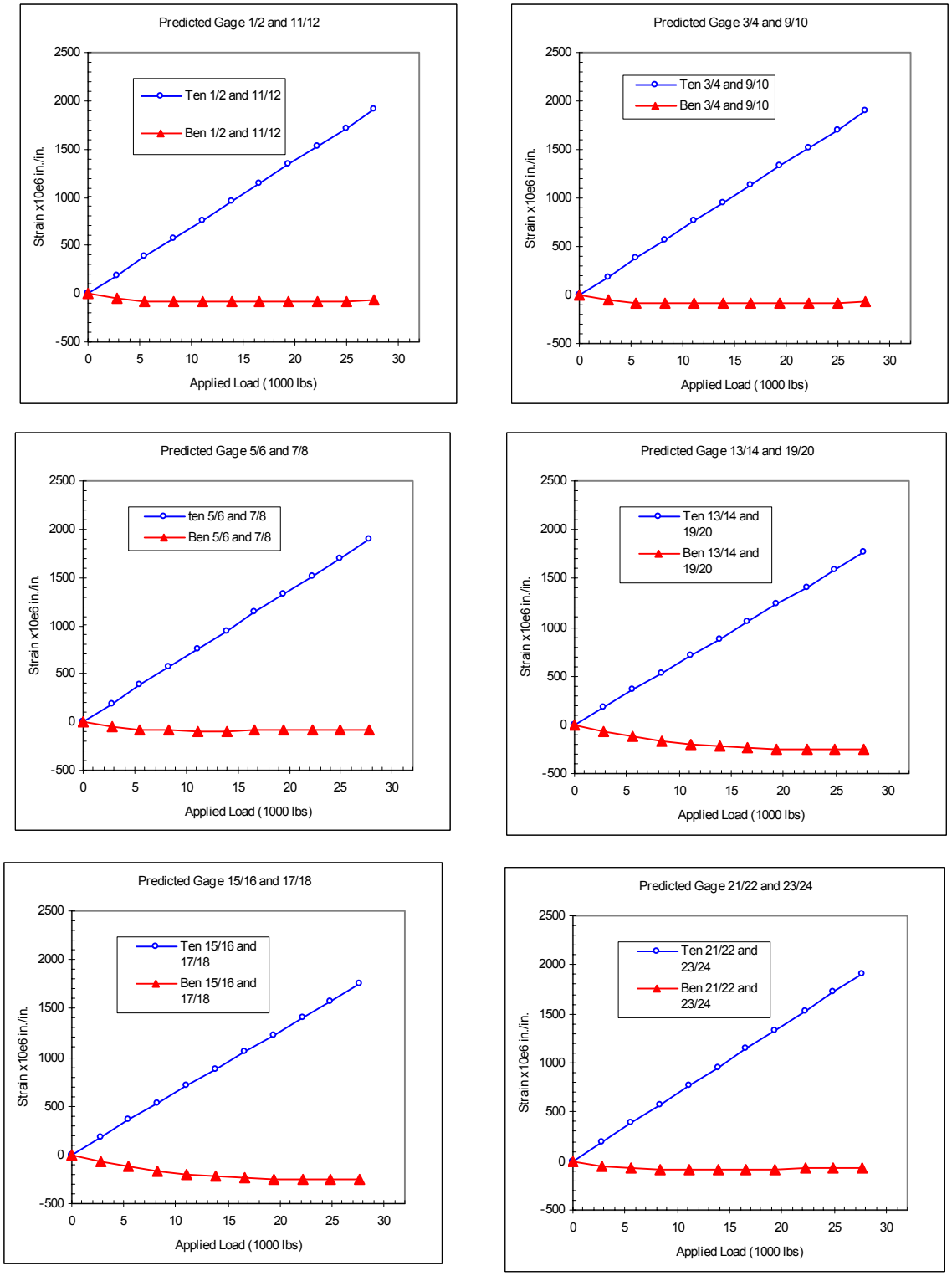
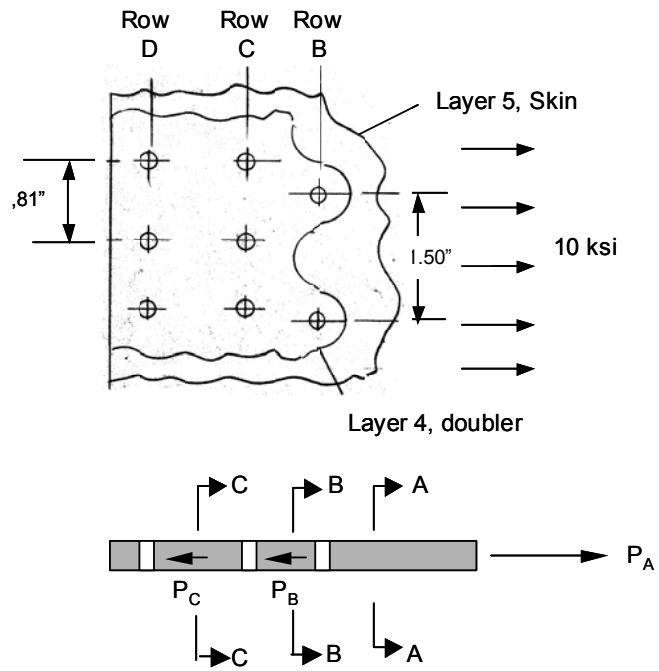


FIGURE E-18. PREDICTED STRAIN FOR EIFS TYPE 4 EIFS PANELS

Example of bearing stress factor and bypass stress factor calculation.

From figure 6-12, the fastener loads for the fastener rows B, C, and D in layer 5 (skin) are listed below:

At Row B F_b=121 lbs
At Row C F_c=225 lbs
At Row D F_d=210 lbs



The bearing stress at each fastener row can be calculated as shown below:

At Row B σ_b=121 lbs/0.1563″/0.063″ =12,288 psi
At Row C σ_b=225 lbs/0.188″/0.063″ =18,997 psi
At Row D σ_b=210 lbs/0.188″/0.063″ =17,730 psi

Where 0.1563″ and 0.188″ are the respective fastener diameters and 0.063″ is the thickness of the skin.

The total force per linear length, P_A, applied at the right end of the skin and the internal forces P_B and P_C at sections B-B and C-C, respectively, are shown below:

P_A = 0.063″ x 10,000 psi = 630 lbs/in.
P_B = 630 lbs/in - 121 lbs/1.5″ = 630 lbs/in - 80.67 lbs/in = 549.3 lbs/in
P_C = 549.3 lbs/in - 225 lbs/0.81″ = 549.3 lbs/in - 277.8 lbs/in =316.5 lbs/in

The average bypass stresses at sections B-B and C-C can be calculated as shown below:

At section B-B σ_{bp}= 549.3 lbs/in/0.063 in. = 8719 psi
At section C-C σ_{bp}= 316.5 lbs/in/0.063 in. = 5024 psi

At fastener row B

The bearing stress factor = 12,280 psi/10,000 psi = 1.228
The bypass factor = 8719 psi/10,000 psi = 0.872

At fastener row C

The bearing stress factor = 18,997 psi/8,719 psi = 2.18
The bypass factor = 5024 psi/8719 psi = 0.576

At fastener row D

The bearing stress factor = 17,730 psi/5,024 psi = 3.53
The bypass factor = 0 psi/5,024 psi = 0.00

E.1 ORIGINAL CRACK GROWTH ANALYSIS.

Formulation of Geometric Correction Factor, β.

The Newman-Raju* K solution for symmetric corner cracks emanating from an open hole subjected to far-field tensile and bending was used as the basic crack growth model. To account for the effects that are pertinent to crack growth in a countersunk hole subjected to far-field stress, bending stress, bypass and bearing stresses, and preload caused by rivet squeezing force, the geometry correction factors were modified to include all of these factors, as shown in figures E-20 and E-21.

In the closure-based crack growth model, the crack growth rate is expressed as a function of the effective stress-intensity factor (SIF) range (ΔK_{eff}):

$$da/dN = f\left(\Delta K_{eff}\right)$$

and

$$\Delta K_{eff} = \beta_{Total} \Delta\sigma_{eff} \sqrt{\pi a}$$

where $\Delta\sigma_{eff}$ is the effective range of a reference stress, without considering the effects of preload in the riveted joint. The effective SIF ΔK_{eff} is further modified to include the effects of the rivet contact forces in the FASTRAN-II code. The procedure to include the effects of the contact stress is discussed in the next section. The extreme fiber stress, including tensile and bending

*Newman, J. C., Jr. and Raju, I. S. (1984), "Stress-Intensity Factor Equations for Cracks in Three-Dimensional Finite Bodies Subjected to Tension and Bending Loads," NASA-TM-85793.

stress, is used as the reference stress. The β_{Total} is the compounded geometry correction factor. β_{Total} is expressed as follows:

$$\beta_{Total} = \beta_{csk} \times \beta_{fw} \times \beta_{neatfit} \times \beta_{LH}$$

where

β_{csk} = The countersunk hole correction factor. The correction factor is based on the published FAA report DOT/FAA/CT-93/68 for a corner crack emanating from an open countersunk hole subjected to far-field tensile stress. The β_{csk} factor is normalized to the well-known Newman-Raju solution of symmetrical corner cracks emanating from a straight shank, open hole subjected to far-field tensile stress. The normalized correction factors for the countersunk hole are shown in table E-1.

$\beta_{neatfit}$ = The correction factor accounting for a through-the-thickness crack emanating from a hole filled with a close-tolerance fastener, under far-field tensile stress. The factor was derived based on a two-dimensional finite element model. This factor is approximately 0.77 when the crack is small and quickly approaches 1.0 as the crack becomes larger. For the depth direction, this factor remains approximately 0.77.

β_{fw} = The correction factor accounting for adjacent crack tips in a series of periodic, colinear, equal-sized cracks. Treating the individual periodic crack as a single crack in a narrow strip of tensile specimen, the β_{fw} is the same as the finite width correction factor for a middle-crack tension (M(T)) specimen. The width of the M(T) specimen is equal to the pitch of the fasteners, such that

$$\beta_{fw} = \sqrt{csc(\pi a/(P))}$$

This correction factor is applied to the surface crack tip only. P is the pitch of the fasteners.

β_{LH} = The compounded solution for a symmetrical corner crack emanating from a loaded hole. The solution is based on Newman-Raju's solution for an open hole modified to include the effects of the bearing as follows:

$$\beta_{LH} = \left(1 - F_{bndg}\right) \times \left(0.50 \times \left(1 + F_{bypass}\right) + F_{brng} \times \beta_{newman} / \beta_{bowie}\right)$$

where β_{newman} is the Newman-Raju solution for symmetrical corner cracks from an open hole and β_{bowie} is Bowie's solution for symmetrical through-the-thickness cracks for an open hole. F_{bndg} is the bending stress factor, F_{bypass} is the bypass stress factor, and F_{brng} is the bearing stress factor.

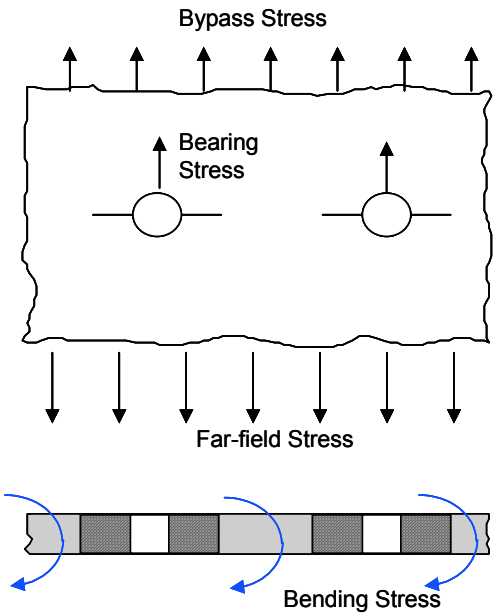
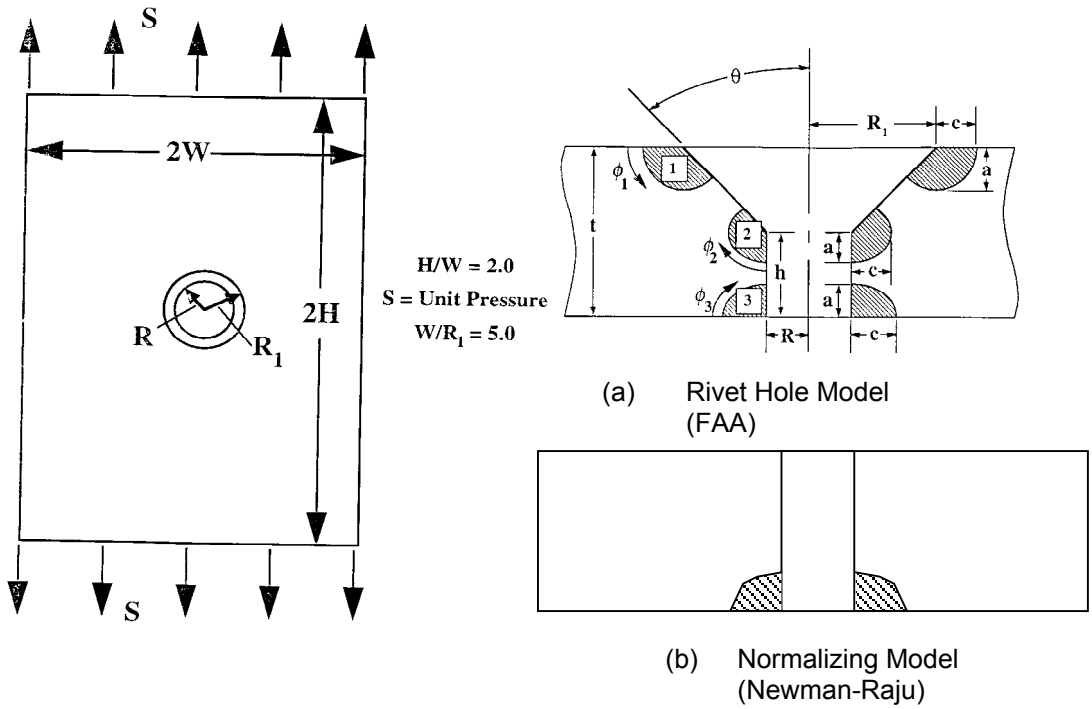


FIGURE E-19. ANALYTICAL CRACK GROWTH MODEL FOR EQUAL-SIZED COLINEAR HOLES WITH MSD



Note: Correction factors from the countersunk hole (a) to be normalized to that of Newman-Raju's model (b)

FIGURE E-20. GEOMETRY CORRECTION FACTOR FOR COUNTRSUNK

TABLE E-1. NORMALIZED GEOMETRY CORRECTION FACTOR FOR COUNTERSUNK HOLES

(a) Correction factor for the crack length (c) at location 3 in figure E-20

		Crack Depth/Thickness (a/t)		
		0.20	0.30	0.40
Crack depth/Length (a/c)	0.40	1.12	1.15	1.10
	0.70	1.22	1.18	1.20
	2.00	0.99	1.04	1.08

(b) Correction factor for the crack depth (a) at location 3 in figure E-20

		Crack Depth/Thickness (a/t)		
		0.20	0.30	0.40
Crack depth/Length (a/c)	0.40	1.15	1.14	1.11
	0.70	1.18	1.17	1.14
	2.00	1.04	1.11	1.17

E.2 EFFECTS OF THE RIVET SURFACE CONTACT STRESS.

The effects of the residual stress in the fastener hole, as a result of rivet installation, is a very complex problem for the following reasons: (1) the actual residual stress is difficult to determine, (2) the contact force distribution is not linear in respect to the various external loads, and (3) the pattern of contact force changes as the crack size changes. However, some attempts were made during this widespread fatigue damage program to include these effects in the crack growth equation.

When a preload is present, the general equation for stress-intensity factor $K = \beta_{Total}\sigma\sqrt{\pi a}$ is no longer true, because K is now a function of the preload stress, the local bearing stress, and the far-field reference stress. Making the solution more difficult is the fact that the relation among these stresses, and the relation between any type of stress and the crack length, are mostly nonlinear in nature. For example, even a small variation in the far-field stress level sometimes changes the local stress distribution pattern completely. Therefore, with preload, the effective stress-intensity factor range can only be expressed as, $\Delta K_{eff} = K'_{\max} - K'_x$, where the $K'_{\max}$ and K'_x correspond to the K under maximum and minimum far-field stress. $K_{\max}$ and K_x can only be

determined on a case by case basis, according to the magnitude of prestress, the magnitude of far-field stress, and the a/R ratio (a: crack length, R: hole radius). The following steps outline the procedures required to determine the ΔK_{eff}, and to implement it into the FASTRAN-II code.

E.2.1 Step 1: Determine the Residual Stress in the Riveted Joint.

The effect of diametric expansion of the rivet during installation is very similar to that of a fastener in an interference-fit hole. The level of the interference in the riveted joint was investigated using the computer code NIKE2D. The strain and stress in a rivet during and after the installation can be analyzed by applying a compressive load to the initially undeformed rivet until a 30% upset is reached. This analysis effort was funded by Boeing's internal IRAD. The predicted residual stress in the hoop and radial direction are shown in figures E-21 and E-22, respectively. The results indicated that there is a contact stress, approximately 7 ksi, at the shank of the fastener.

E.2.2 Step 2: Determine the Corresponding Interference-Fit Level of the Residual Stress.

This 7-ksi stress level corresponds to an approximate 0.15% interference between the fastener and the hole, based on the classic solution for oversized fasteners. The interference is defined as $(d_o-d_i)/d_i$, where d_o is the diameter of the fastener before installation, and d_i is the diameter of the hole. This 0.15% interference is subsequently used in the crack growth analyses.

E.2.3 Step 3: Determine the K_{max} and K_{min} as a Function of Interference-Fit Levels, Crack Length, and Applied Stress.

The effects of the interference fit on the K solution were analyzed using a NASTRAN finite element model, as shown in figure E-23. The model represented a strip of skin containing only one hole. Symmetry boundary conditions are applied to the two lateral edges simulating an infinitely repeated fastener hole pattern. The ratio between the width of the strip and the hole radius resulted in a bearing stress factor of 2.4 and a bypass stress factor of 0.66. The interference between the fastener and the hole was simulated by applying an elevated temperature to the fastener. Four interference levels were considered: 0%, 0.15%, 0.50%, and 1%, under two far-field stress levels: 15 ksi (max stress) and 1.5 ksi (min stress). The stress contour and the deformed shapes of symmetrical cracks emanating from the hole under various load cases are shown in figure E-24 for preload only and for maximum applied stress.

The effects of the interference on the K solution as a function of crack length are plotted in figure E-25. The effects of the interference for a constant crack length can be seen in figure E-26. This figure shows that for a/R = 0.125 with 15-ksi far-field tensile stress, the SIF decreases initially for interference less than 0.5% and then increases as the level of interference increases. The normalized K solution for various crack lengths under three interference levels are shown in figure E-27 for the case with 15-ksi tensile stress and in figure E-28 for the case with 1.5-ksi tensile stress.

E.2.4 Step 4: Determine the Effective ΔK for Interference-Fit Hole.

The crack growth rates in the closure-based model are a function of the effective SIF range, ΔK_{eff}, which, in turn, is a function of the effective stress range, $\Delta K = (\sigma_{max} - \sigma_x)\sqrt{\pi a}$, as shown in figure E-29. For cases with fastener preload, ΔK_{eff} is expressed as the modified $K'_{\max}$ and K'_x, where K_x is the larger of $K'_{\min}$ or K'_{open}, as shown in figure E-30.

The effective SIF range for the preloaded hole is:

$$\Delta K_{eff} = K'_{\max} - K'_x \tag{E-1}$$

by substituting $K'_{\max}$ and K'_x with modified reference stresses, one has

$$K'_{\max} = \sigma'_{\max}\beta\sqrt{\pi a} \tag{E-2}$$

$$\text{and } K'_x = \sigma'_x\beta\sqrt{\pi a} \tag{E-3}$$

where

$$\sigma'_{\max} = \sigma_{\max}\left(\frac{K'_{\max}}{K_{\max}}\right) \tag{E-4}$$

and

$$\sigma'_x = \sigma_x\left(\frac{K'_{\min}}{K_{\max}}\right) \tag{E-5}$$

σ_x is the larger of $\sigma_{\min}$ or σ_{open}.

By substituting the reference stress (σ_{max}, σ_{min}) with modified stresses (σ'_{max}, σ'_{min}), the effects of the preload can be included in the closure-based crack growth model. The ratio of $K'_{\max}/K_{\max}$ for 15 ksi, and $K'_{\min}/K_{\max}$ for the 1.5 ksi case, are shown in figures E-27 and E-28, respectively. An example of the preload effects on the crack growth prediction is depicted in figure E-31. The analyses indicated that as one would have expected, the crack growth lives increase with higher level of interference.

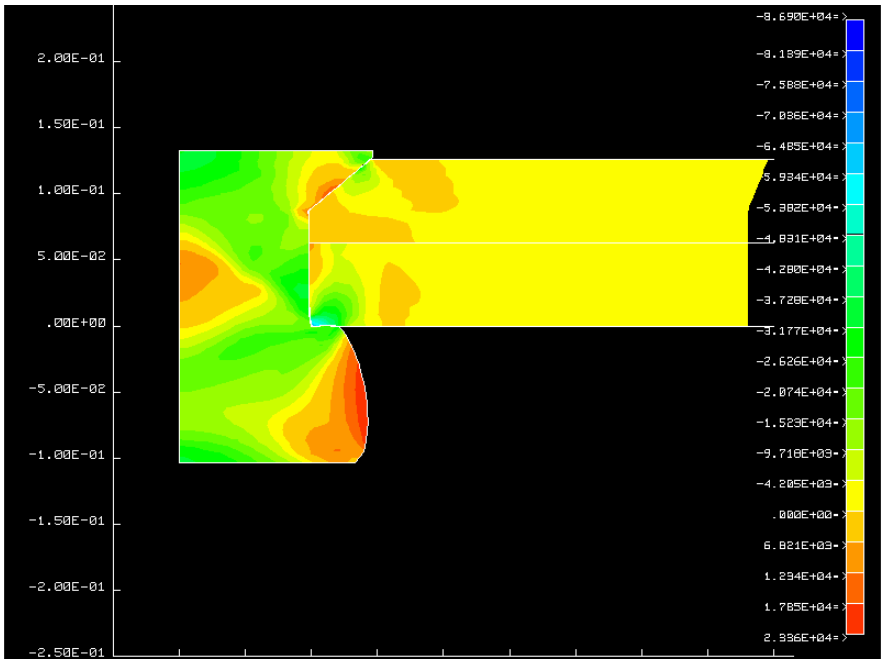


FIGURE E-21. RESIDUAL STRESS IN THE RADIAL DIRECTION DUE TO INSTALLATION

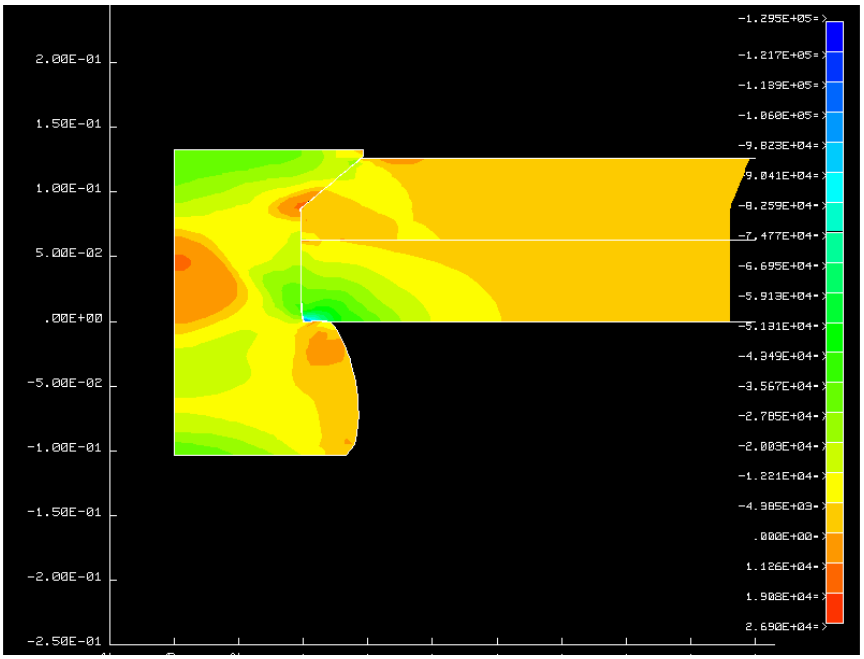


FIGURE E-22. RESIDUAL STRESS IN THE TANGENTIAL DIRECTION DUE TO INSTALLATION

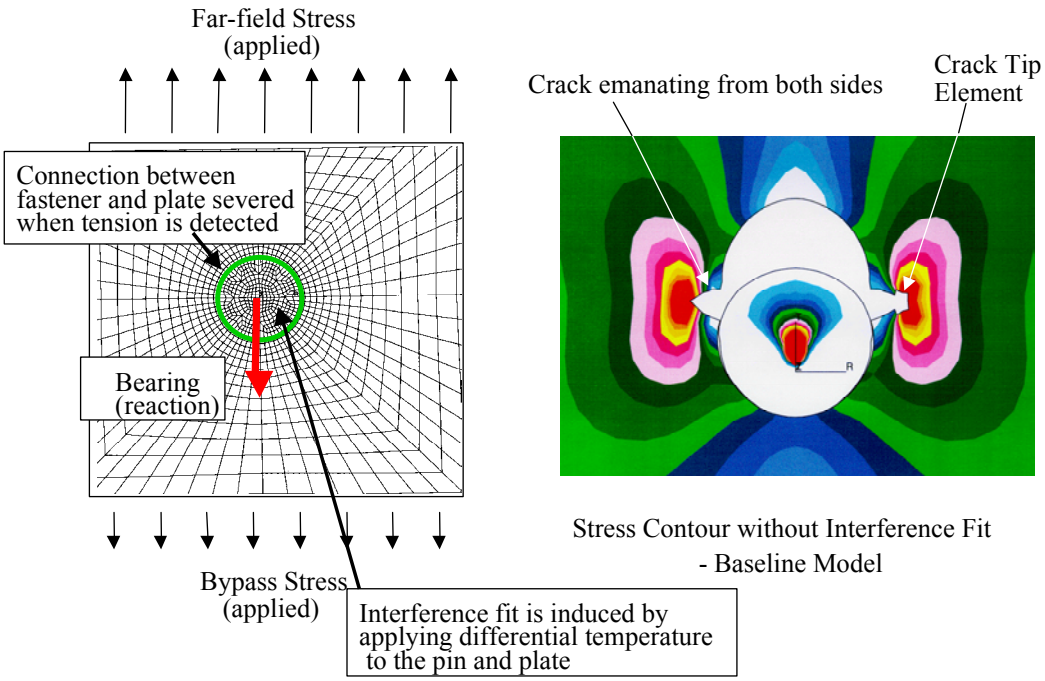


FIGURE E-23. FINITE ELEMENT MODEL FOR EFFECTS OF INTERFERENCE FIT TO THE SIF

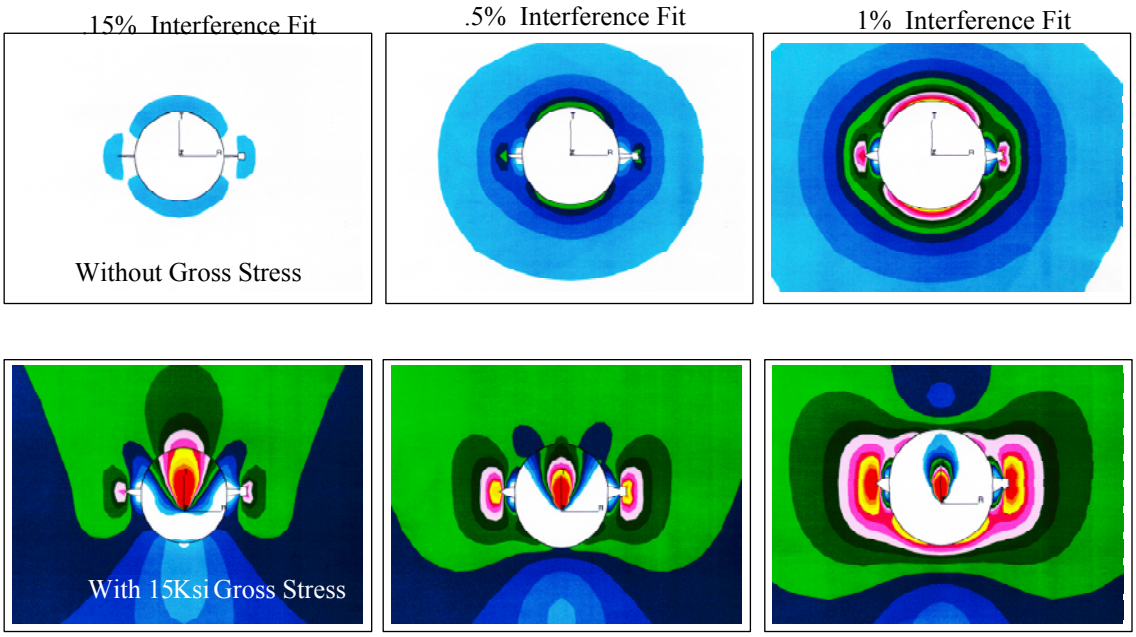


FIGURE E-24. STRESS CONTOUR AND DEFORMED SHAPE OF FASTENER HOLE WITH VARIOUS INTERFERENCE FIT

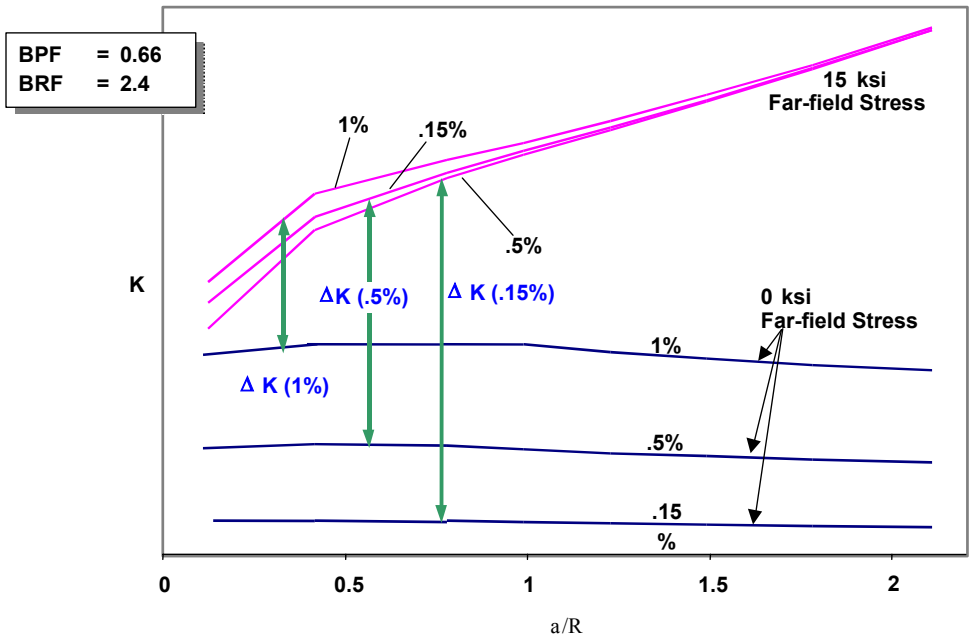


FIGURE E-25. EFFECTS OF INTERFERENCE FIT TO THE SIF

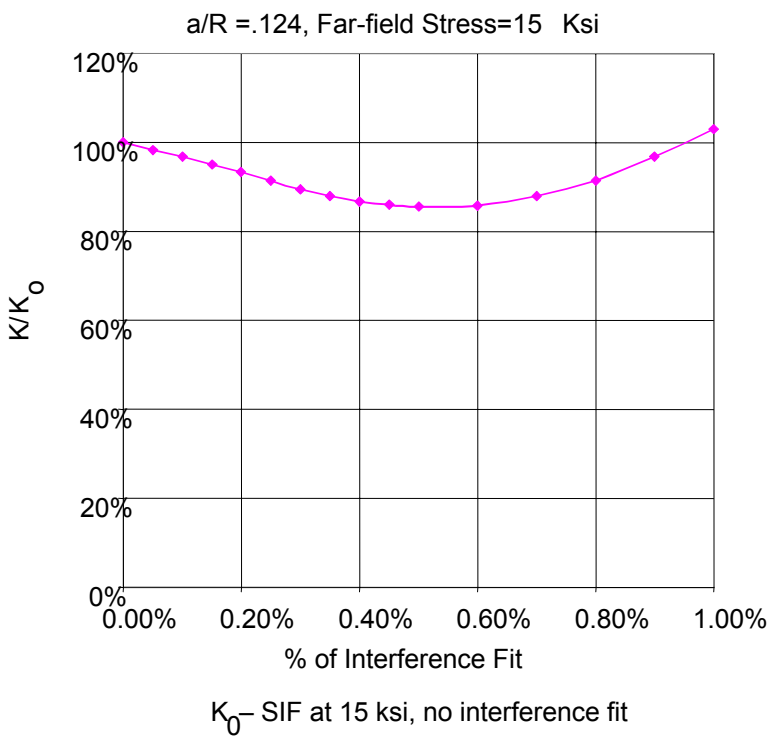


FIGURE E-26. EFFECTS OF INTERFERENCE FIT FOR A CONSTANT CRACK LENGTH

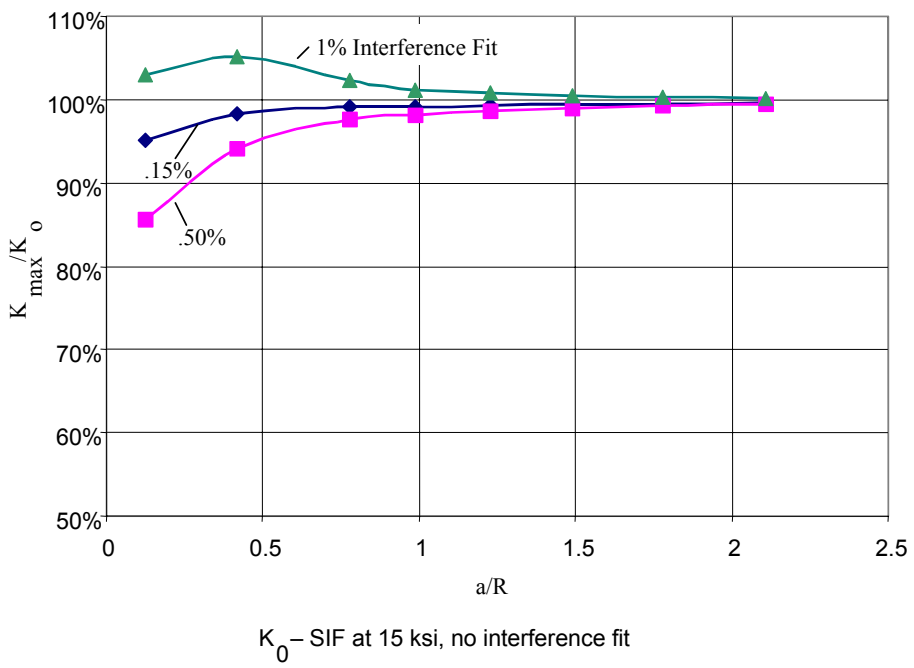


FIGURE E-27. NORMALIZED SIF UNDER 15 ksi FAR-FIELD STRESS

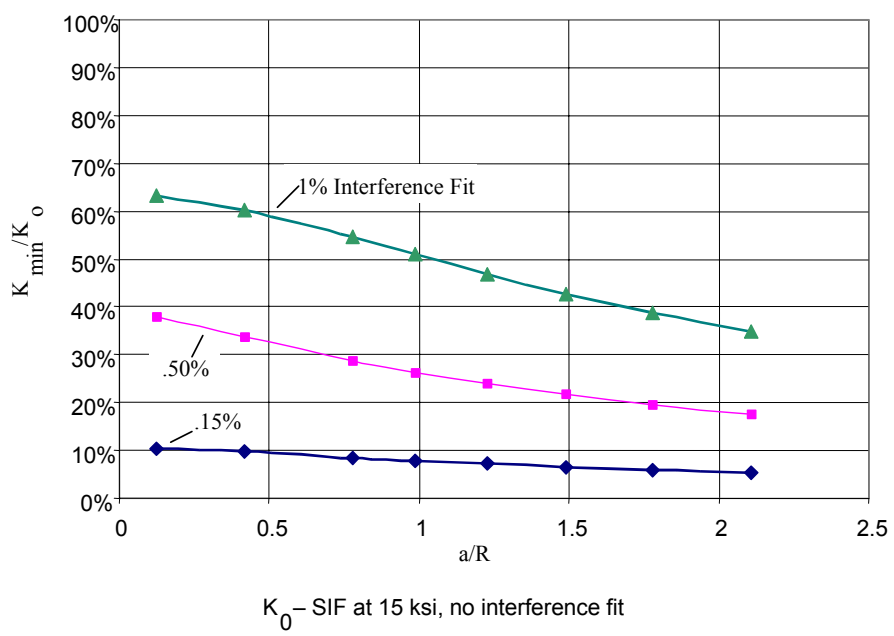


FIGURE E-28. NORMALIZED SIF UNDER 1.5 ksi FAR-FIELD STRESS

$$\frac{da}{dN} = f(\Delta K_{eff})$$

$$\Delta K_{eff} = (\sigma_{max} - \sigma_x)\sqrt{\pi c_x}F$$

$\sigma_x = \sigma_{min}$ or σ'_o

c_x = current crack length and cycle rate

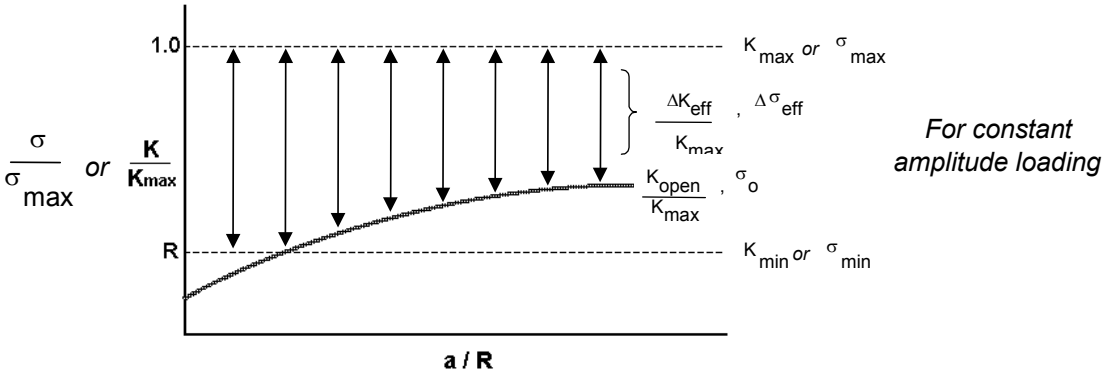
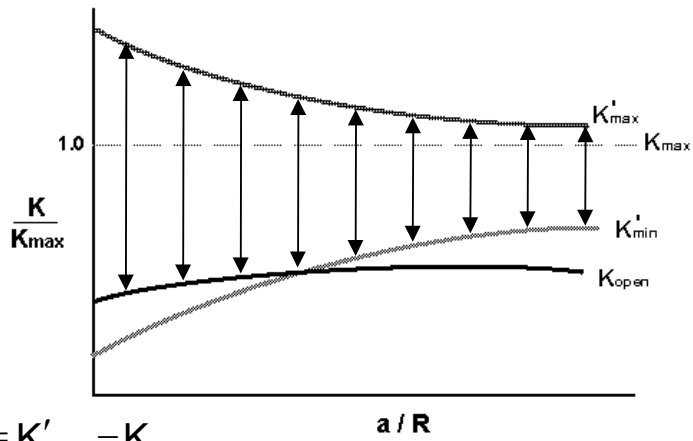


FIGURE E-29. ORIGINAL CLOSURE-BASED CRACK GROWTH RATE EQUATIONS



$$\Delta K_{eff} = K'_{max} - K_x$$
$$= (\sigma'_{max} - \sigma_x)\sqrt{\pi c_x}F$$

where $\sigma'_{max} = \sigma_{max}\left(\frac{K'_{max}}{K_{max}}\right)$

σ_x — opening stress or σ'_{min}

$\sigma'_{min} = \sigma_{min}\left(\frac{K'_{min}}{K_{max}}\right)$

FIGURE E-30. MODIFIED CRACK GROWTH RATE EQUATION IN CLOSURE-BASED CODE

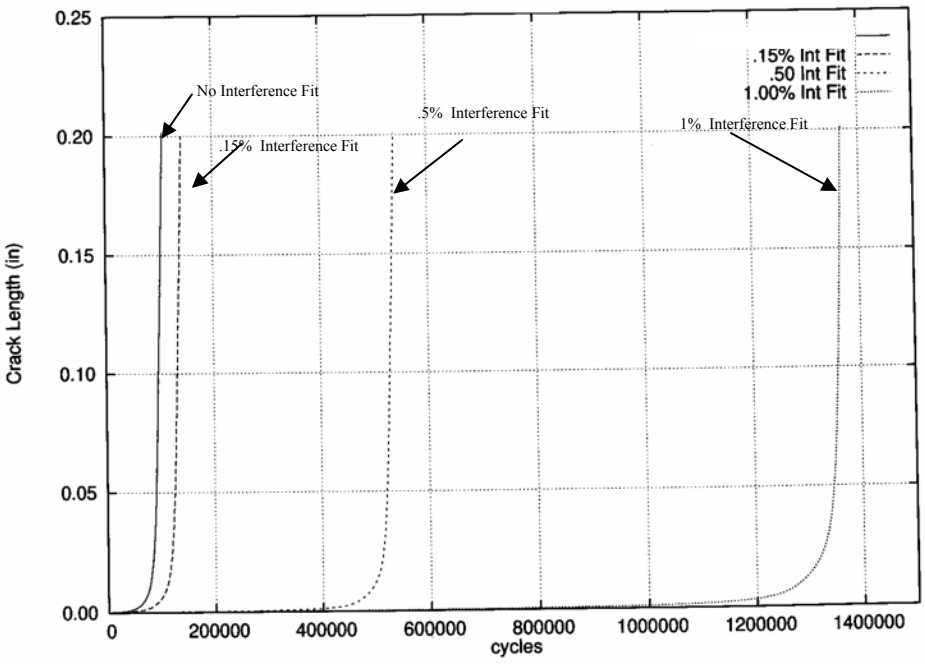


FIGURE E-31. COMPARISON OF CRACK GROWTH WITH/WITHOUT INTERFERENCE FIT

The following pages contain the comparison of the measured crack growth history and the collapsed crack growth history for EIFS test panels, which were discussed in section 6.10.5.2.

TABLE E-2. MODIFED NUMBER OF CYCLES

Crack Location	Modified Cycles
03C14R	147079
03C17R	110886
03D13R	157873
03D15L	76578
03D15R	83602
04C09R	121879
04C10R	124113
04C11R	127026
04C12R	122870
07A06L	26438
07A06R	19200
07A07L	30412
07A07R	54134
07A08L	96503
07A12R	33201
07A13R	46681
07A14L	12576
07A14R	26338
07A15R	35948
07A16L	26730
07A16R	104195
07A17L	44193
07A17R	16292
15E02R	149639
15E11R	115205
15E02R	149639
15E11R	115205
15E16L	148994
15E16R	111282

Crack Location	Modified Cycles
15E16L	148994
15E16R	111282
15E20L	113105
15E26R	120876
15E28R	164982
08A10L	65029
08A10R	65290
08A19L	84339
09A05L	459985
09A05R	468512
10F05R	105134
10F06L	95609
10F06R	90114
10F07L	99483
10F07R	97410
10F08L	88216
10F08R	101305
10F10R	82816
11F06L	116718
11F06R	106207
11F07L	116368
11F07R	115643
11F08L	123908
11F08R	123995
11F09R	107679
11F10R	111206
15E20L	113105
15E26R	120876
15E28R	164982

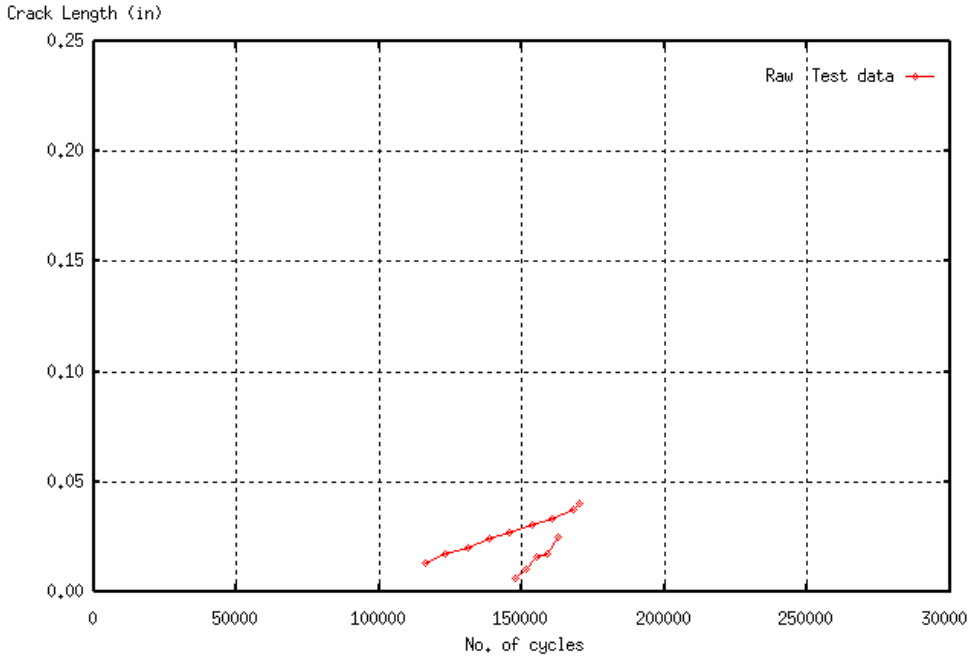


FIGURE E-32. CRACK GROWTH HISTORY FOR EIFS-3, ROW C

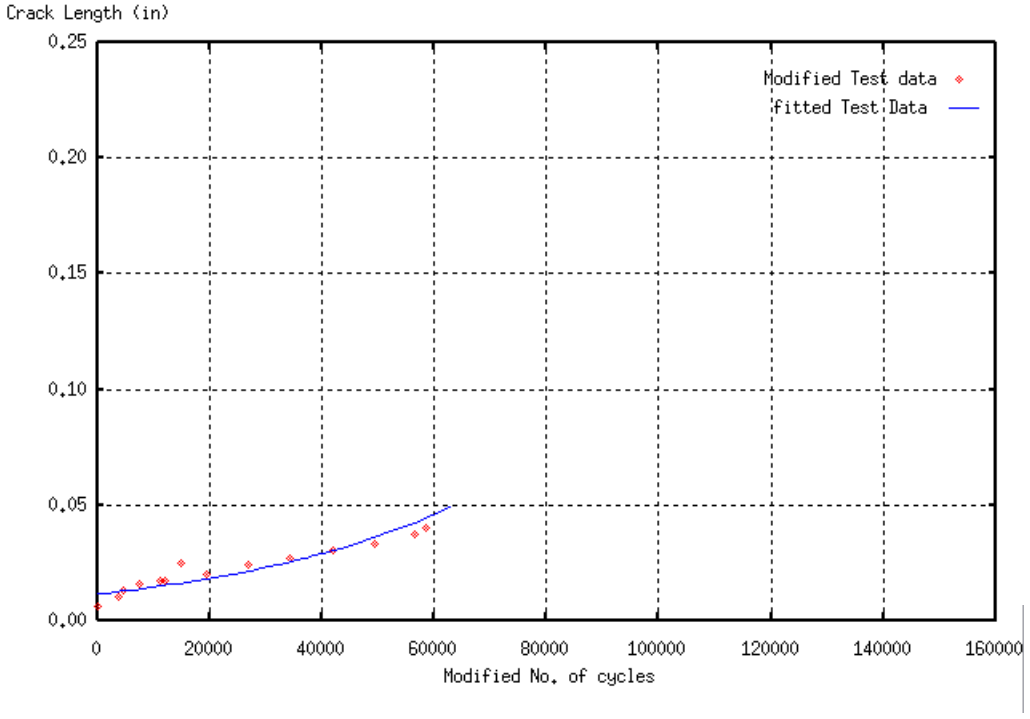


FIGURE E-33. MODIFIED CRACK GROWTH HISTORY FOR EIFS-3, ROW C

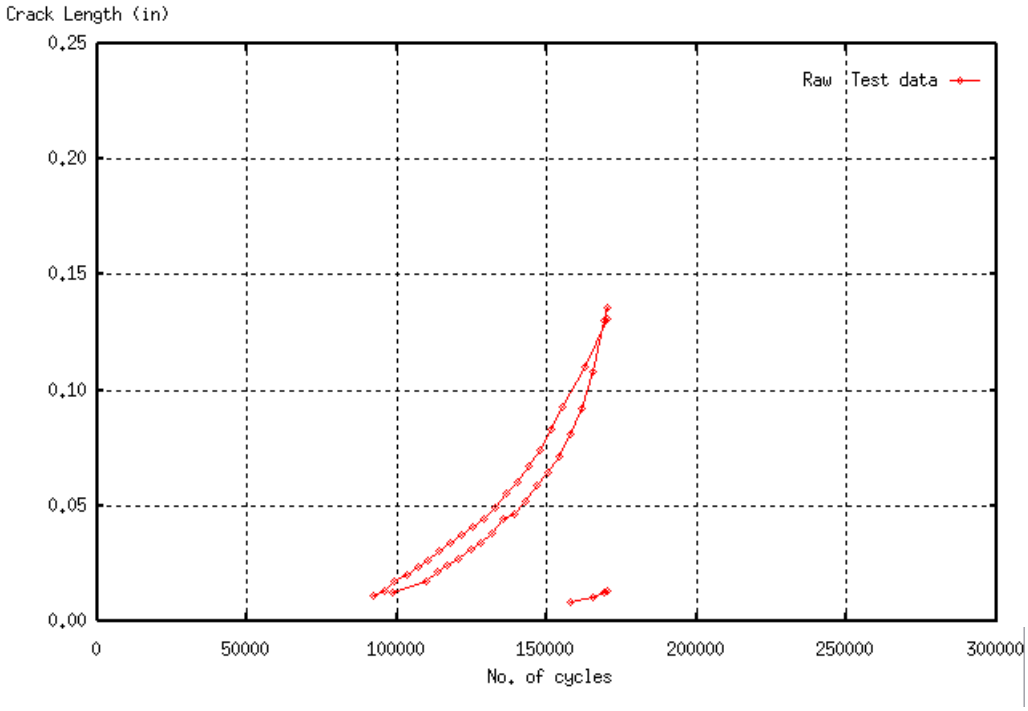


FIGURE E-34. CRACK GROWTH HISTORY FOR EIFS-3, ROW D

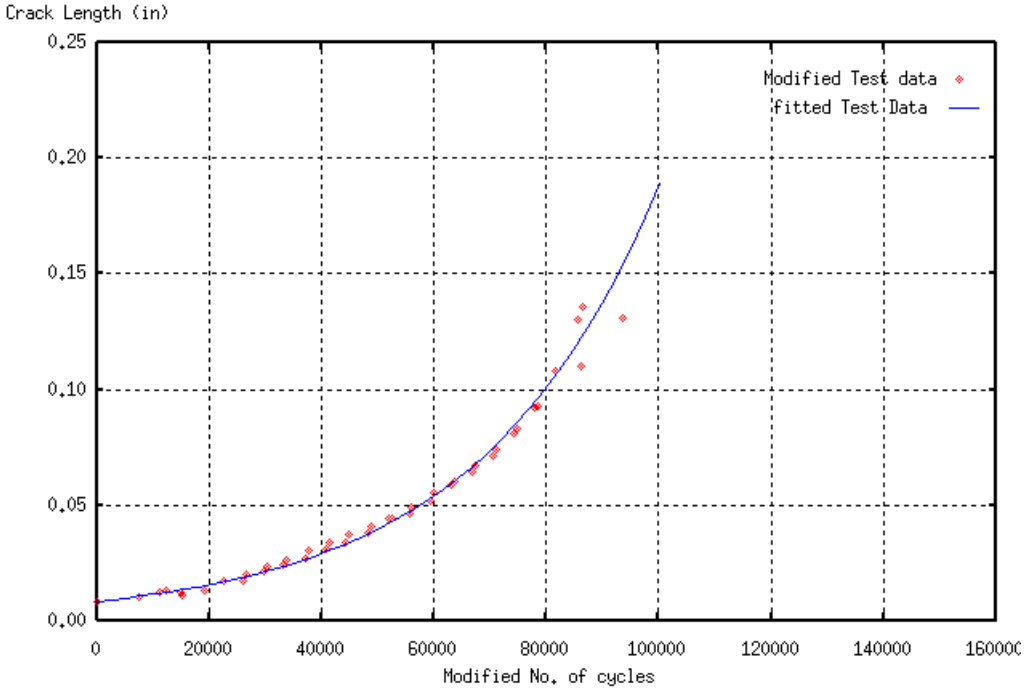


FIGURE E-35. MODIFIED CRACK GROWTH HISTORY FOR EIFS-3, ROW D

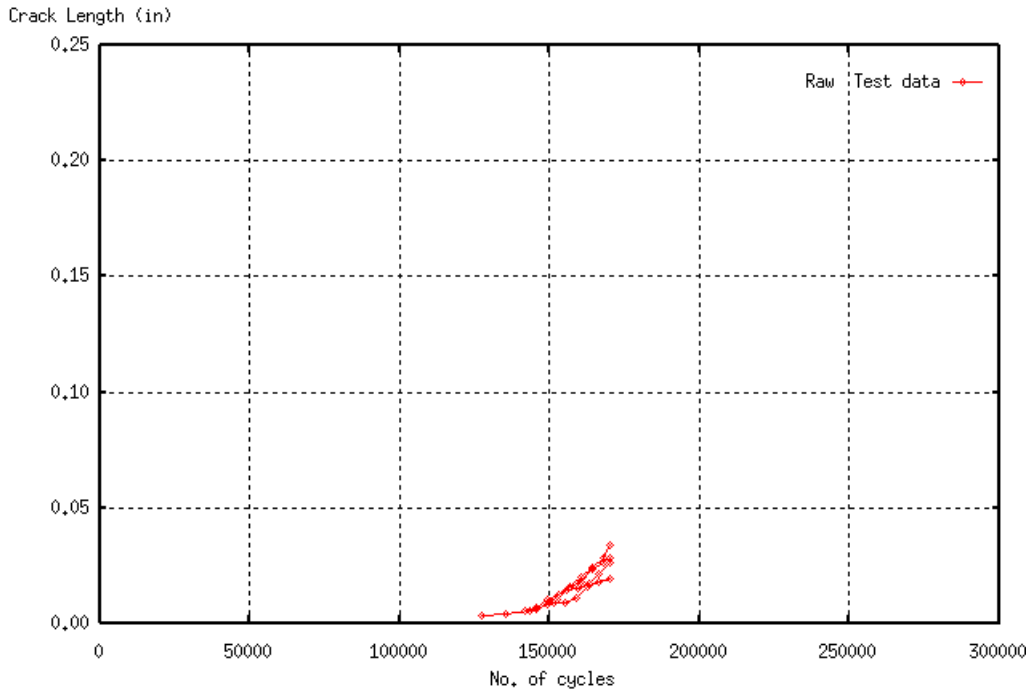


FIGURE E-36. CRACK GROWTH HISTORY FOR EIFS-4

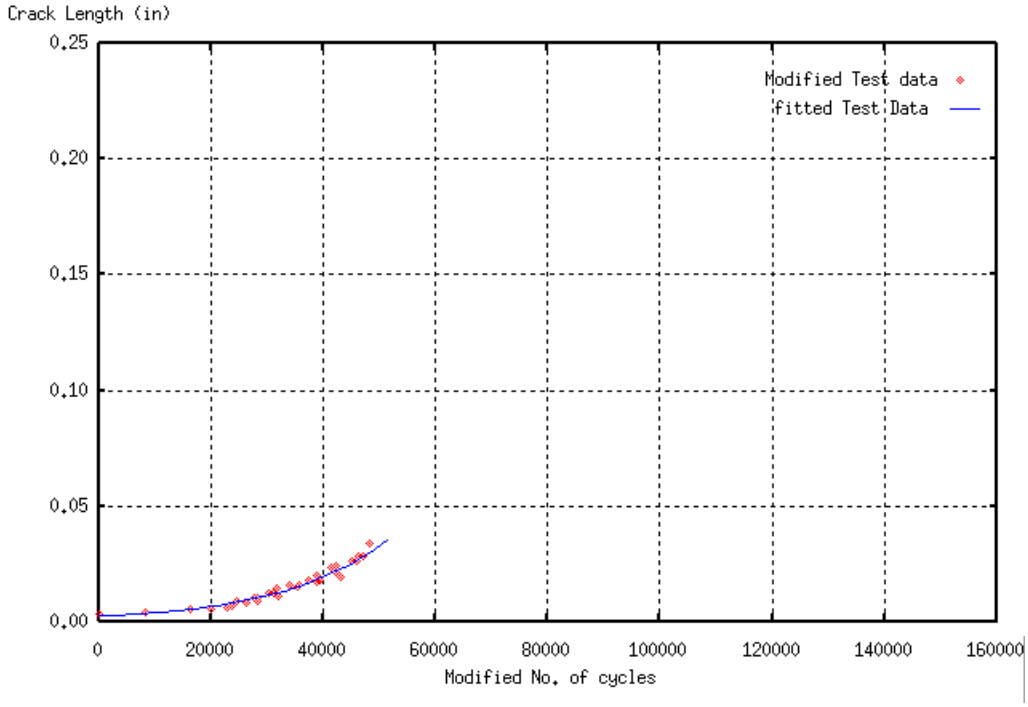


FIGURE E-37. MODIFIED CRACK GROWTH HISTORY FOR EIFS-4

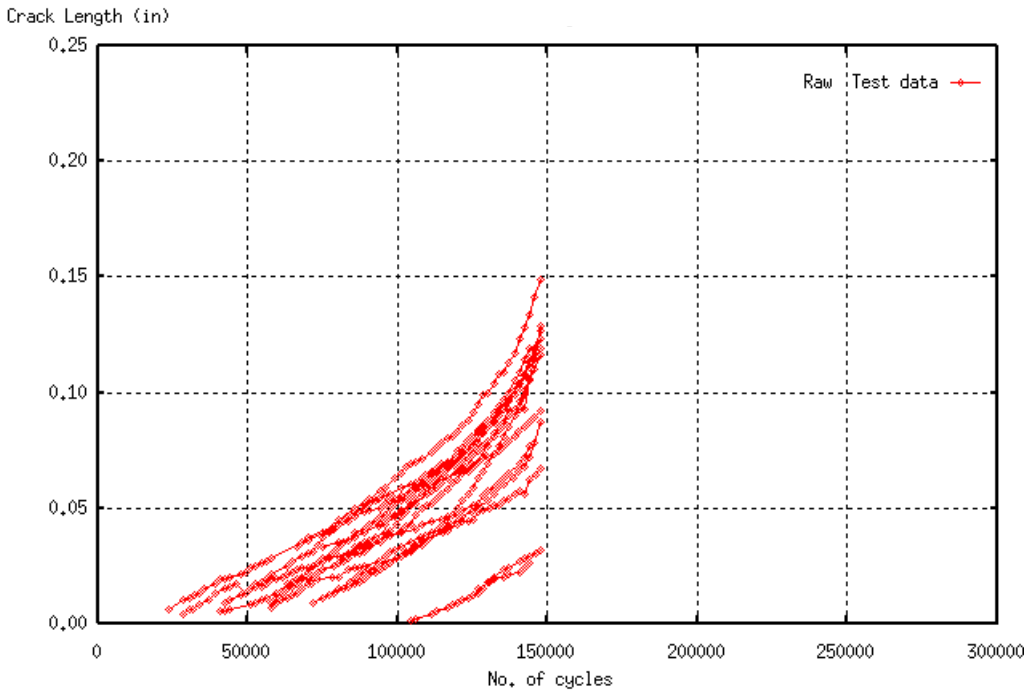


FIGURE E-38. CRACK GROWTH HISTORY FOR EIFS-7

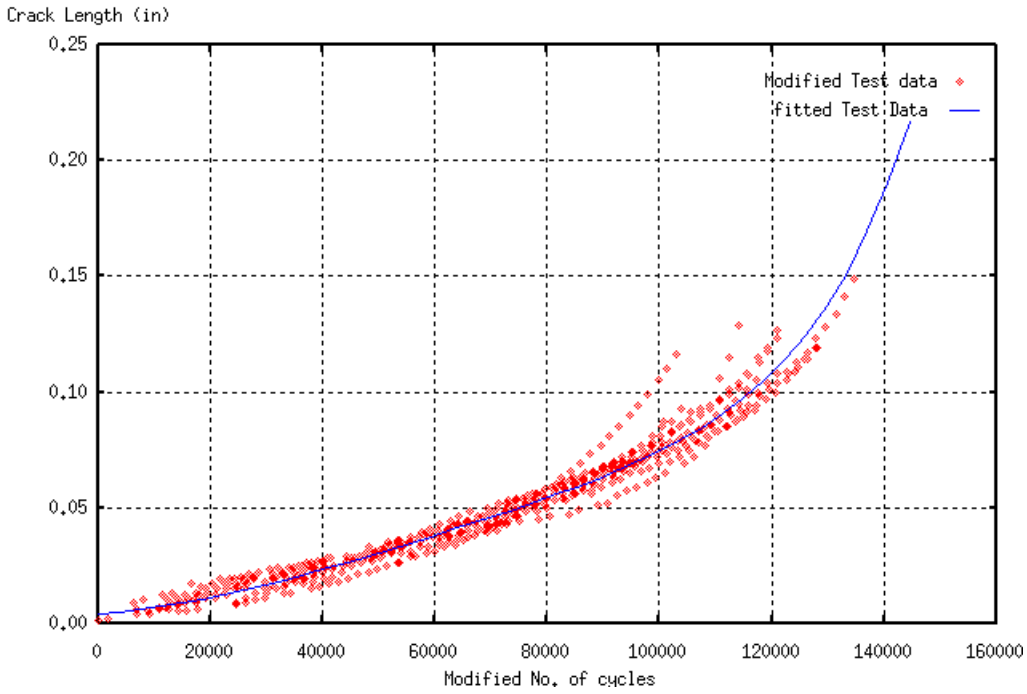


FIGURE E-39. MODIFIED CRACK GROWTH HISTORY FOR EIFS-7

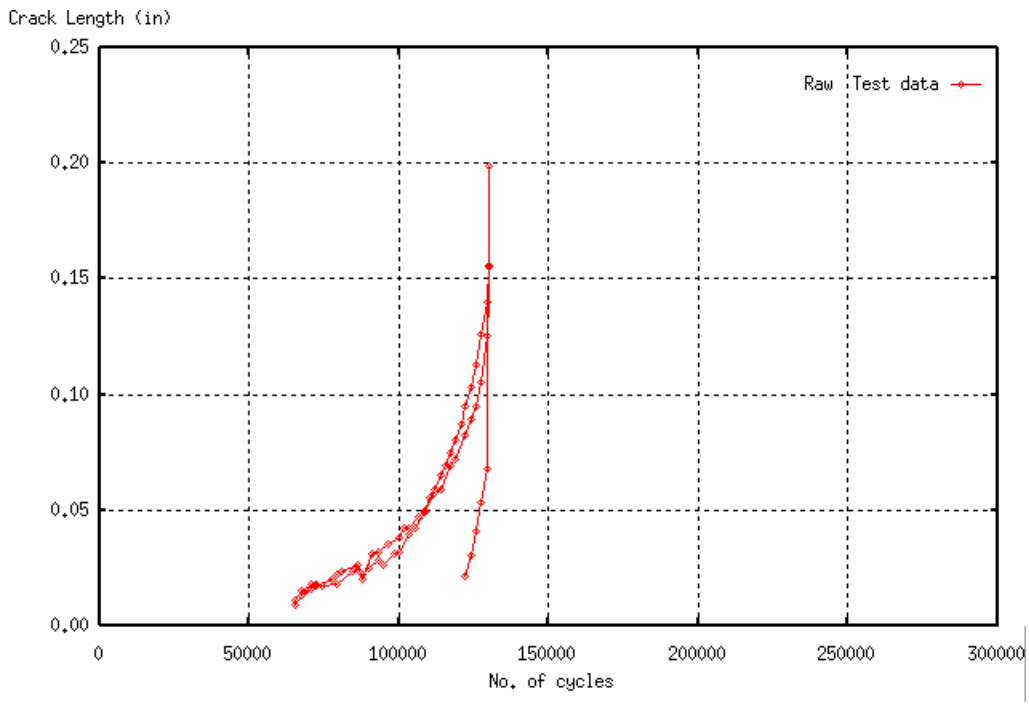


FIGURE E-40. CRACK GROWTH HISTORY FOR EIFS-8

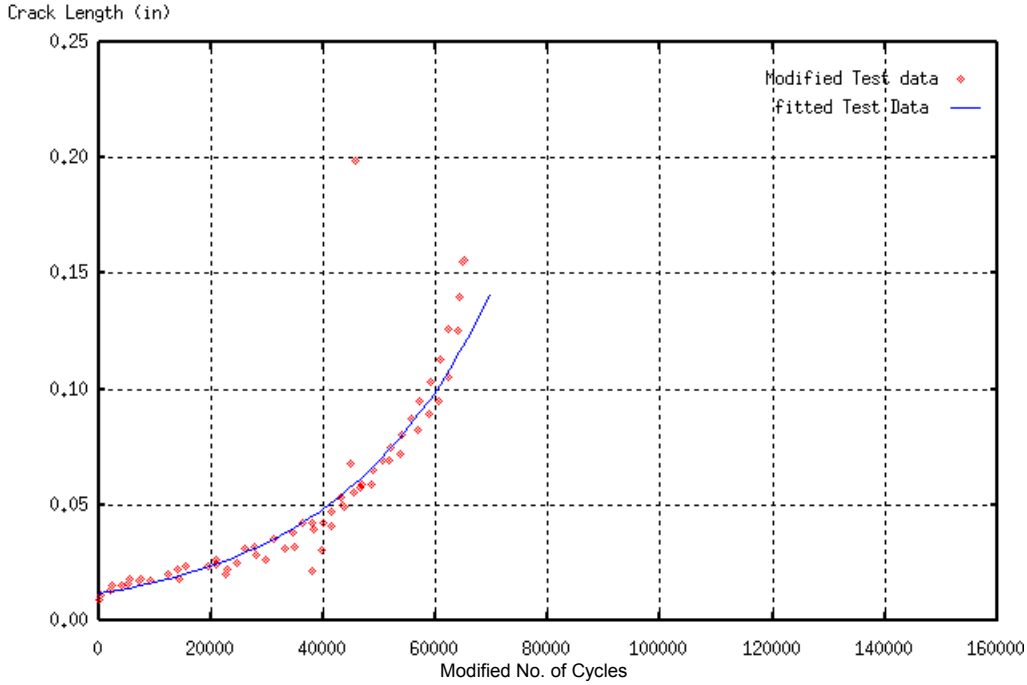


FIGURE E-41. MODIFIED CRACK GROWTH HISTORY FOR EIFS-8

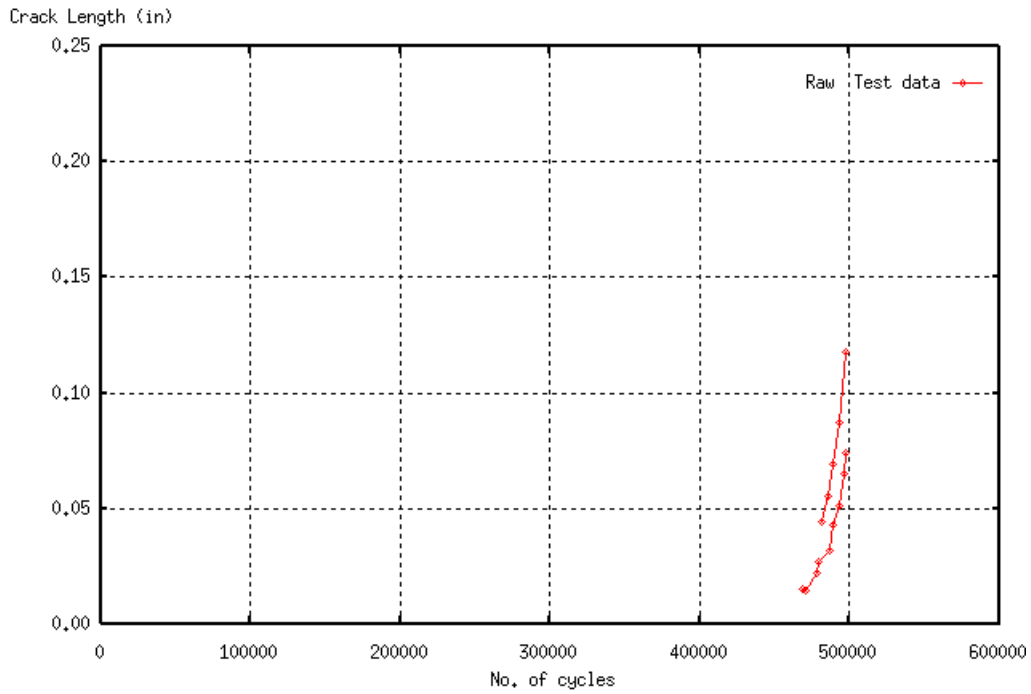


FIGURE E-42. CRACK GROWTH HISTORY FOR EIFS-9

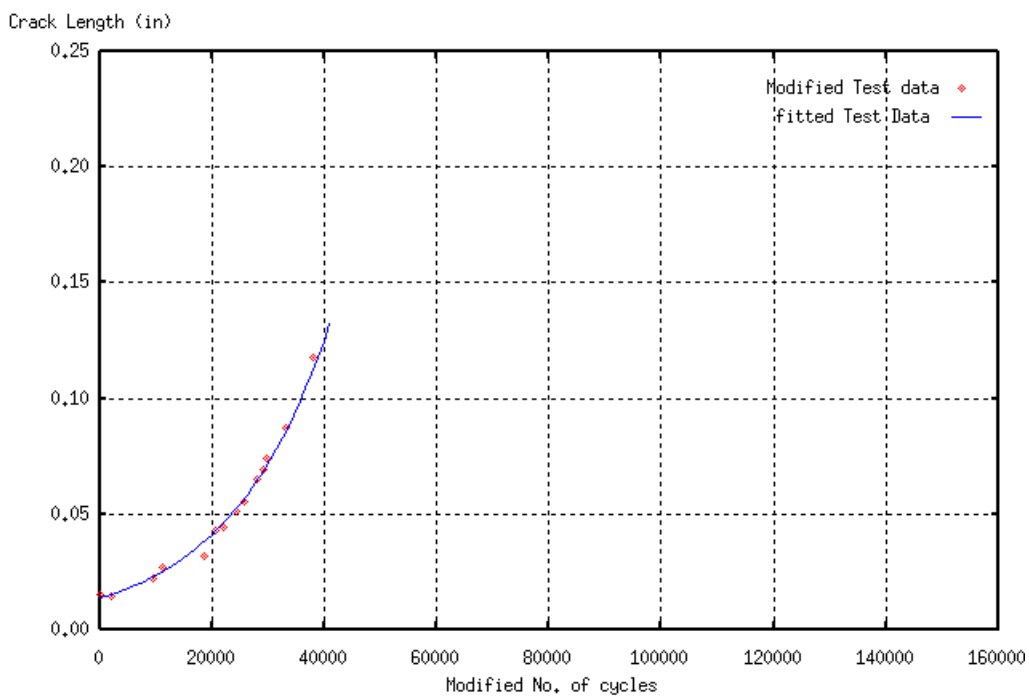


FIGURE E-43. MODIFIED CRACK GROWTH HISTORY FOR EIFS-9

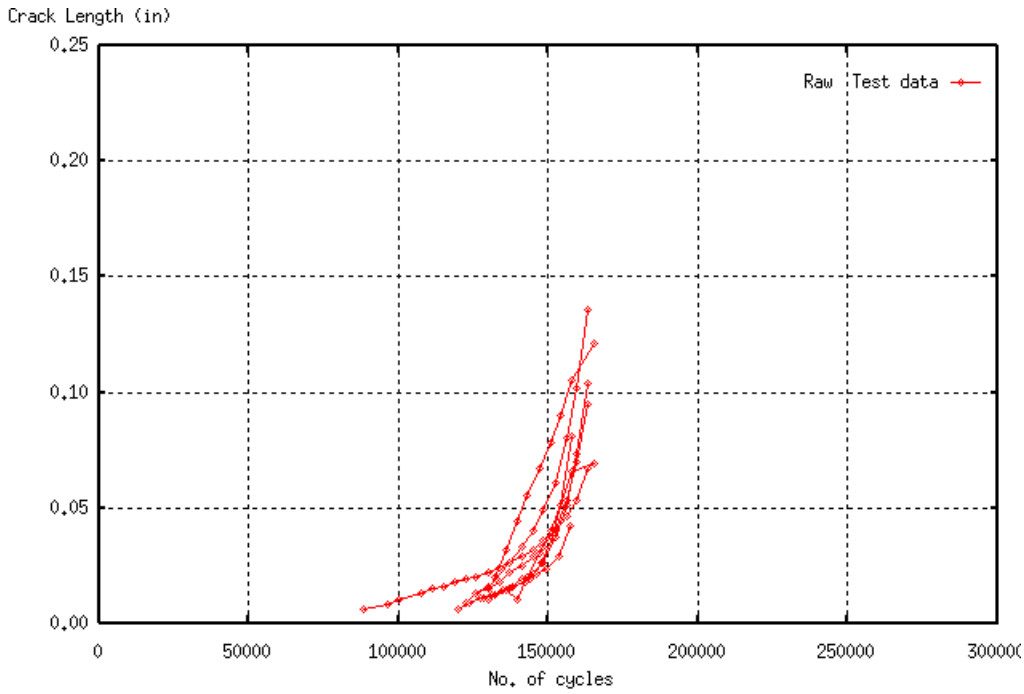


FIGURE E-44. CRACK GROWTH HISTORY FOR EIFS-10

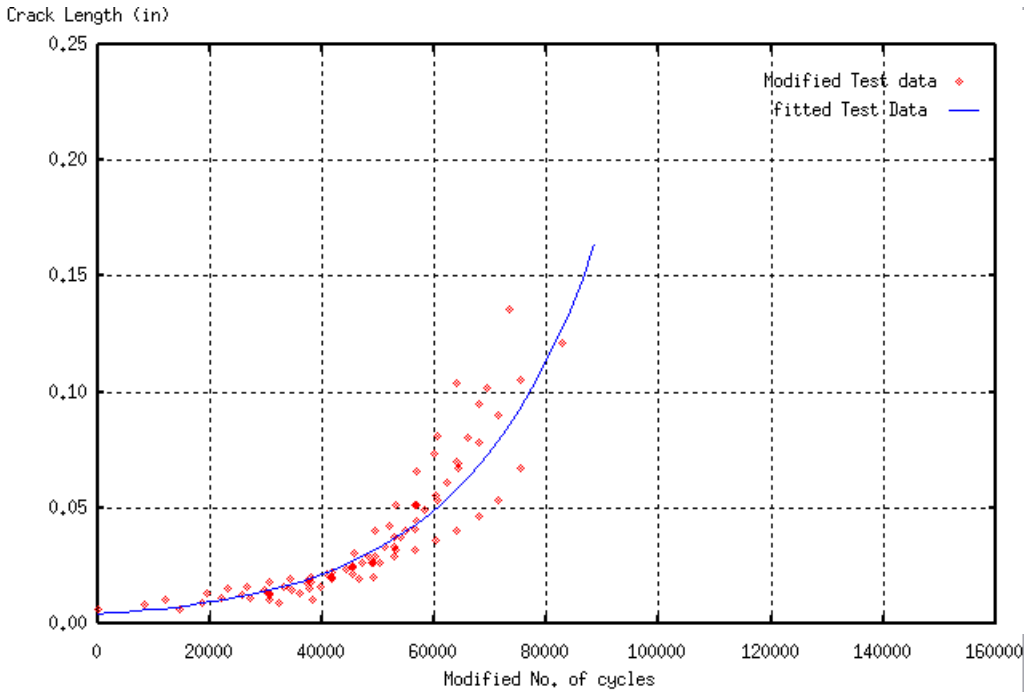


FIGURE E-45. MODIFIED CRACK GROWTH HISTORY FOR EIFS-10

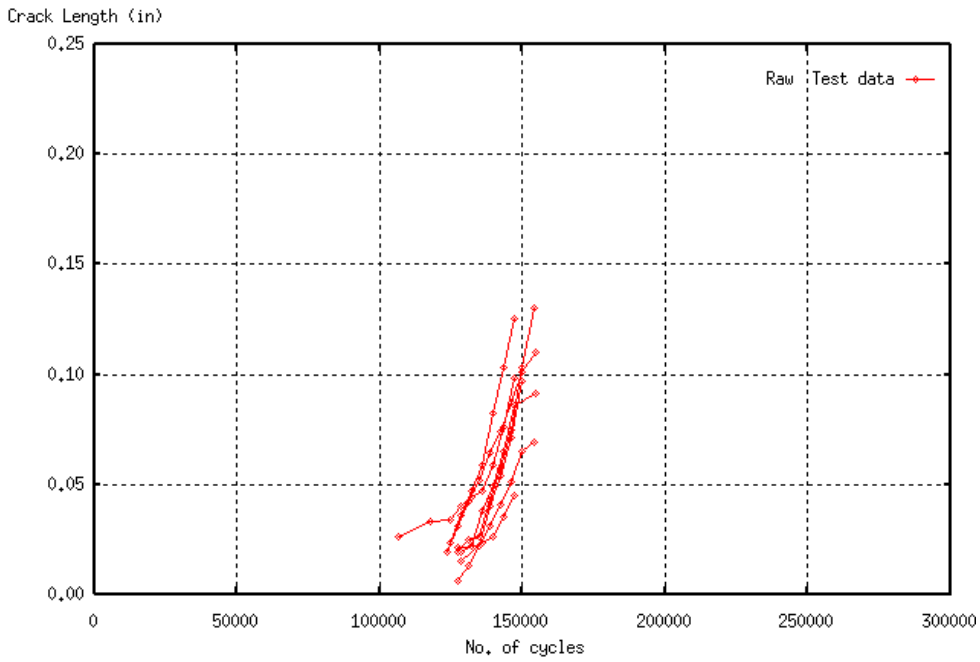


FIGURE E-46. CRACK GROWTH HISTORY FOR EIFS-11

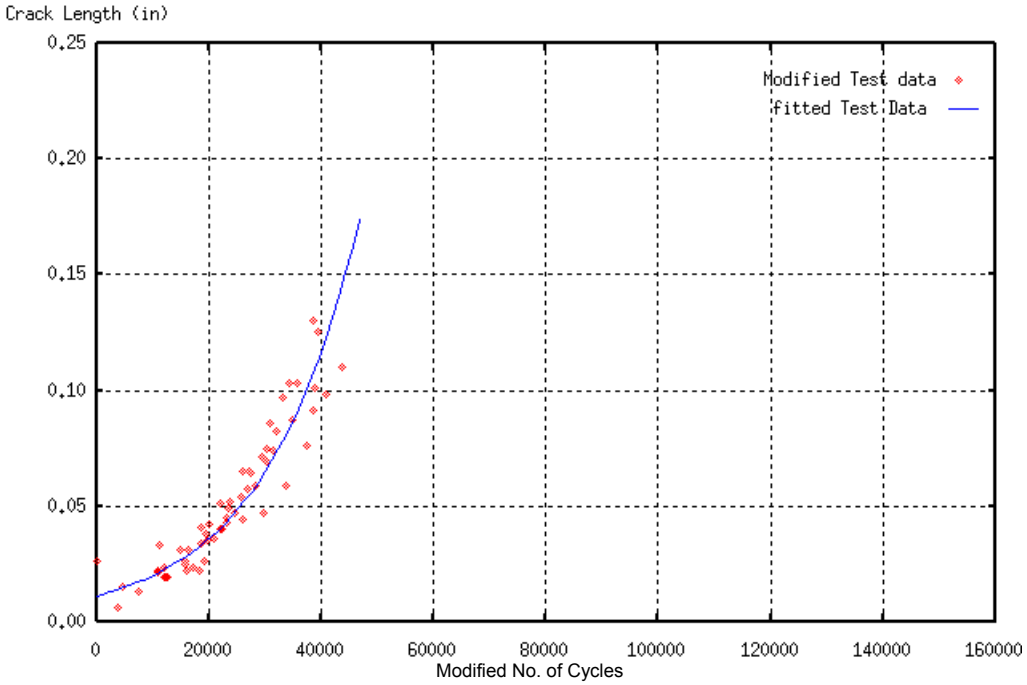


FIGURE E-47. MODIFIED CRACK GROWTH HISTORY FOR EIFS-11

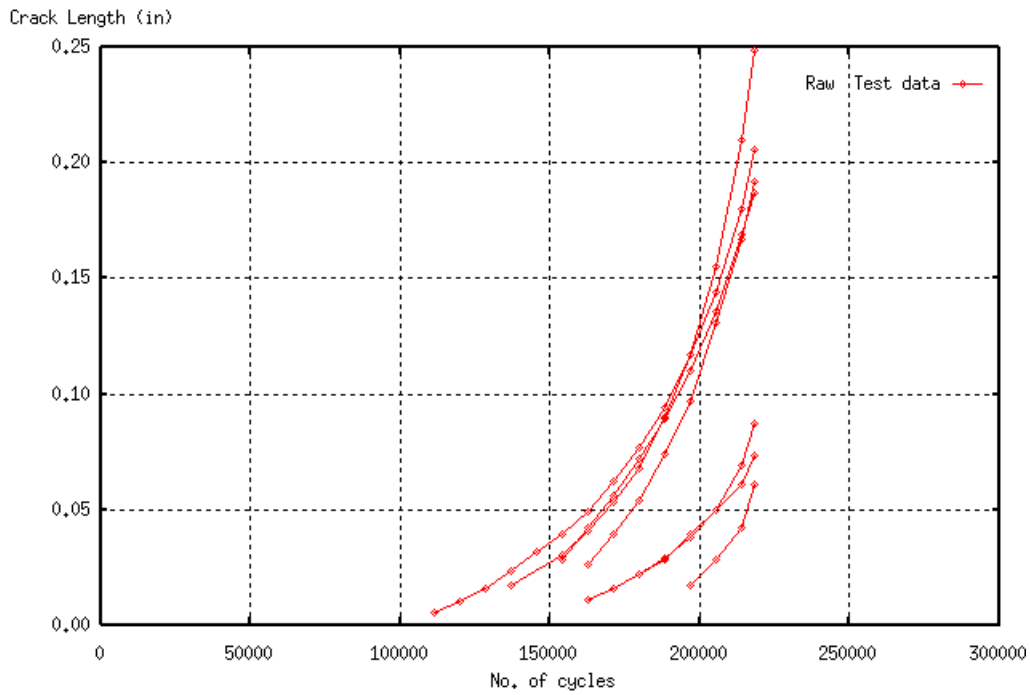


FIGURE E-48. CRACK GROWTH HISTORY FOR EIFS-15

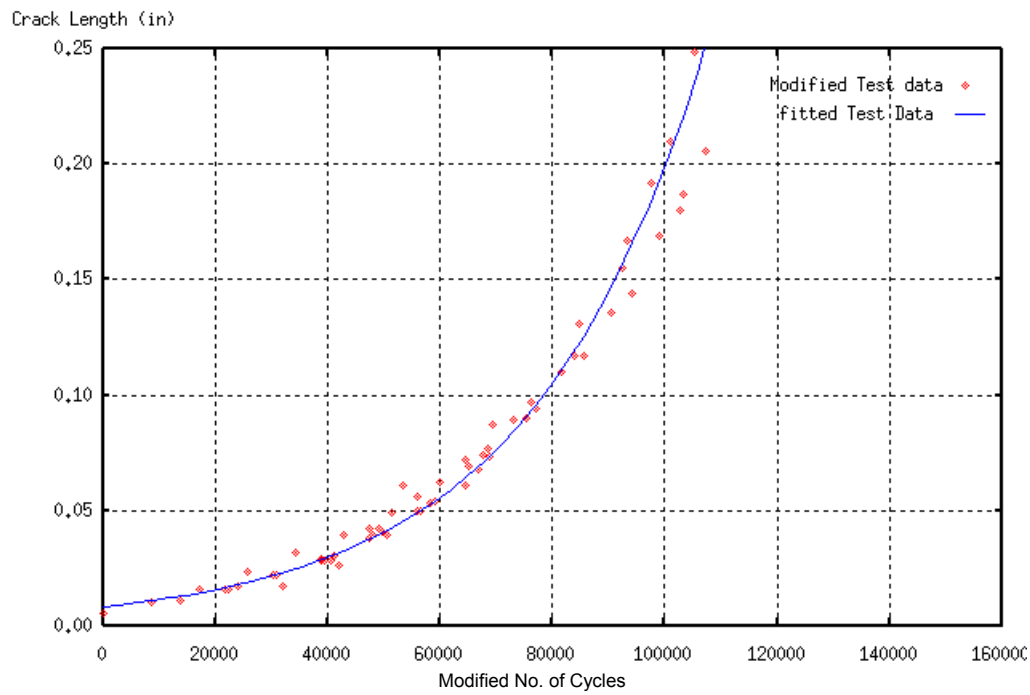


FIGURE E-49. MODIFIED CRACK GROWTH HISTORY FOR EIFS-15

TABLE E-3. AVERAGE EIFS FOR EIFS-3

Crack ID	No. of Data	EIFS Based on β_u	EIFS Based on β_{u7}
03C14R	5	6.39E-04	5.15E-04
03C17R	9	9.63E-04	8.65E-04
Total/Average	14	0.0008	0.00069

Crack ID	No. of Data	EIFS Based on β_u	EIFS Based on β_{u7}
03D13R	4	3.48E-04	2.47E-04
03D15L	20	8.76E-04	1.16E-03
03D15R	19	7.94E-04	1.07E-03
Total/Average	43	0.00067	0.00083

TABLE E-4. AVERAGE EIFS FOR EIFS-4

Crack ID	No. of Data	EIFS Based on β_u	EIFS Based on β_{u7}
04C09R	8	1.23E-04	3.40E-04
04C10R	6	1.23E-04	3.39E-04
04C11R	9	1.20E-04	2.82E-04
04C12R	8	1.23E-04	3.38E-04
Total/Average	31	0.00012	0.00032

TABLE E-5. AVERAGE EIFS FOR EIFS-7 USING ORIGINAL TEST RESULTS
(β_u are identical to β_{u7} for the original set of EIFS-7 test data)

Crack ID	No. of Data	EIFS Based on β_u and β_{u7}
07A06L	38	9.91E-04
07A06R	54	1.25E-03
07A07L	28	8.27E-04
07A07R	36	4.80E-04
07A08L	10	2.57E-04
07A12R	50	8.06E-04
07A13R	42	5.63E-04
07A14L	38	1.56E-03
Total/Average	296	0.00084

TABLE E-6. AVERAGE EIFS FOR EIFS-7 USING COMPLETE TEST RESULTS

Crack ID	No. of Data	EIFS Based on β_u	EIFS Based on β_{u7}
07A06L	38	6.70E-04	4.82E-04
07A06R	60	8.90E-04	6.85E-04
07A07L	28	5.68E-04	4.27E-04
07A07R	36	3.06E-04	3.39E-04
07A08L	10	1.60E-04	2.01E-04
07A12R	50	5.33E-04	4.74E-04
07A13R	42	3.66E-04	3.96E-04
07A14L	38	1.17E-03	6.41E-04
07A14R	55	6.67E-04	5.40E-04
07A15R	46	5.03E-04	5.29E-04
07A16L	31	6.42E-04	4.80E-04
07A16R	19	1.39E-04	1.76E-04
07A17L	39	4.08E-04	3.77E-04
07A17R	57	9.99E-04	7.68E-04
Total/Average	549	0.00057	0.00047

TABLE E-7. AVERAGE EIFS FOR EIFS-8

Crack ID	No. of Data	EIFS Based on β_u	EIFS Based on β_{u7}
08A10L	31	1.31E-03	5.12E-04
08A10R	27	1.30E-03	4.98E-04
08A19L	6	9.31E-04	3.60E-04
Total/Average	64	0.0012	0.00046

TABLE E-8. AVERAGE EIFS FOR EIFS-9

Crack ID	No. of Data	EIFS Based on β_u	EIFS Based on β_{u7}
09A05L	5	4.44E-05	7.67E-05
09A05R	9	4.01E-05	6.69E-05
Total/Average	14	0.00014	0.00007

TABLE E-9. AVERAGE EIFS FOR EIFS-10

Crack ID	No. of Data	EIFS Based on β_u	EIFS Based on β_{u7}
10F05R	11	3.02E-04	1.93E-04
10F06L	11	3.35E-04	2.25E-04
10F06R	11	3.57E-04	2.45E-04
10F07L	9	3.21E-04	2.17E-04
10F07R	5	3.28E-04	2.26E-04
10F08L	19	3.70E-04	2.40E-04
10F08R	10	3.15E-04	2.09E-04
10F10R	9	4.01E-04	2.80E-04
Total/Average	85	0.00034	0.00023

TABLE E-10. AVERAGE EIFS FOR EIFS-11

Crack ID	No. of Data	EIFS Based on β_u	EIFS Based on β_{u7}
11F06L	6	3.10E-04	2.74E-04
11F06R	9	3.58E-04	3.26E-04
11F07L	7	3.10E-04	2.78E-04
11F07R	8	3.13E-04	2.84E-04
11F08L	5	2.91E-04	2.27E-04
11F08R	8	2.80E-04	2.33E-04
11F09R	7	3.45E-04	3.39E-04
11F10R	9	3.29E-04	3.14E-04
Total/Average	59	0.00032	0.00028

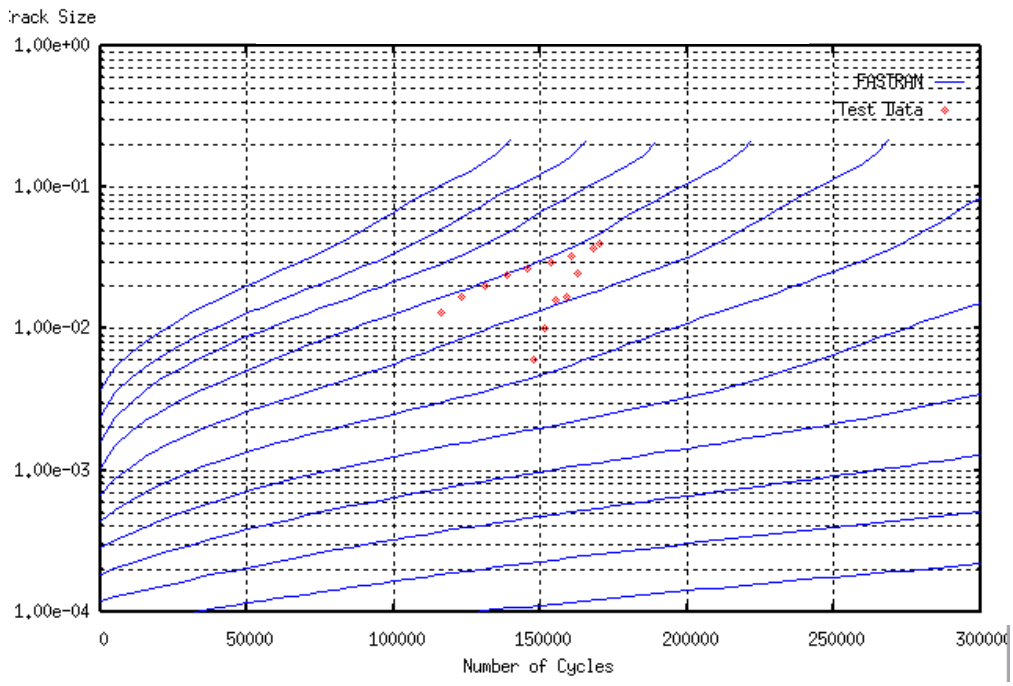


FIGURE E-50. COMPARISON OF CRACK GROWTH HISTORY FOR EIFS-3, ROW C, USING BEST-MATCHED β_u

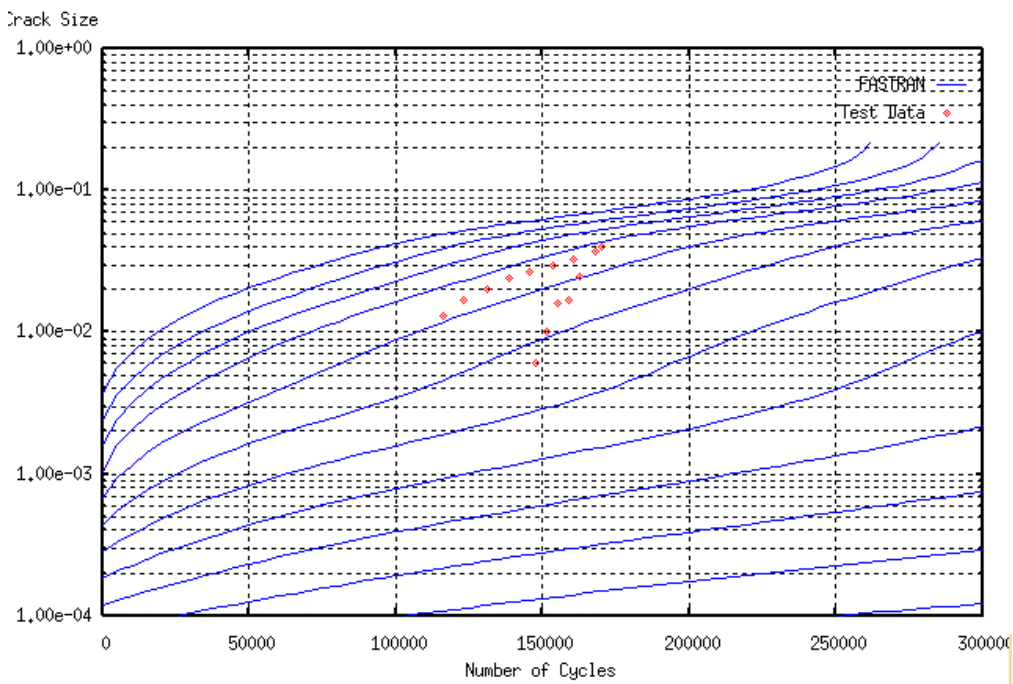


FIGURE E-51. COMPARISON OF CRACK GROWTH HISTORY FOR EIFS-3, ROW C, USING β_{u7}

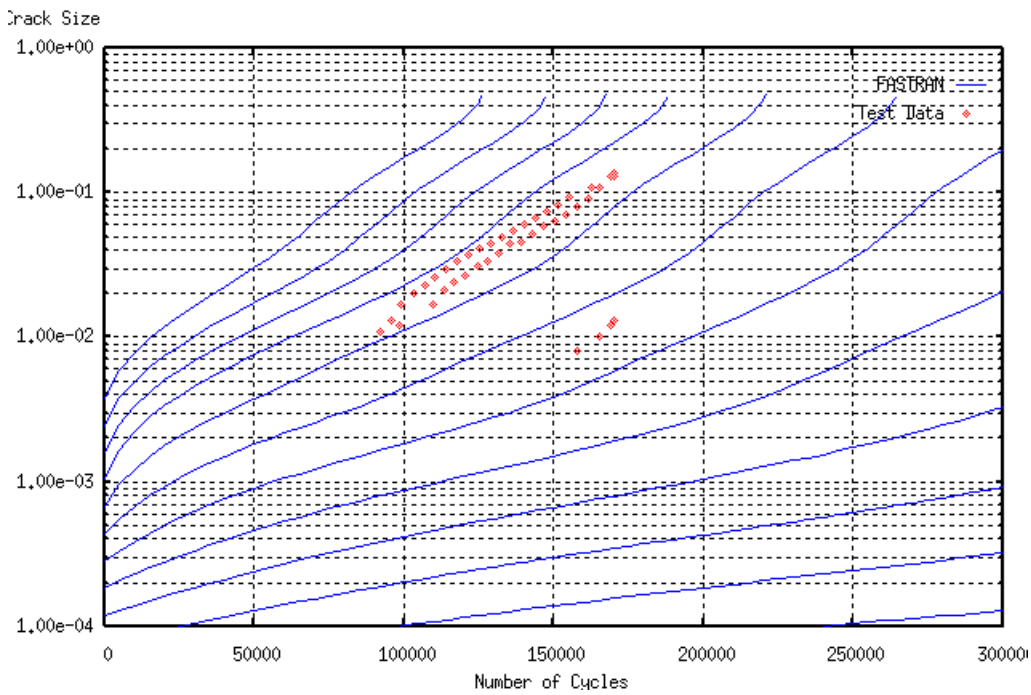


FIGURE E-52. COMPARISON OF CRACK GROWTH HISTORY FOR EIFS-3, ROW D, USING BEST-MATCHED β_u

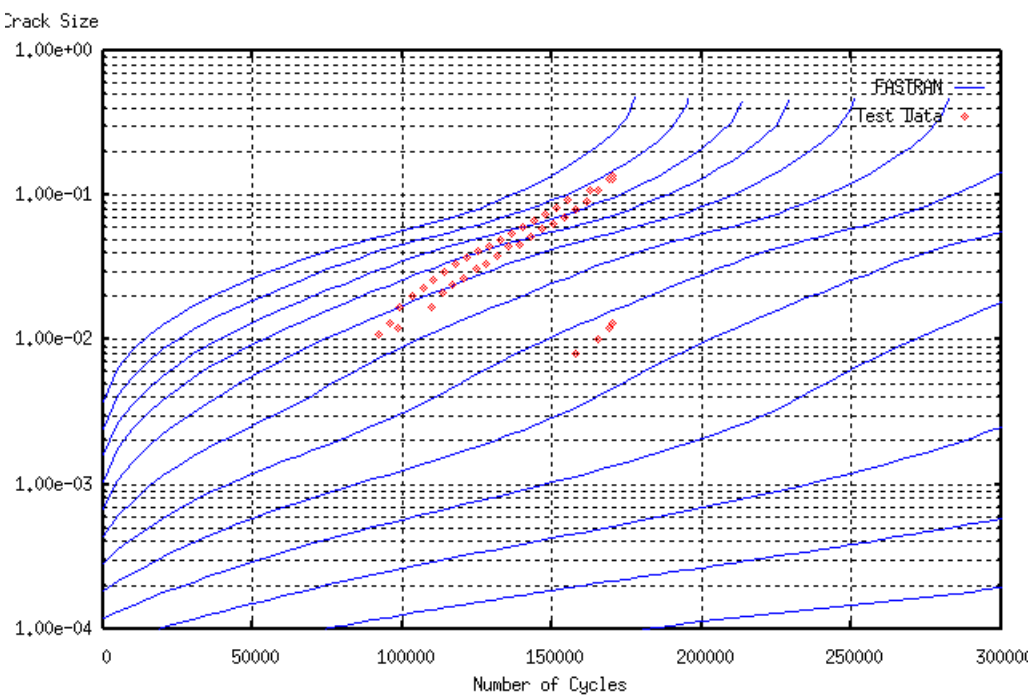


FIGURE E-53. COMPARISON OF CRACK GROWTH HISTORY FOR EIFS-3, ROW D, USING BEST-MATCHED β_{u7}

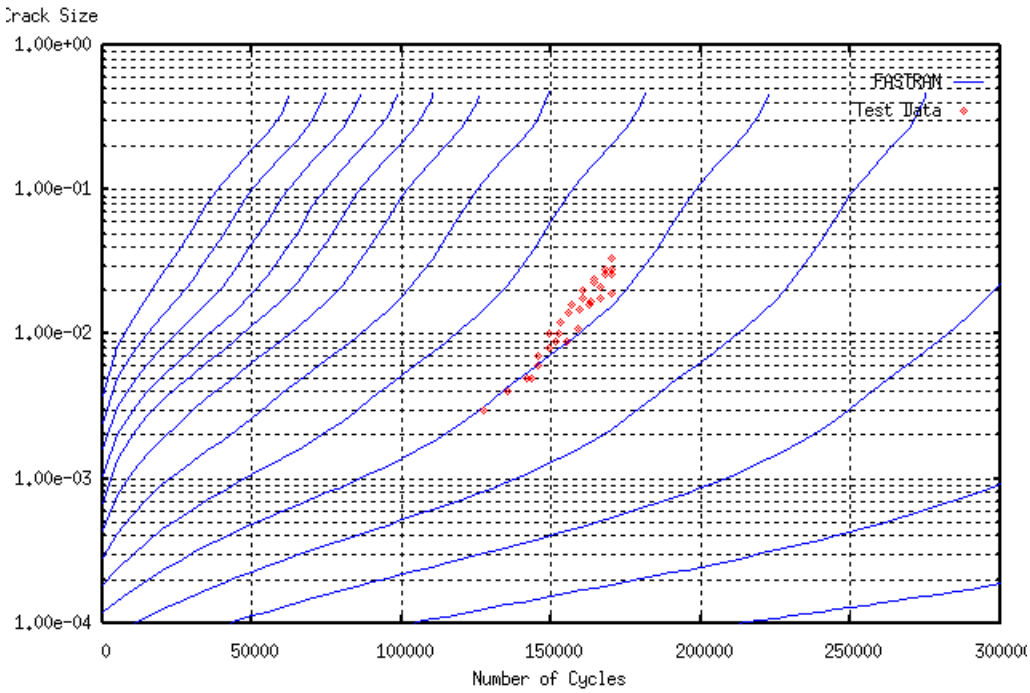


FIGURE E-54. COMPARISON OF CRACK GROWTH HISTORY FOR EIFS-4 USING BEST-MATCHED β_u

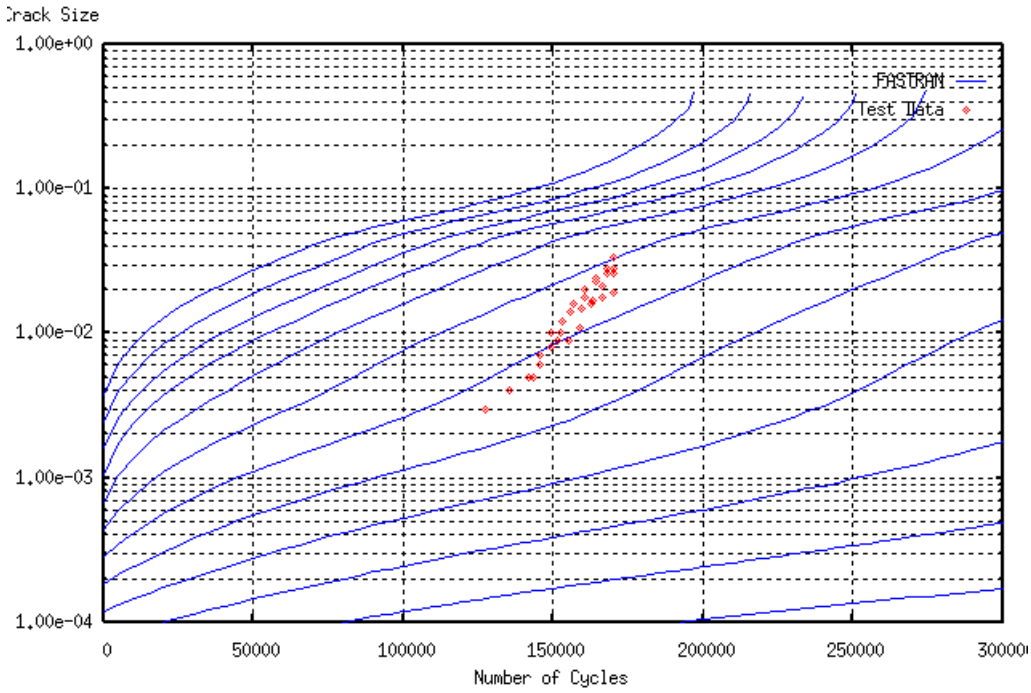


FIGURE E-55. COMPARISON OF CRACK GROWTH HISTORY FOR EIFS-4 USING BEST-MATCHED β_{u7}

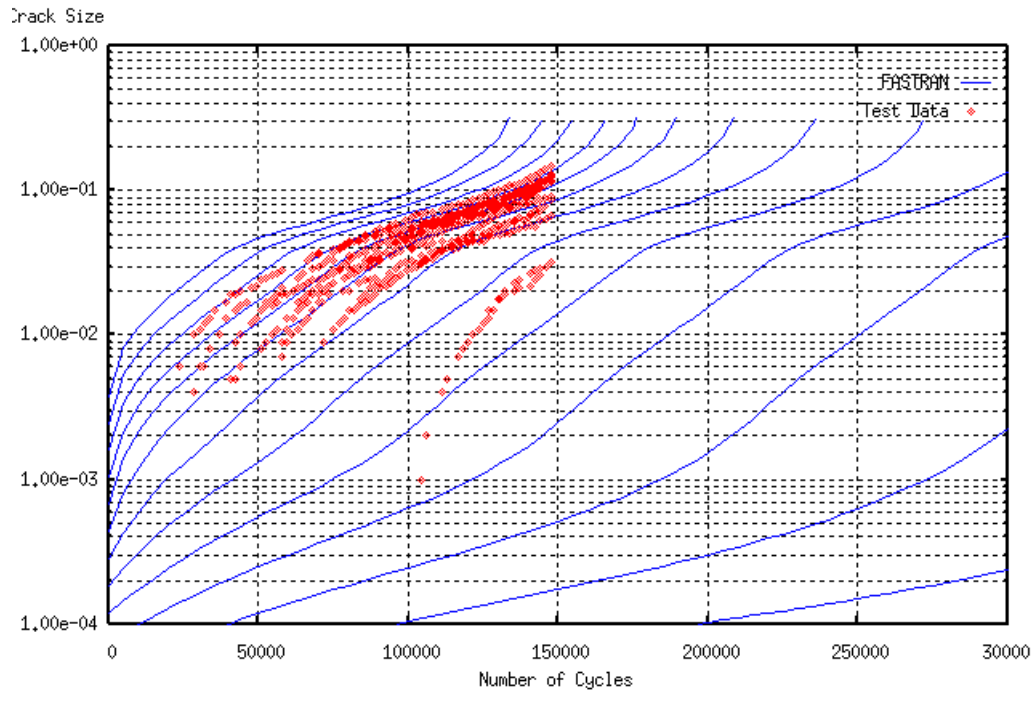


FIGURE E-56. COMPARISON OF CRACK GROWTH HISTORY FOR EIFS-7 USING BEST-MATCHED β_u

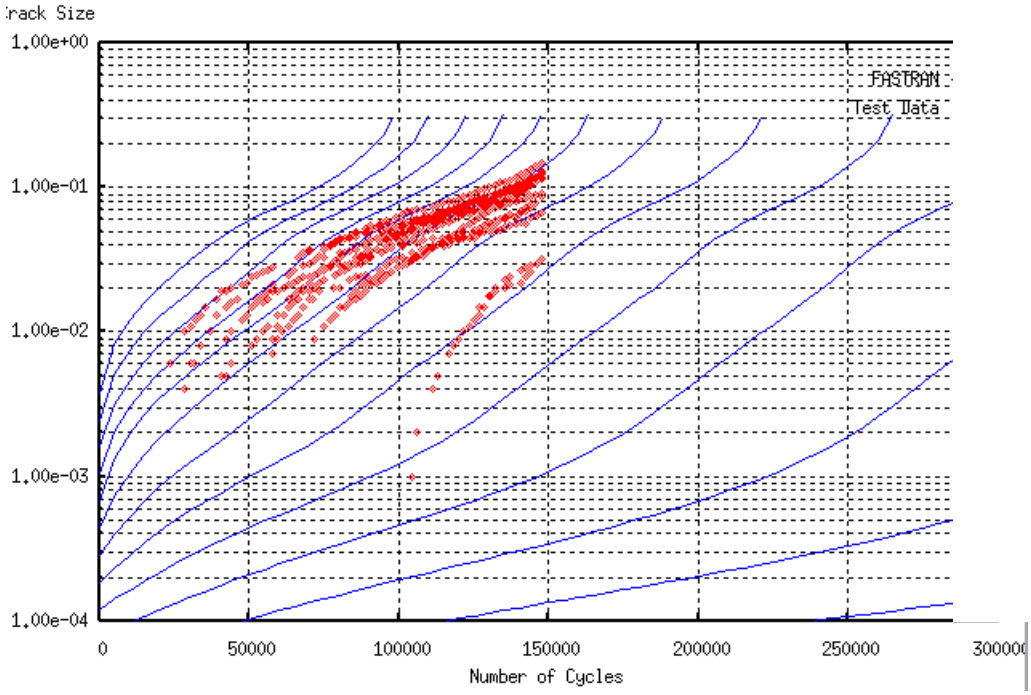


FIGURE E-57. COMPARISON OF CRACK GROWTH HISTORY FOR EIFS-7 USING BEST-MATCHED β_{u7}

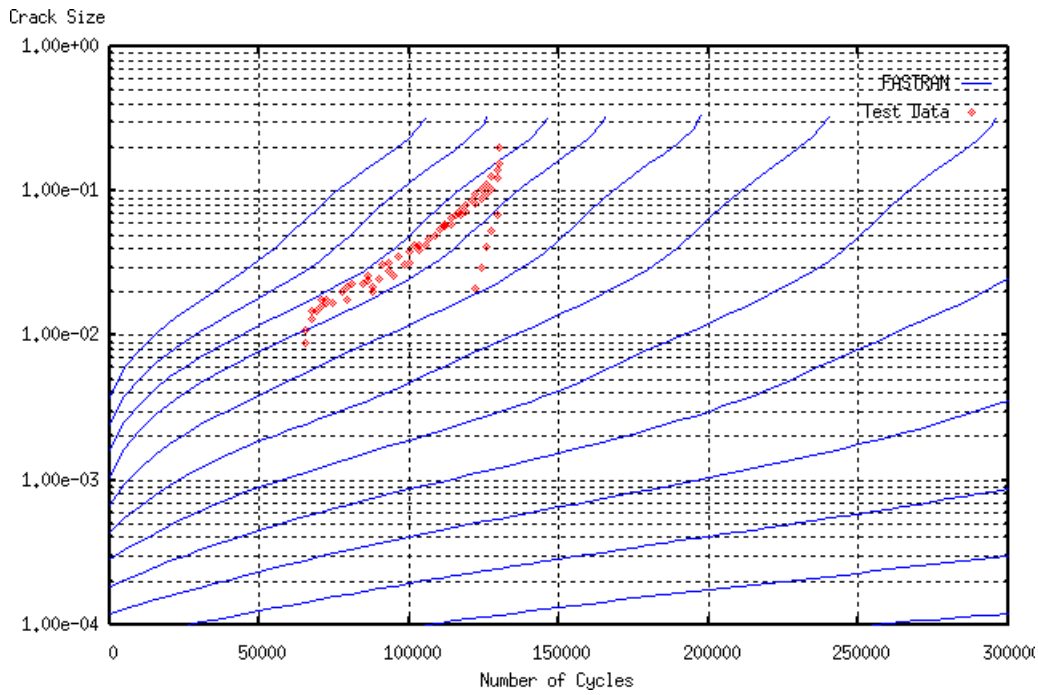


FIGURE E-58. COMPARISON OF CRACK GROWTH HISTORY FOR EIFS-8 USING BEST-MATCHED β_u

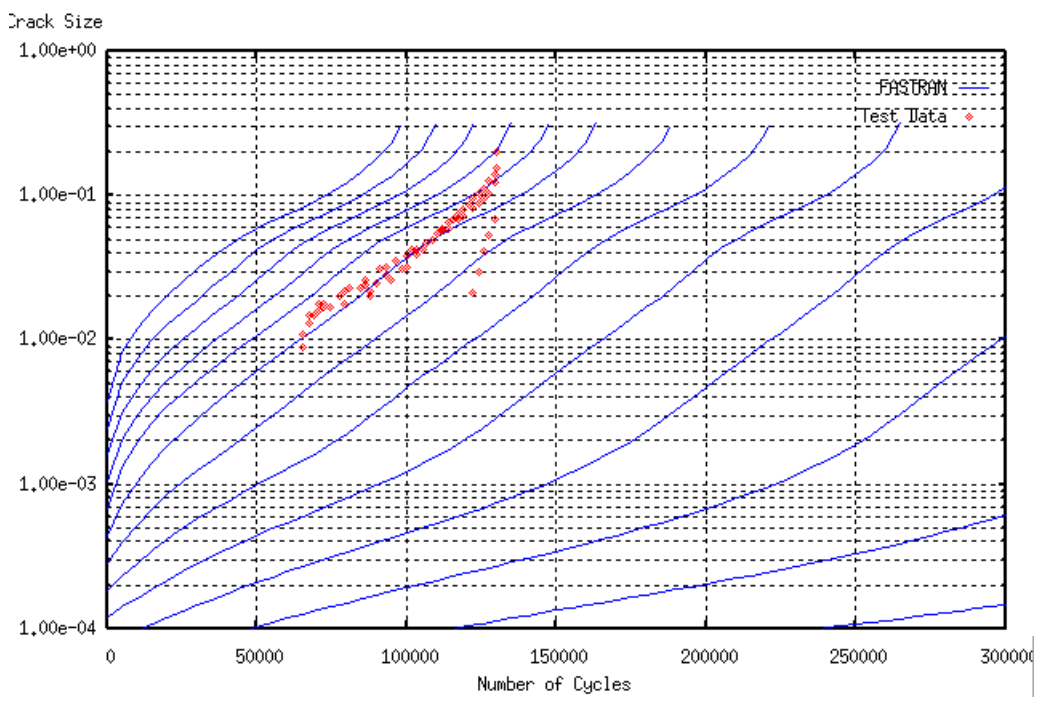


FIGURE E-59. COMPARISON OF CRACK GROWTH HISTORY FOR EIFS-8 USING BEST-MATCHED β_{u7}

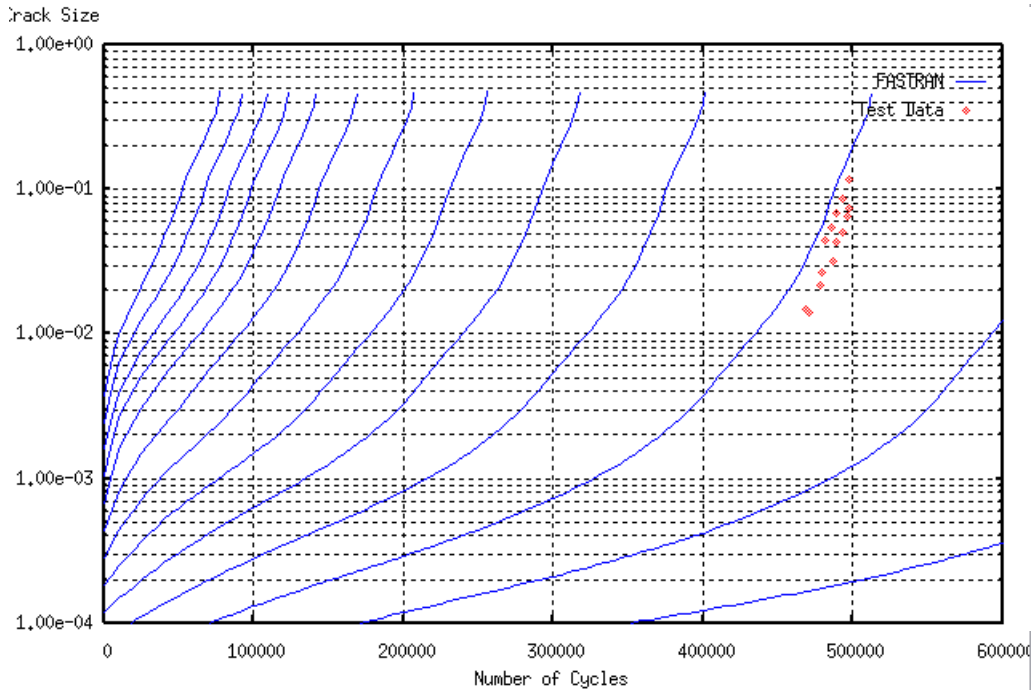


FIGURE E-60. COMPARISON OF CRACK GROWTH HISTORY FOR EIFS-9 USING BEST-MATCHED β_u

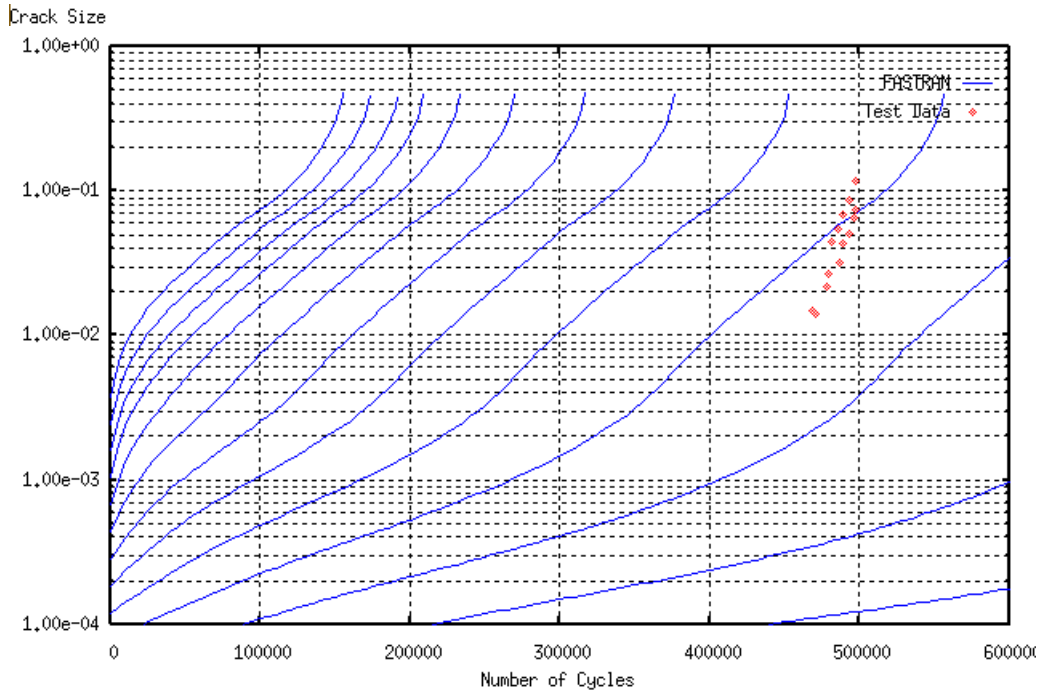


FIGURE E-61. COMPARISON OF CRACK GROWTH HISTORY FOR EIFS-9 USING BEST-MATCHED β_{u7}

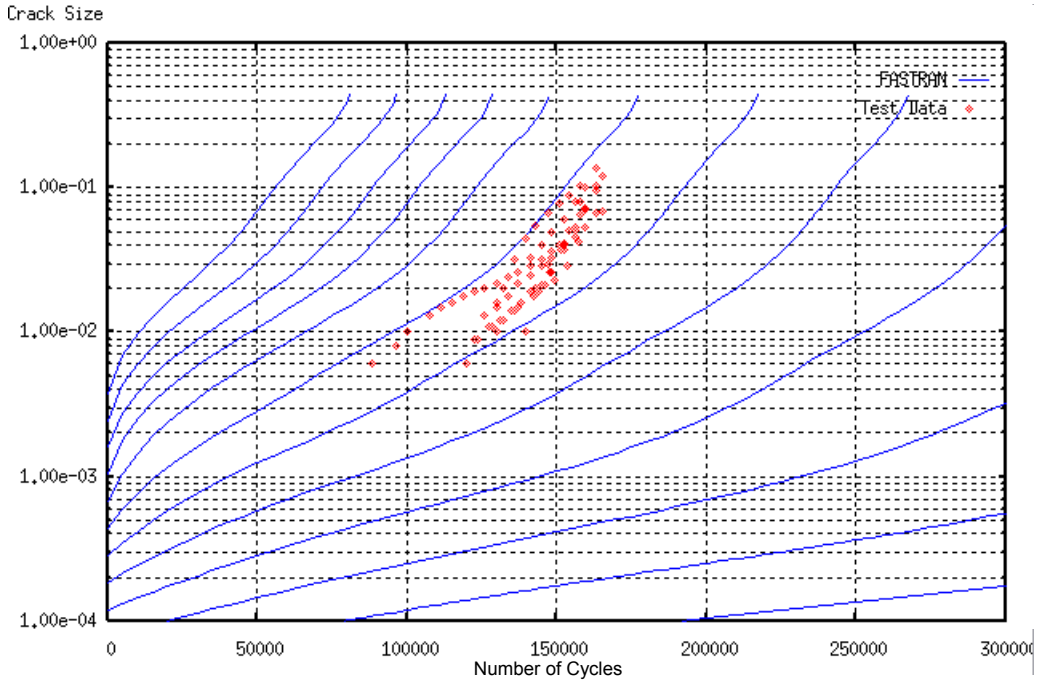


FIGURE E-62. COMPARISON OF CRACK GROWTH HISTORY FOR SPECIMEN NO. 10 USING BEST-MATCHED β_u

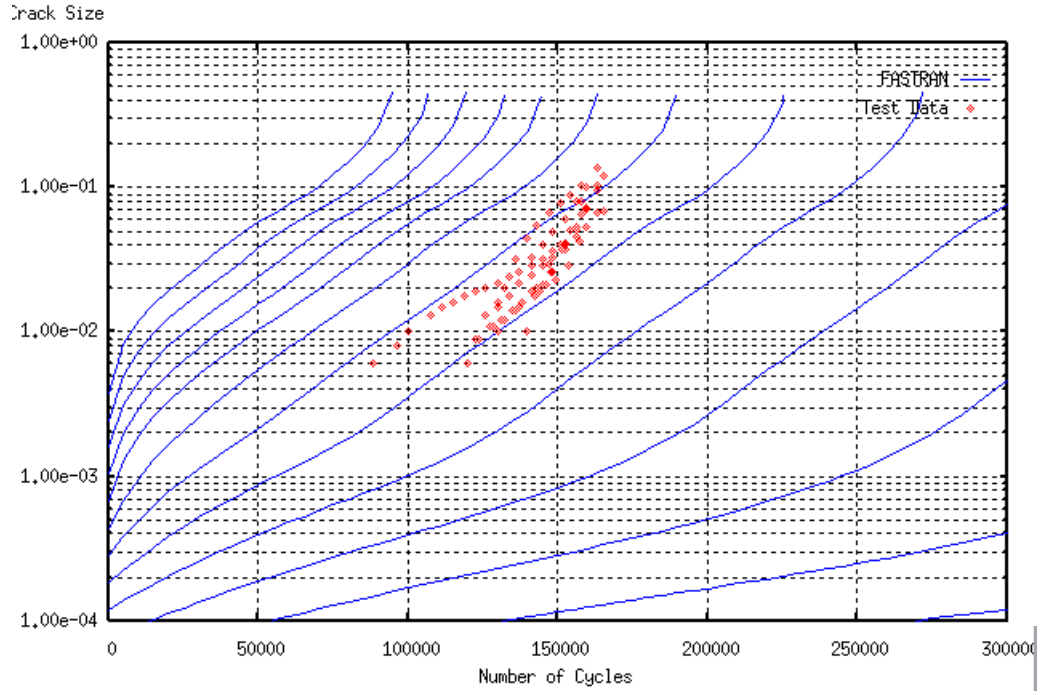


FIGURE E-63. COMPARISON OF CRACK GROWTH HISTORY FOR EIFS-10 USING BEST-MATCHED β_{u7}

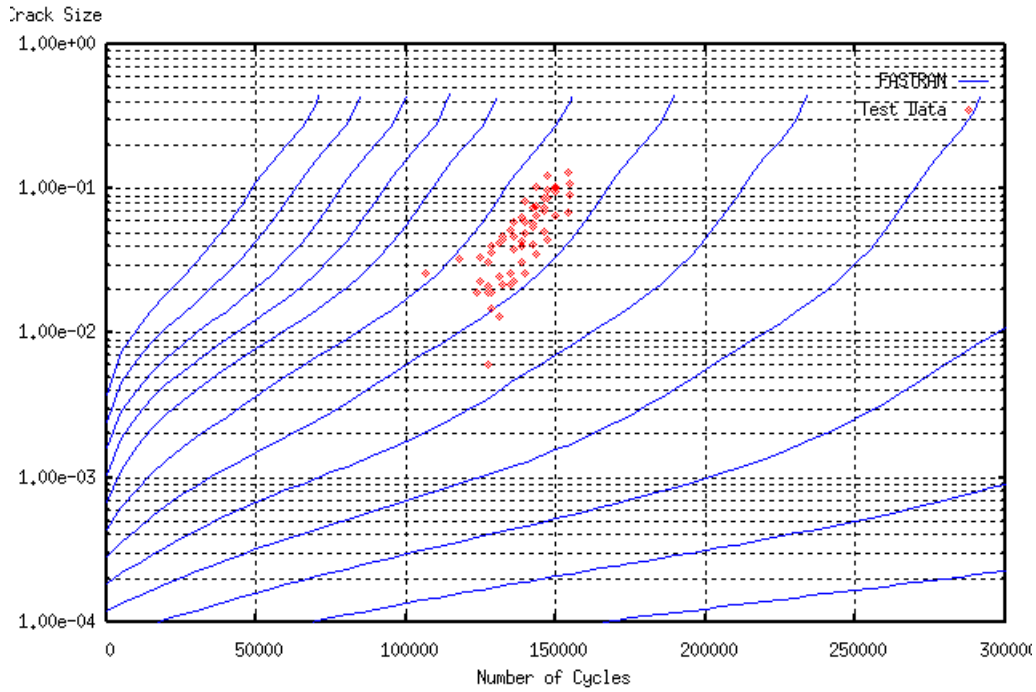


FIGURE E-64. COMPARISON OF CRACK GROWTH HISTORY FOR EIFS-11 USING BEST-MATCHED β_u

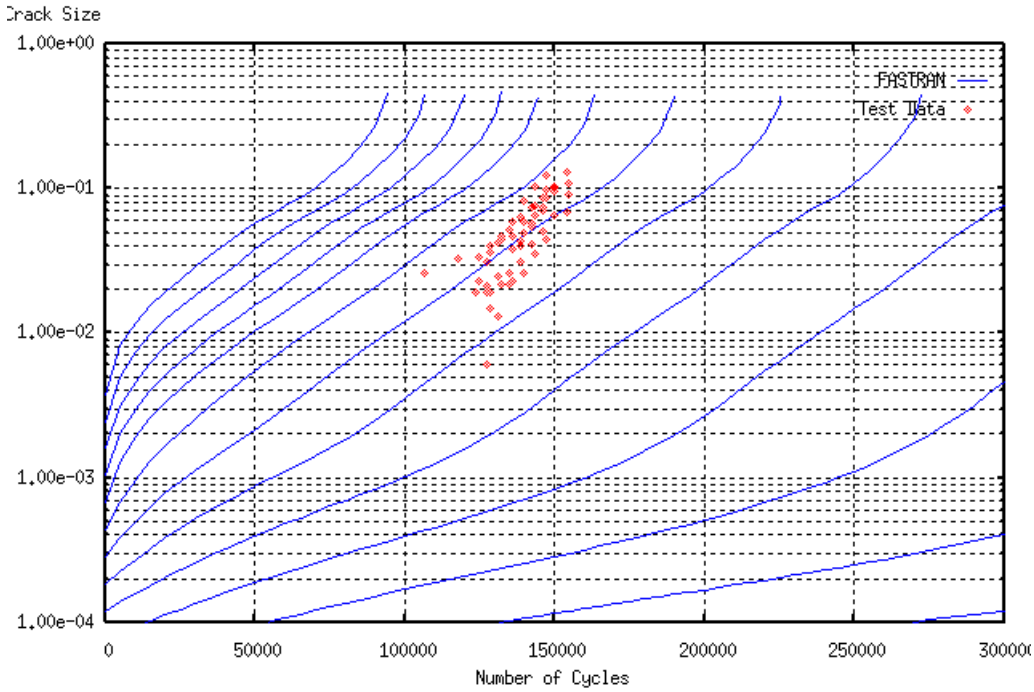


FIGURE E-65. COMPARISON OF CRACK GROWTH HISTORY FOR EIFS-11 USING BEST-MATCHED β_{u7}

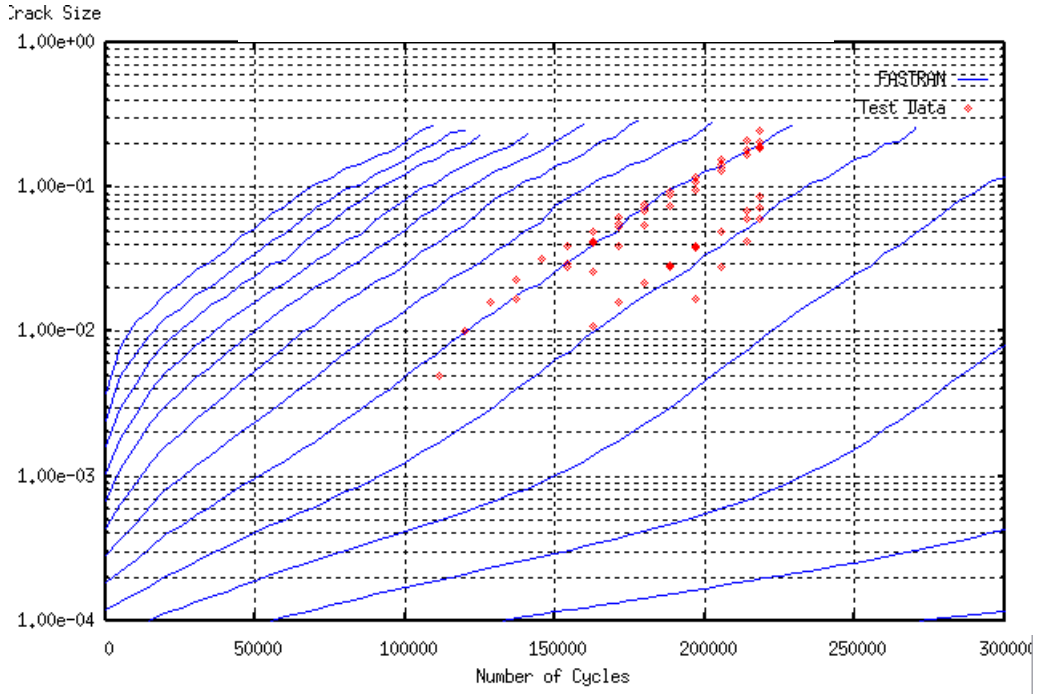


FIGURE E-66. COMPARISON OF CRACK GROWTH HISTORY FOR EIFS-15 USING BEST-MATCHED β_u

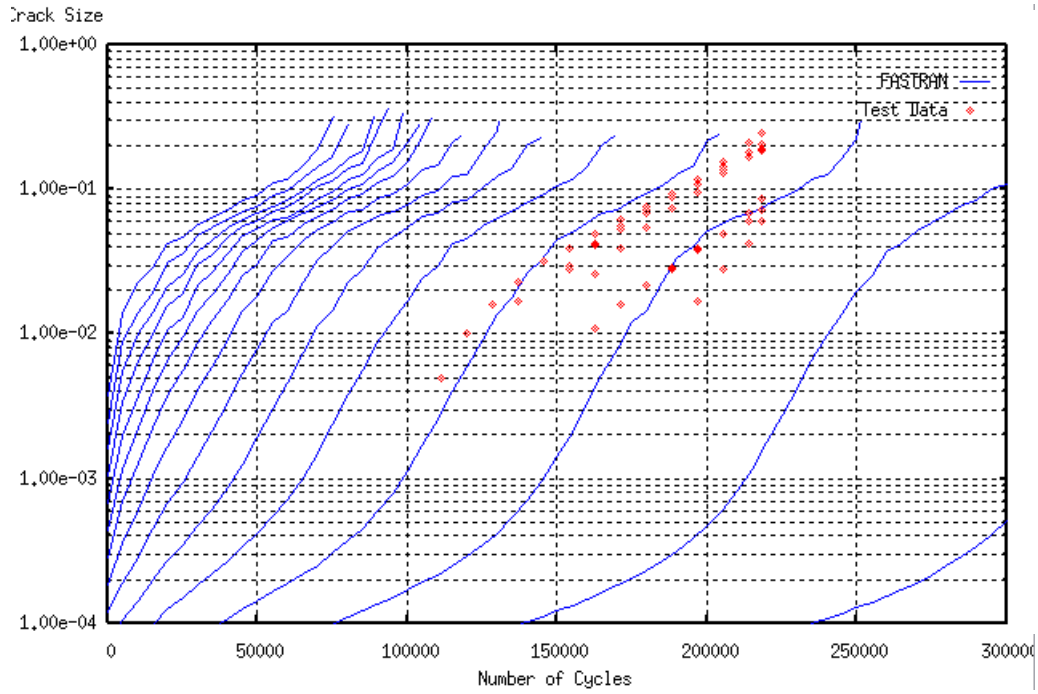


FIGURE E-67. COMPARISON OF CRACK GROWTH HISTORY FOR EIFS-15 USING BEST-MATCHED β_{u7}

APPENDIX F—SMALL CRACK GROWTH

This appendix contains the small crack growth specimen assembly and calibration drawings, dimension of the titanium pins, crack growth test results, strain surveys, FEM stress distributions, and the load transfer with crack extension as discussed in section 7.

Page No.	Description
F-2	Small crack growth specimen assembly drawing (figure F-1)
F-6	Small crack growth specimen calibration drawing (figure F-2)
F-10	Dimensions of titanium pin, washer, shim, and cotter pin (figure F-3)
F-14	Crack growth test results (tables F-1 to F-15)
F-22	SCG-1s strain survey (figures F-4 to F-14)
F-28	SCG-2 strain survey (figures F-15 to F-37)
F-39	SCG-5 strain survey (figures F-38 to F-53)
F-47	SCG-6 strain survey (figures F-54 to F-67)
F-54	SCG-7 strain survey (figures F-68 to F-79)
F-60	SCG-8 strain survey (figures F-80 to F-89)
F-65	SCG-9 strain survey (figures F-90 to F-93)
F-67	SCG-11 strain survey (figures F-94 to F-103)
F-72	Specimen stress distributions (figures F-104 to F-106)
F-74	Change in load transfer with crack extension (figures F-107 to F-118)

ER ANSI Y14.5M-1994.
1.07-2. THE -5
TER THE PIN HOLES

SURE TO COMPRESS
BLY, ADJUST THE
ZERO CLEARANCE
THE S224504296-0024

NOTE B: AN EQUIVALENT MATERIAL MAY BE SUBSTITUTED WITHOUT ENGINEERING APPROVAL.
NOTE A: AN EQUIVALENT PIN OR WASHER MAY BE SUBSTITUTED WITHOUT ENGINEERING APPROVAL.

QTY REQ PER NOTED DASH NO. -503	-501	-1	PART NO.	DESCRIPTION	STOCK SIZE	MATERIAL DESCRIPTION	MATERIAL SPECIFICATION	ZONE	NOTE
			ANSI Y14.5M -1994	STANDARD					
			DPS 4.710	PROCESS					
			DPS 3.02	PROCESS					
			DPS 2.70	PROCESS					
			DPS 1.999	PROCESS					
			DPS 1.07-2	PROCESS					
			DPS 1.001	AND THE FOLLOWING DOCUMENTS ARE REQUIRED TO SUPPLEMENT THE DRAWING					
AR	AR	AR	EA9330.3	ADHESIVE					B
2	2	2	EA-13-062AQ -350	STRAIN GAGE			(MEASUREMENTS GROUP INC. RALEIGH, NC)	9	
2	2	2	S224504296 -0024	PIN				9	A
4	4	4	NAS1252-10L	WASHER				8	
2			MS20392 -2A13	PIN				13	A
	2	2	MS20392 -2A9	PIN				9	A
AR	AR	AR	-13	SHIM		(MAKE FROM) NAS1252-10H		9	A
2			-11	DOUBLER	.125 x 3 x 7 GR LGWISE	SHEET BARE 2024-T3	QQ-A-250/4 TEMP T3	13	
	2		-9	DOUBLER	.063 x 3 x 7 GR LGWISE	SHEET 4130 A	MIL-S-18729 COND A	9	
		2	-7	DOUBLER	.063 x 3 x 7 GR LGWISE	SHEET BARE 2024-T3	QQ-A-250/4 TEMP T3	9	
4	4	4	-5	DOUBLER	.063 x 4 x 4	SHEET CLAD 2024-T3	QQ-A-250/5 TEMP T3	7	
1	1	1	-3	SPECIMEN	.063 x 4 x 19 GR LGWISE	SHEET BARE 2024-T3	QQ-A-250/4 TEMP T3	8	
•			-503	SPECIMEN ASSY				13	
	•		-501	SPECIMEN ASSY				9	
		•	-1	SPECIMEN ASSY				9	

NONE

TEST SPECIMEN - CRACK GROWTH

J1 88277 ZJ151920

FIGURE F-1. SMALL CRACK GROWTH SPECIMEN DETAIL DRAWINGS

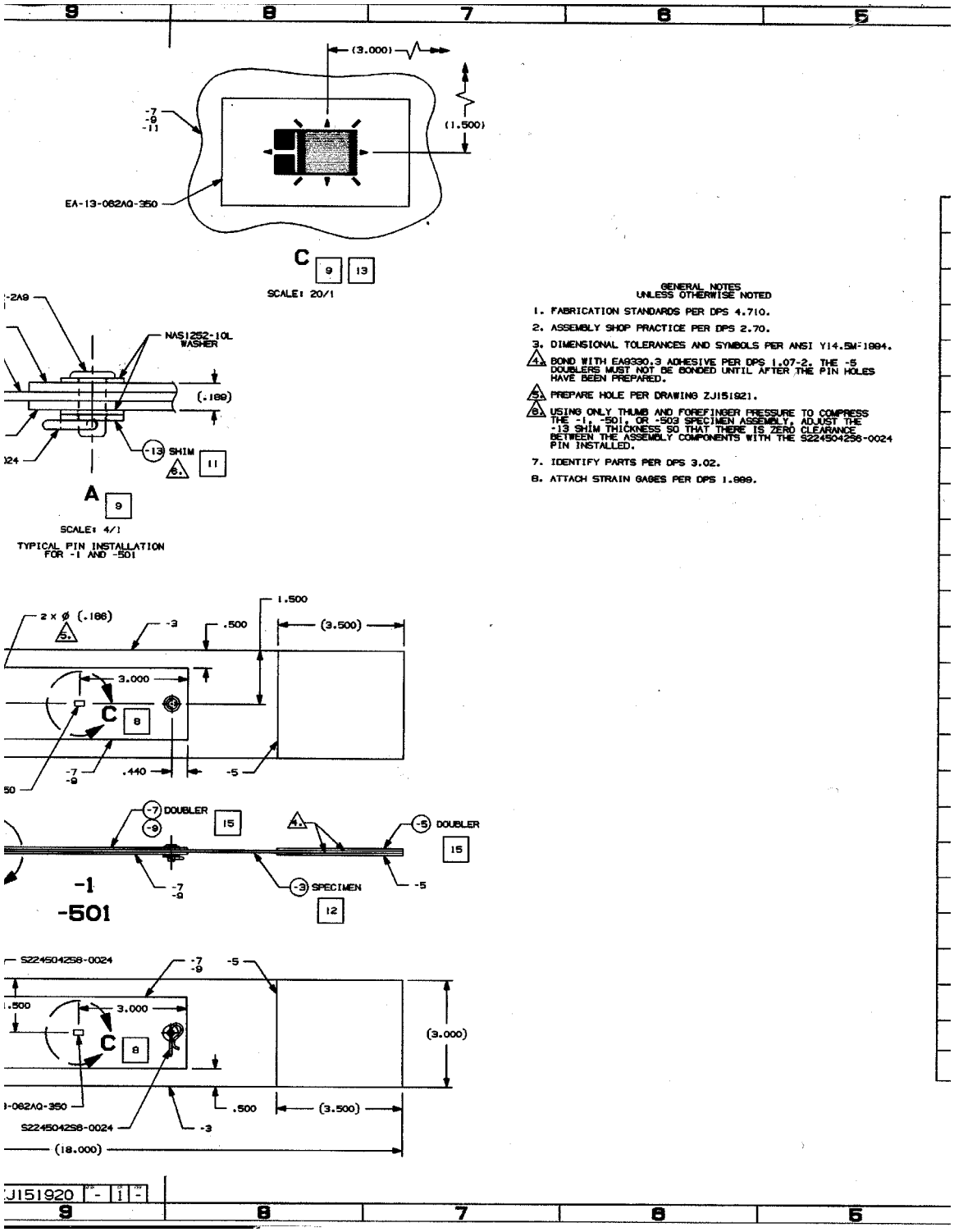


FIGURE F-1. SMALL CRACK GROWTH SPECIMEN DETAIL DRAWINGS (Continued)

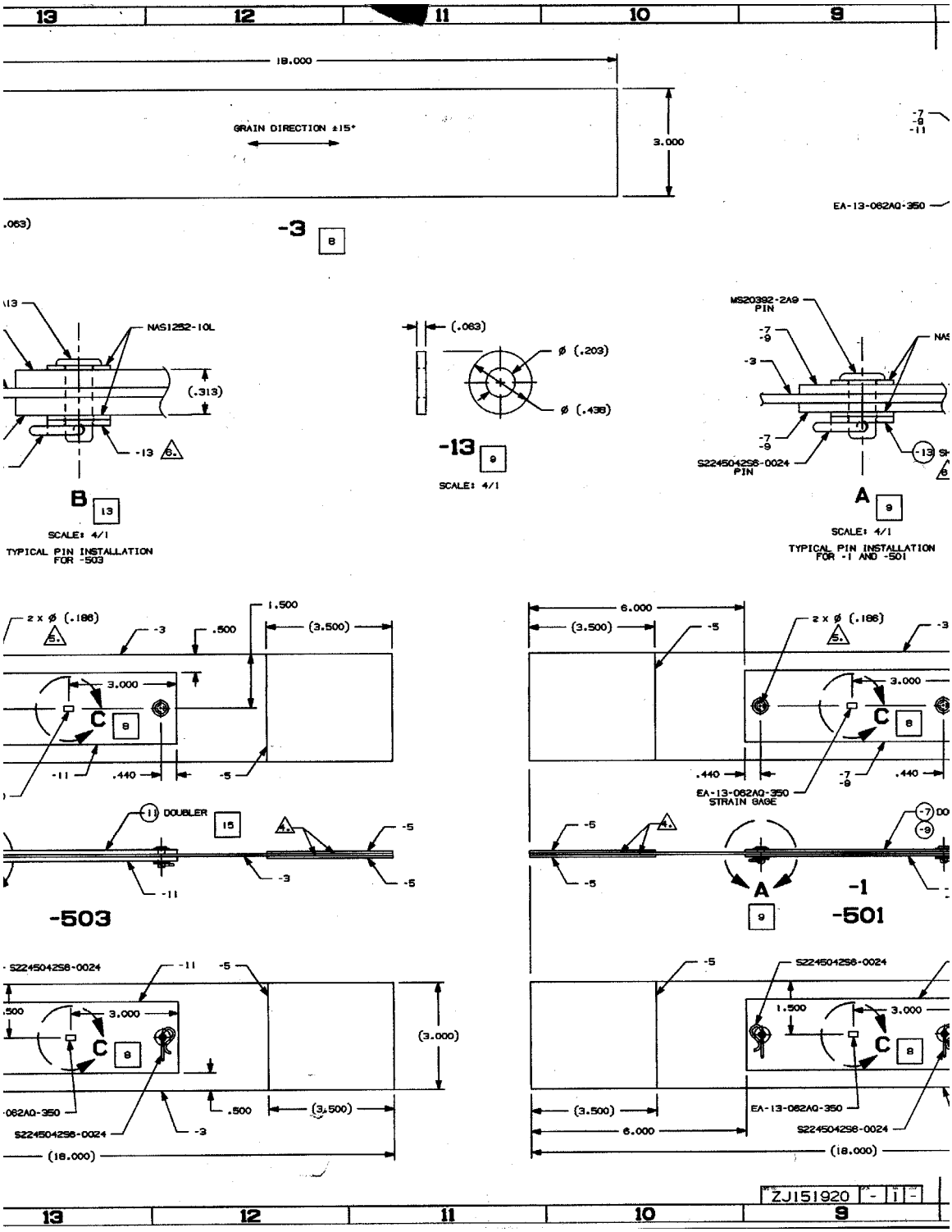


FIGURE F-1. SMALL CRACK GROWTH SPECIMEN DETAIL DRAWINGS (Continued)

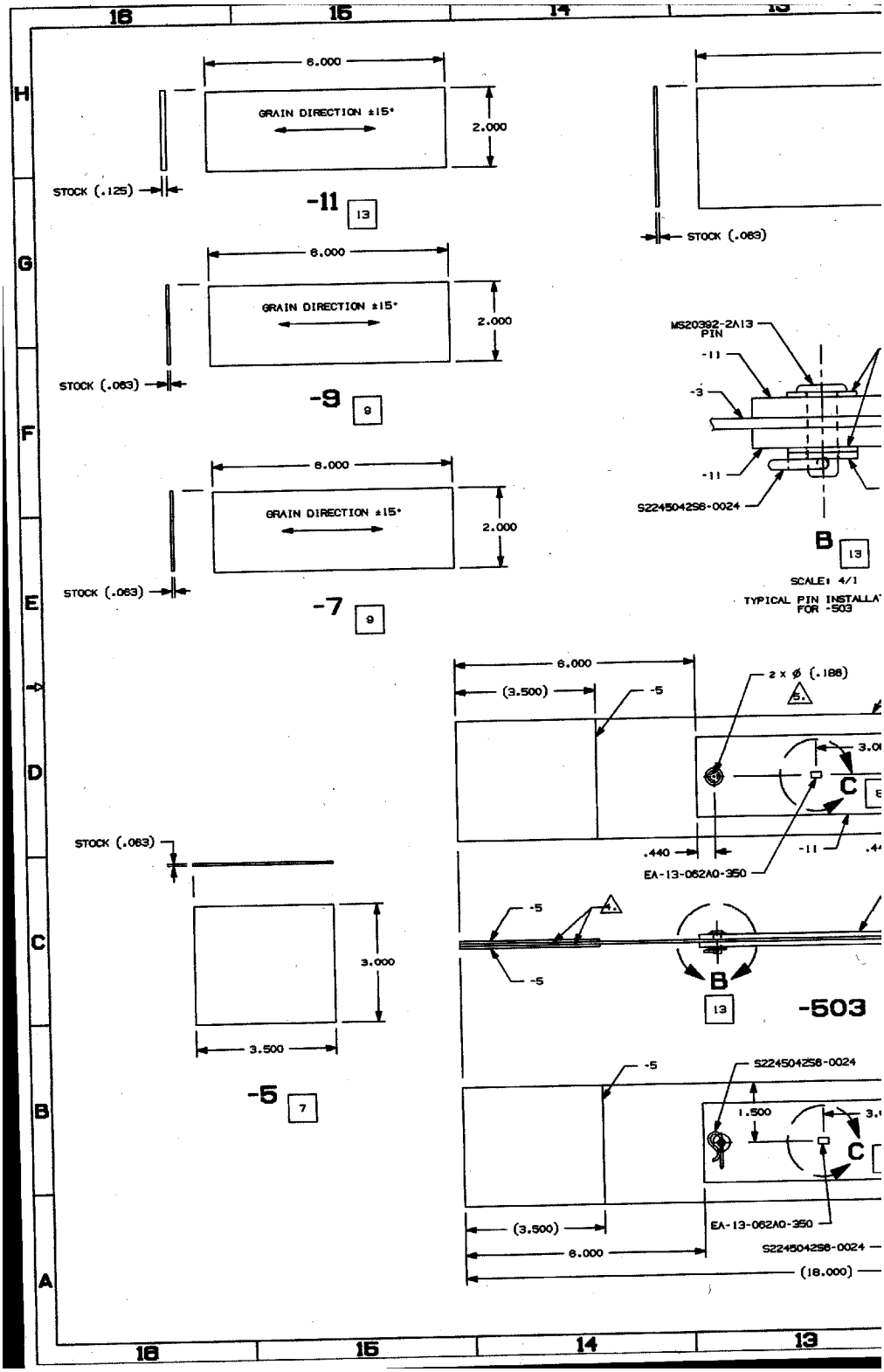


FIGURE F-1. SMALL CRACK GROWTH SPECIMEN DETAIL DRAWINGS (Continued)

5 4 3 2 1

ED
).
).
PER ANSI Y14.5M-1994.

) PART STACK-UP PER

ESSURE TO COMPRESS
ASSEMBLY, ADJUST THE
THERE IS ZERO
PONENTS WITH THE

IN GAGES ON THE -1,
IES PER TEST PLAN

E ZJ151920-3 SPECIMEN
01, OR -503 SPECIMEN
IBRATION.

J151921-1, -501, OR
SED IN THE
-503 SPECIMEN
D DRAWING

-503	-501	-1	PART NO.	DESCRIPTION	STOCK SIZE	MATERIAL DESCRIPTION	MATERIAL SPECIFICATION	ZONE
			NOTE A:	OBTAIN PART FROM DRAWING ZJ151920. BOTH ZJ151920 AND ZJ151921.		PART TO BE USED	ON CORRESPONDING ASSEMBLIES FO	
			ANSI Y14.5M -1994	STANDARD				
			DPS 4.710	PROCESS				
			DPS 3.02	PROCESS				
			DPS 2.70	PROCESS				
			DPS 1.001	AND THE FOLLOWING DOCUMENTS ARE REQUIRED TO SUPPLEMENT THE DRAWING				
2	2	2	S224504298 -0024	PIN				10
4	4	4	NAS1252-10L	WASHER				8
2			MS20392 -2A13	PIN				13
	2	2	MS20392 -2A9	PIN				9
AR	AR	AR	ZJ151920 -13	SHIM				9
2			ZJ151920 -11	DOUBLER				12
	2		ZJ151920 -9	DOUBLER				8
		2	ZJ151920 -7	DOUBLER				8
1	1	1	ZJ151920 -3	SPECIMEN				8
2	2	2	-3	CALIBRATION SPECIMEN	.063 x 4 x 10 GR LGWISE	SHEET BARE 2024-T3	QQ-A-250/4 TEMP T3	8
*			-503	CALIBRATION ASSY				13
	*		-501	CALIBRATION ASSY				9
		*	-1	CALIBRATION ASSY				9

QTY REQ PER NOTED DASH NO.

NONE

J. DOGUE 980651
J. DOGUE 980651

CALIBRATION ASSEMBLY
STRAIN GAGE, CRACK GR

J 88277 ZJ151921

NONE

FIGURE F-2. SMALL CRACK GROWTH SPECIMEN CALIBRATION ASSEMBLY

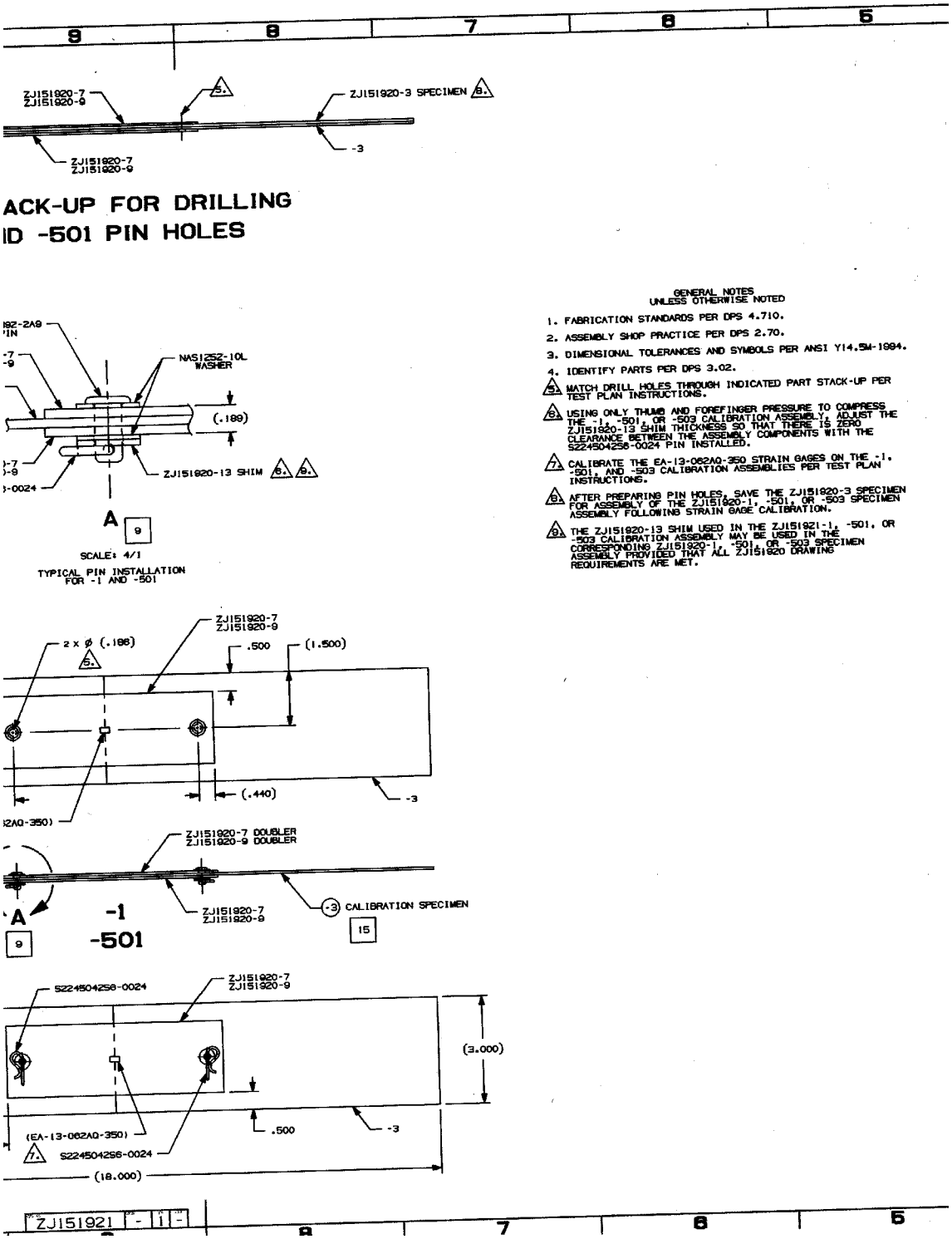


FIGURE F-2. SMALL CRACK GROWTH SPECIMEN CALIBRATION ASSEMBLY (Continued)

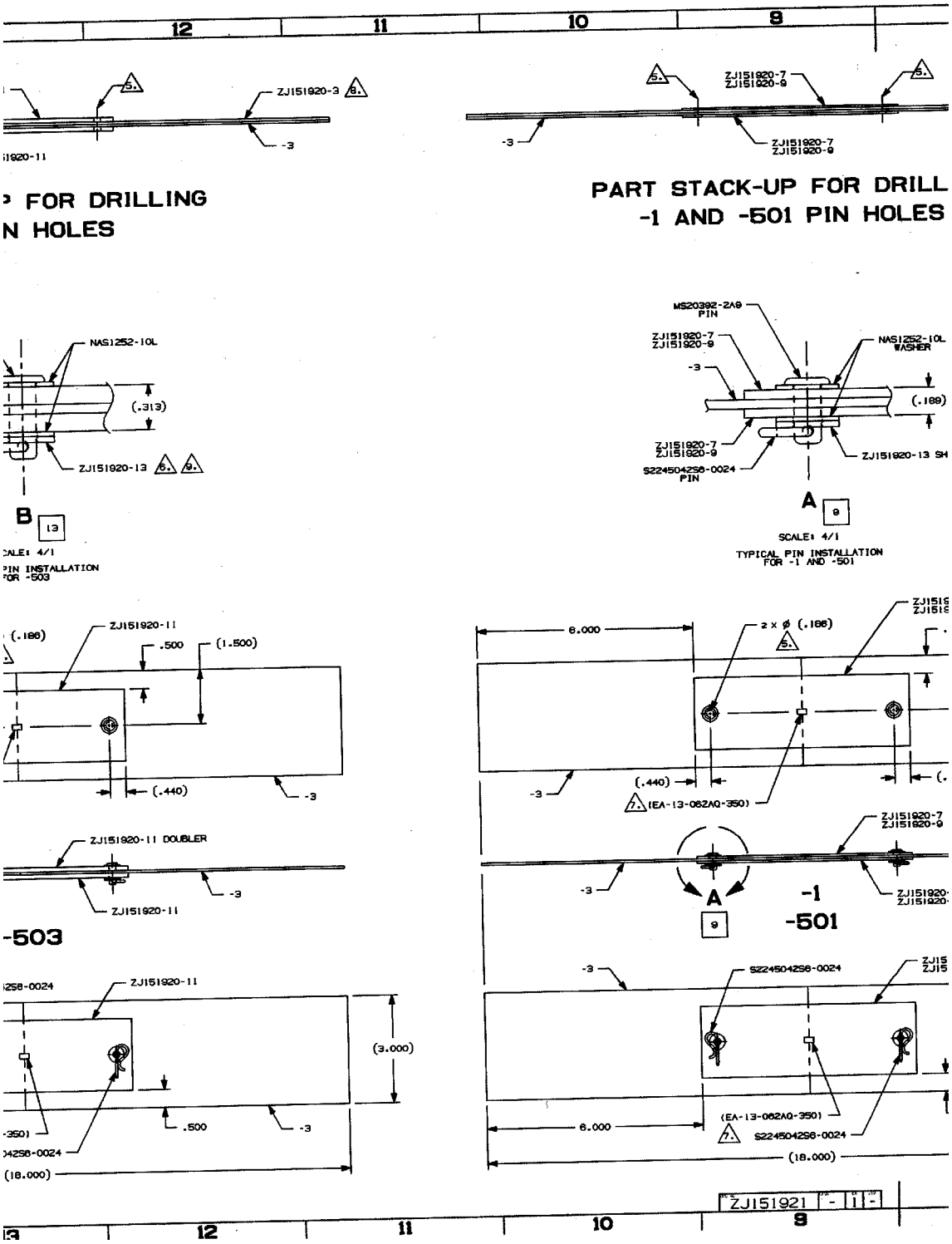


FIGURE F-2. SMALL CRACK GROWTH SPECIMEN CALIBRATION ASSEMBLY (Continued)

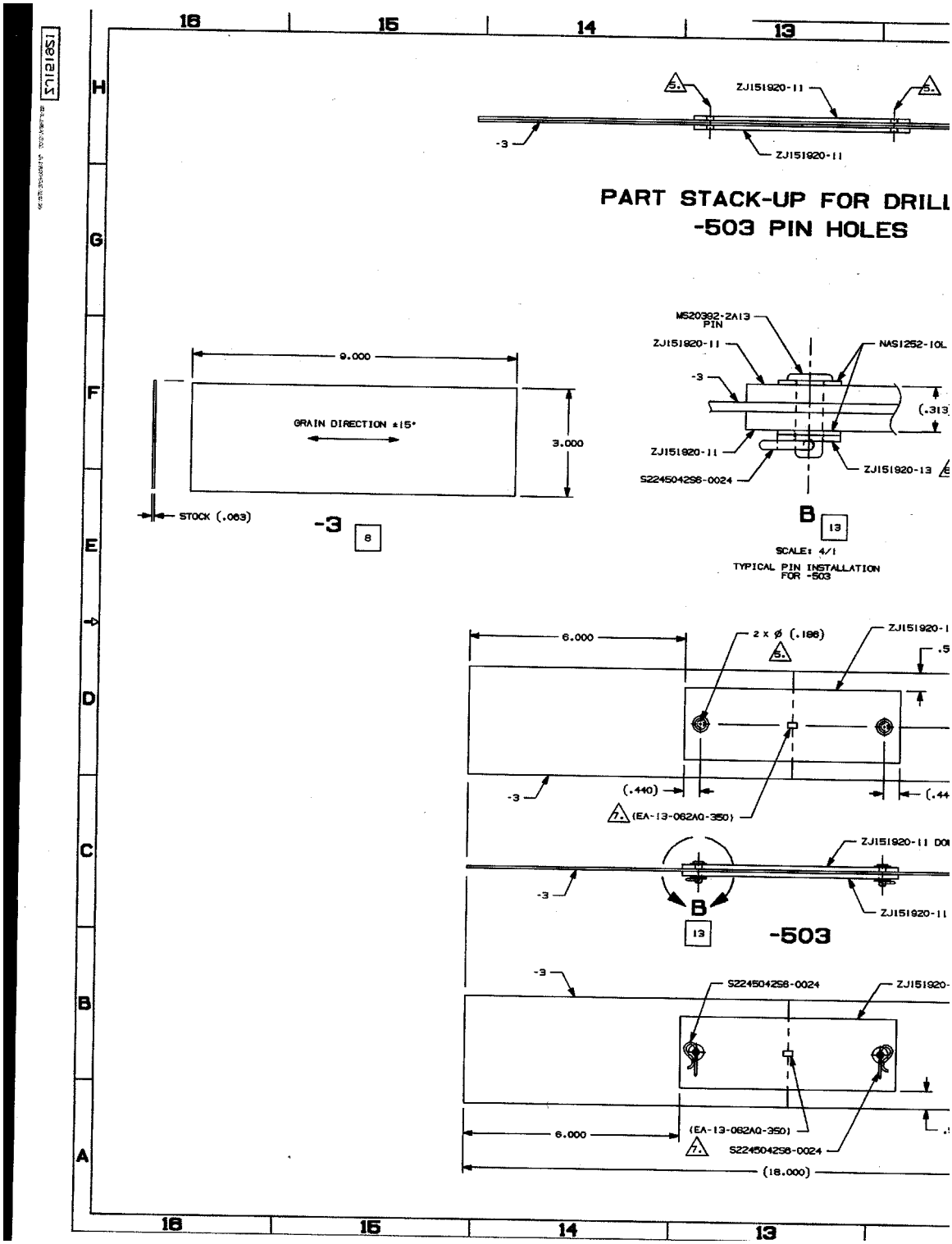


FIGURE F-2. SMALL CRACK GROWTH SPECIMEN CALIBRATION ASSEMBLY (Continued)

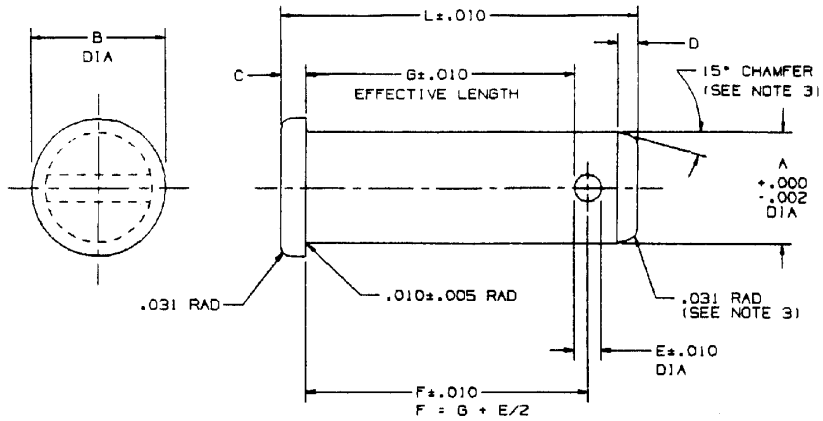


TABLE I

DIMENSION	DASH NUMBER DESIGNATING NOMINAL PIN DIAMETER												
	1	13	2	3	4	5	6	7	8	9	10	11	12
	.125	.156	.188	.250	.312	.375	.438	.500	.562	.625	.750	.875	1.000
A	.124	.155	.186	.248	.311	.373	.436	.497	.560	.622	.747	.871	.996
B	.250	.281	.312	.375	.437	.500	.562	.625	.687	.750	.875	1.062	1.187
C	.046	.046	.046	.062	.062	.062	.093	.093	.093	.093	.093	.125	.125
D	.046	.046	.046	.062	.078	.078	.078	.078	.078	.078	.078	.093	.093
E	.070	.070	.078	.078	.108	.108	.108	.108	.141	.141	.141	.171	.171
	MIN DOUBLE SHEAR STRENGTH (LBS)												
STEEL 1/	1,840	2,860	4,140	7,360	11,500	16,580	22,540	29,440	37,280	46,020	66,280	90,200	117,820
CRES	3,080	4,780	6,900	12,280	19,180	27,620	37,580	49,080	62,120	76,700	110,460	150,320	196,360
TITANIUM	2,340	3,640	5,240	9,320	14,580	21,000	28,560	37,300	47,220	58,300	83,940	114,240	149,220
STEEL,8740	2,660	4,120	5,960	10,600	16,560	23,860	32,480	42,420	53,680	66,260	95,420	129,880	169,640

1/ VALUES SHOWN ARE FOR 4037, 4130 OR 8630 STEEL.

REQUIREMENTS:

1. MATERIAL:
   STEEL ALLOY-UNS G40370 (AISI 4037) PER AMS 6300 OR UNS G41300 (AISI 4130) PER MIL-S-6758 OR UNS G86300 (AISI 8630) PER MIL-S-6050.
   STEEL ALLOY-UNS G87400 (AISI 8740) PER MIL-S-6049.
   CORROSION RESISTANT STEEL (CRES) (PH 13Mo)-UNS S13800 (AISI 13800) PER AMS 5629.
   TITANIUM ALLOY (Ti-6AL-4V)-UNS R56400 PER MIL-T-9047.

2. FINISH:
   STEEL ALLOY-CADMIUM PLATED IN ACCORDANCE WITH QQ-P-416, TYPE II, CLASS 2.
   CRES-CHROME PLATED IN ACCORDANCE WITH QQ-C-320, CLASS 2.
   CRES-CLEANED, DESCALED AND PASSIVATED IN ACCORDANCE WITH ASTM A380.
   TITANIUM ALLOY-NO FINISH
   TITANIUM ALLOY-ALUMINUM COATED IN ACCORDANCE WITH MIL-C-83438, CLASS 3, AND LUBRICATED WITH SOLID FILM LUBRICANT IN ACCORDANCE WITH MIL-L-46010.

EXAMPLE OF PART NUMBER

MS20392 -1 C 33 = .125 NOMINAL DIA X 1.031 EFFECTIVE LENGTH, STEEL ALLOY, 4037, 4130 OR 8630, CADMIUM PLATED.

- "G" - EFFECTIVE LENGTH IN 1/32 (SEE TABLE I)
- MATERIAL AND FINISH
  - "C" = STEEL ALLOY, 4037, 4130 OR 8630, CADMIUM PLATED
  - "S" = STEEL ALLOY, 8740, CADMIUM PLATED
  - "R" = CORROSION RESISTANT STEEL, PH13-8Mo, CHROME PLATED
  - "T" = TITANIUM ALLOY, Ti-6AL-4V, NO FINISH
  - "A" = TITANIUM ALLOY, Ti-6AL-4V, ALUMINUM COATED AND LUBRICATED WITH SOLID FILM LUBRICANT
  - "P" = CORROSION RESISTANT STEEL, PH13-8Mo, CLEANED, DESCALED AND PASSIVATED
- PIN DIA (NOM.) DASH NUMBER (SEE TABLE I)
- MILITARY STANDARD NUMBER

PROCUREMENT SPECIFICATION: MIL-P-5673

MS20392	PIN, STRAIGHT, HEADED, DRILLED SHANK	REVISED (E) 07-12-84

REVISED 09-12-88

07.010
1 OF 3

FIGURE F-3. DETAIL DIMENSION OF TITANIUM PIN, WASHER AND SHIM, AND COTTER PIN

NOTES:

1. DIMENSIONS SHOWN ARE AFTER FINISH.
2. TOLERANCES ON DECIMALS SHALL BE ±.016 AND ON ANGLES SHALL BE ±1/2°.
3. THE SHANK END OF PINS MAY HAVE EITHER A CHAMFER OR RADIUS AT THE OPTION OF THE VENDOR.
4. DASH NUMBER SPECIFYING EFFECTIVE LENGTH "G" IN 1/32 INCREMENTS. USE ONLY THOSE DASH NUMBERS LISTED IN TABLE II.

TABLE II

		LENGTH												
PIN DIA (NOM)		.125	.156	.188	.250	.312	.375	.438	.500	.562	.625	.750	.875	1.000
4 DASH NO.	G	L	L	L	L	L	L	L	L	L	L	L	L	L
- 7	.219	.391	.391	.391										
- 9	.281	.453	.453	.453										
- 11	.344	.516	.516	.516	.547	.594								
- 13	.406	.578	.578	.578	.609	.656								
- 15	.469	.641	.641	.641	.672	.719	.719	.750	.750	.797	.797	.797		
- 17	.531	.703	.703	.703	.734	.781	.781	.812	.812	.859	.859	.859		
- 19	.594	.766	.766	.766	.797	.844	.844	.875	.875	.922	.922	.922	1.000	1.000
- 21	.646	.828	.828	.828	.859	.906	.906	.938	.938	.984	.984	.984	1.062	1.062
- 23	.719	.891	.891	.891	.927	.969	.969	1.000	1.000	1.047	1.047	1.047	1.125	1.125
- 25	.781	.953	.953	.953	.984	1.031	1.031	1.062	1.062	1.109	1.109	1.109	1.188	1.188
- 27	.844	1.016	1.016	1.016	1.047	1.094	1.094	1.125	1.125	1.172	1.172	1.172	1.250	1.250
- 29	.906	1.078	1.078	1.078	1.109	1.156	1.156	1.188	1.188	1.234	1.234	1.234	1.312	1.312
- 31	.969	1.141	1.141	1.141	1.172	1.219	1.219	1.250	1.250	1.297	1.297	1.297	1.375	1.375
- 33	1.031	1.203	1.203	1.203	1.234	1.281	1.281	1.312	1.312	1.359	1.359	1.359	1.438	1.438
- 35	1.094	1.266	1.266	1.266	1.297	1.344	1.344	1.375	1.375	1.422	1.422	1.422	1.500	1.500
- 37	1.156	1.328	1.328	1.328	1.359	1.406	1.406	1.438	1.438	1.484	1.484	1.484	1.562	1.562
- 39	1.219	1.391	1.391	1.391	1.422	1.469	1.469	1.500	1.500	1.547	1.547	1.547	1.625	1.625
- 41	1.281	1.453	1.453	1.453	1.484	1.531	1.531	1.562	1.562	1.609	1.609	1.609	1.688	1.688
- 43	1.344	1.516	1.516	1.516	1.547	1.594	1.594	1.625	1.625	1.672	1.672	1.672	1.750	1.750
- 45	1.406	1.578	1.578	1.578	1.609	1.656	1.656	1.688	1.688	1.734	1.734	1.734	1.812	1.812
- 47	1.469	1.641	1.641	1.641	1.672	1.719	1.719	1.750	1.750	1.797	1.797	1.797	1.875	1.875
- 49	1.531	1.703	1.703	1.703	1.734	1.781	1.781	1.812	1.812	1.859	1.859	1.859	1.938	1.938
- 51	1.594	1.766	1.766	1.766	1.797	1.844	1.844	1.875	1.875	1.922	1.922	1.922	2.000	2.000
- 53	1.656	1.828	1.828	1.828	1.859	1.906	1.906	1.938	1.938	1.984	1.984	1.984	2.062	2.062
- 55	1.719	1.891	1.891	1.891	1.922	1.969	1.969	2.000	2.000	2.047	2.047	2.047	2.125	2.125
- 57	1.781	1.953	1.953	1.953	1.984	2.031	2.031	2.062	2.062	2.109	2.109	2.109	2.188	2.188
- 59	1.844	2.016	2.016	2.016	2.047	2.094	2.094	2.125	2.125	2.172	2.172	2.172	2.250	2.250
- 61	1.906	2.078	2.078	2.078	2.109	2.156	2.156	2.188	2.188	2.234	2.234	2.234	2.312	2.312
- 63	1.969	2.141	2.141	2.141	2.172	2.219	2.219	2.250	2.250	2.297	2.297	2.297	2.375	2.375
- 65	2.031	2.203	2.203	2.203	2.234	2.281	2.281	2.312	2.312	2.359	2.359	2.359	2.438	2.438
- 67	2.094	2.266	2.266	2.266	2.297	2.344	2.344	2.375	2.375	2.422	2.422	2.422	2.500	2.500
- 69	2.156			2.328	2.359	2.406	2.406	2.438	2.438	2.484	2.484	2.484	2.562	2.562
- 71	2.219			2.391	2.422	2.469	2.469	2.500	2.500	2.547	2.547	2.547	2.625	2.625
- 73	2.281			2.453	2.484	2.531	2.531	2.562	2.562	2.609	2.609	2.609	2.688	2.688
- 75	2.344			2.516	2.547	2.594	2.594	2.625	2.625	2.672	2.672	2.672	2.750	2.750
- 77	2.406			2.578	2.609	2.656	2.656	2.688	2.688	2.734	2.734	2.734	2.812	2.812
- 79	2.469			2.641	2.672	2.719	2.719	2.750	2.750	2.797	2.797	2.797	2.875	2.875
- 81	2.531			2.703	2.734	2.781	2.781	2.812	2.812	2.859	2.859	2.859	2.938	2.938
- 83	2.594			2.766	2.797	2.844	2.844	2.875	2.875	2.922	2.922	2.922	3.000	3.000
- 85	2.656			2.828	2.859	2.906	2.906	2.938	2.938	2.984	2.984	2.984	3.062	3.062
- 87	2.719			2.891	2.922	2.969	2.969	3.000	3.000	3.047	3.047	3.047	3.125	3.125
- 89	2.781			2.953	2.984	3.031	3.031	3.062	3.062	3.109	3.109	3.109	3.188	3.188
- 91	2.844			3.016	3.047	3.094	3.094	3.125	3.125	3.172	3.172	3.172	3.250	3.250
- 93	2.906			3.078	3.109	3.156	3.156	3.188	3.188	3.234	3.234	3.234	3.312	3.312
- 95	2.969			3.141	3.172	3.219	3.219	3.250	3.250	3.297	3.297	3.297	3.375	3.375

REVISED 09-12-88

REVISED (E) 07-12-84	PIN, STRAIGHT, HEADED, DRILLED SHANK	MS20392

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FIGURE F-3. DETAIL DIMENSION OF TITANIUM PIN, WASHER AND SHIM, AND COTTER PIN (Continued)

TABLE II CONTINUED

		LENGTH												
PIN DIA (NOM)		.125	.156	.188	.250	.312	.375	.438	.500	.562	.625	.750	.875	1.000
DASH NO.	G	L	L	L	L	L	L	L	L	L	L	L	L	L
- 97	3.031				3.234	3.281	3.281	3.312	3.312	3.359	3.359	3.359	3.438	3.438
- 99	3.094						3.344	3.375	3.375	3.422	3.422	3.422	3.500	3.500
-101	3.156						3.406	3.438	3.438	3.484	3.484	3.484	3.562	3.562
-103	3.219						3.469	3.500	3.500	3.547	3.547	3.547	3.625	3.625
-105	3.281						3.531	3.562	3.562	3.609	3.609	3.609	3.688	3.688
-107	3.344						3.594	3.625	3.625	3.672	3.672	3.672	3.750	3.750
-109	3.406						3.656	3.688	3.688	3.734	3.734	3.734	3.812	3.812
-111	3.469						3.719	3.750	3.750	3.797	3.797	3.797	3.875	3.875
-113	3.531						3.781	3.812	3.812	3.859	3.859	3.859	3.938	3.938
-115	3.594						3.844	3.875	3.875	3.922	3.922	3.922	4.000	4.000
-117	3.656						3.906	3.938	3.938	3.984	3.984	3.984	4.062	4.062
-119	3.719						3.969	4.000	4.000	4.047	4.047	4.047	4.125	4.125
-121	3.781						4.031	4.062	4.062	4.109	4.109	4.109	4.188	4.188
-123	3.844						4.094	4.125	4.125	4.172	4.172	4.172	4.250	4.250
-125	3.906						4.156	4.188	4.188	4.234	4.234	4.234	4.312	4.312
-127	3.969						4.219	4.250	4.250	4.297	4.297	4.297	4.375	4.375
-129	4.031												4.438	4.438
-131	4.094												4.500	4.500
-133	4.156												4.500	4.500
-135	4.219												4.625	4.625
-137	4.281												4.688	4.688

REVISED 09-12-88

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MS20392	PIN, STRAIGHT, HEADED, DRILLED SHANK	REVISED (E) 07-12-84

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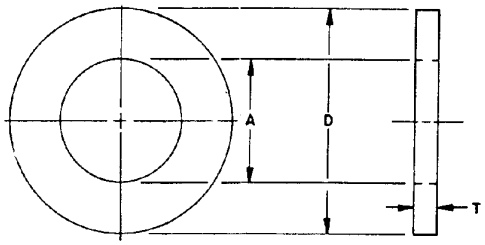
FIGURE F-3. DETAIL DIMENSION OF TITANIUM PIN, WASHER AND SHIM, AND COTTER PIN (Continued)



THREAD SIZE	A ± .010 DIAMETER	D + .020 − .005 DIAMETER	DASH NUMBERS T THICKNESS .032 ± .004	DASH NUMBERS T THICKNESS .063 ± .006
.112	.125	.312	4L	
.138	.149	.375	6L	
.164	.174	.375	8L	
.190	.203	.438	10L	10H
.250	.265	.500	416L	416H
.3125	.328	.562	516L	516H
.375	.390	.625	616L	616H
.4375	.453	.750	716L	716H
.500	.515	.875	816L	816H
.5625	.578	1.062	916L	916H
.625	.640	1.188	1016L	1016H
.750	.765	1.312	1216L	1216H
.875	.890	1.500	1416L	1416H
1.000	1.015	1.750	1616L	1616H
1.0625	1.078	1.812	1716L	1716H
1.125	1.140	1.875	1816L	1816H
1.250	1.265	2.000	2016L	2016H
1.3125	1.328	2.062	2116L	2116H
1.375	1.640	2.375	2616L	2616H
1.875	1.890	2.625	3016L	3016H
2.250	2.265	3.000	3616L	3616H
2.500	2.515	3.250	4016L	4016H

MATERIAL: 7075-T6 ALUMINUM ALLOY PER QQ-A-250/12

FINISH: * ANODIZE, MIL-A-8625 Type II CLASS 2 (YELLOW), ELECTRICALLY NON-CONDUCTIVE
* CHEMICAL CONVERSION COATING, MIL-C-81706 CLASS 3 FORM II PER MIL-C-5541 CLASS 3, ELECTRICALLY CONDUCTIVE

DISCOLORATION IS PERMITTED WHERE WASHER MAKES CONTACT WITH WIRE WHICH SUSPENDS WASHER IN SOLUTION

CODE: DASH NUMBER INDICATES THREAD SIZE.
"C" SUFFIX INDICATES CHEMICAL CONVERSION COATING (OMIT FOR ANODIZE).

EXAMPLE: NAS1252-10L = 7075-T6 AL ALY WASHER for .190 SCREW, .032 THICK, ANODIZE FINISH
NAS1252-516H = 7075-T6 AL ALY WASHER for .312 SCREW, .063 THICK, ANODIZE FINISH
NAS1252-516HC = 7075-T6 AL ALY WASHER for .312 SCREW, .063 THICK, CHEM CVRSN CTG FINISH

REMOVE ALL BURRS AND SHARP EDGES.

WASHER FACES SHALL BE PARALLEL WITHIN .002 INCH.

WASHER FACES SHALL BE FLAT WITHIN .007 FOR SIZES UP THROUGH .500 AND .010 FOR SIZES .562 TO 1.250 SIZE INCLUSIVE, AND .015 FOR 1.312 AND LARGER.

DIMENSIONS IN INCHES.

DESIGN CONSIDERATION

1. USE NAS1252 FOR GENERAL APPLICATION

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REVISED 08-01-90

REVISED REV. (2) 7-12-1984	WASHER-7075 ALUMINUM ALLOY FLAT	NAS1252

1-24.000

FIGURE F-3. DETAIL DIMENSION OF TITANIUM PIN, WASHER AND SHIM, AND COTTER PIN (Continued)

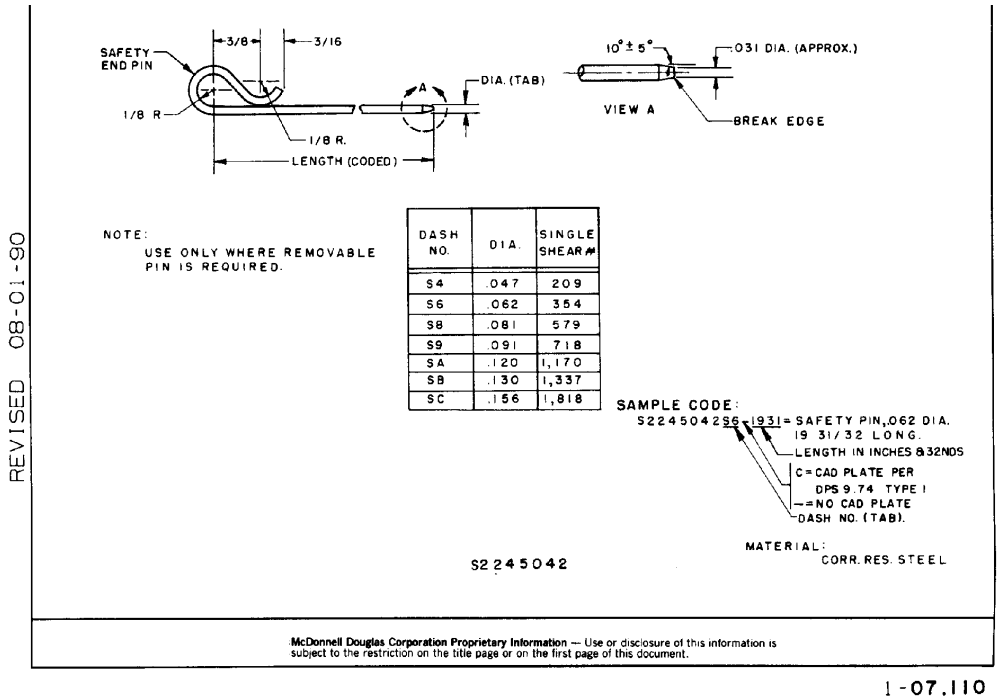

FIGURE F-3. DETAIL DIMENSION OF TITANIUM PIN, WASHER AND SHIM, AND COTTER PIN (Continued)

TABLE F-1. CRACK GROWTH DATA FOR SCG-1s

Doubler: 0.063″ Al			
Constant amplitude w/marker bands			
σ_{max} = 15 ksi			
Cycles	Crack Length, c (in)		
	Front	Back	Back Opposite
200	0.00855	0.00739	
2,200	0.0121	0.01227	
4,200	0.02096	0.02173	
9,400	0.04531	0.04509	
14,600	0.0712	0.07153	
19,800	0.09224	0.09407	
25,800	0.11347	0.11739	
31,800	0.13843	0.1431	
37,800	0.16081	0.16405	
43,800	0.18461	0.18594	
51,800	0.22273	0.21913	0.00535
57,800	0.2539	0.24894	0.01271
Failure Load: 8678 lbf.			

TABLE F-2. CRACK GROWTH DATA FOR SCG-2

Doubler: 0.063″ Al		
Constant amplitude w/marker bands		
σ_{max} = 15 ksi		
Cycles	Crack Length, c (in)	
	Front	Back
0	0.0625	0.0628
2,000	0.07328	0.07635
4,000	0.08594	0.0887
6,000	0.09637	0.09917
8,000	0.10476	0.10783
10,000	0.11545	0.11766
12,000	0.12487	0.12575
14,000	0.13347	0.1344
20,000	0.16522	0.16513
26,000	0.19319	0.19343
32,000	0.22143	0.22284
38,000	0.24899	0.25303
Failure Load: 8964 lbf.		

TABLE F-3. CRACK GROWTH DATA FOR SCG-5

Doubler: 0.063″ Al		
Constant amplitude w/marker bands		
σ_{max} = 15 ksi		
Cycles	Crack Length, c (in)	
	Front	Back
500	0.00852	0.00713
5,700	0.03063	0.02328
10,900	0.0506	0.05081
16,100	0.07756	0.07991
21,300	0.10375	0.10334
26,500	0.12451	0.12634
31,700	0.14616	0.14678
36,900	0.17365	0.17254
42,100	0.19837	0.19821
47,300	0.22443	0.2268
52,500	0.25319	0.25642
Failure Load: 8822 lbf.		

TABLE F-4. CRACK GROWTH DATA FOR SCG-6

Doubler: 0.120″ Al				
Constant amplitude w/marker bands				
σ_{max} = 12.5 ksi				
	Crack Length, c (in)			
Cycles	Front	Back	Front Opposite	Back Opposite
0	0.0042	0.00181		
5,200	0.0126	0.00849		
10,400	0.02373	0.02113		
20,800	0.05918	0.05796		
28,600	0.08433	0.08306		
36,600	0.11004	0.10618		
44,400	0.13215	0.12859		
52,200	0.14946	0.14916		
62,600	0.1742	0.17744		
73,000	0.207	0.20664		
83,400	0.24146	0.24393	0.06528	0.05081
Failure Load: 8542 lbf.				

TABLE F-5. CRACK GROWTH DATA FOR SCG-7

Doubler: 0.120″ Al			
Constant amplitude w/marker bands			
σ_{max} = 12.5 ksi			
	Crack Length, c (in)		
Cycles	Front	Back	Back Opposite
0	0.00394	0.00432	
2,000	0.00548	0.00661	
7,200	0.01085	0.01351	
12,400	0.02369	0.02647	
22,800	0.06548	0.06652	
30,300	0.09618	0.0953	
37,800	0.12149	0.11964	
45,300	0.14408	0.14571	
52,800	0.16812	0.17059	0.00241
Failure Load: 8406 lbf.			

TABLE F-6. CRACK GROWTH DATA FOR SCG-8

Doubler: 0.120″ Al		
EIFS Spectrum loading		
σ_{max} = 13.4 ksi		
Cycles	Crack Length, c (in)	
	Front	Back
100	0.00203	0.0029
2,000	0.00216	0.00302
4,000	0.00295	0.00392
6,000	0.00304	0.00463
56,000	0.00742	0.01164
125,000	0.01063	0.01521
325,000	0.02606	0.02795
725,000	0.09575	0.09904
825,000	0.11889	0.12144
925,000	0.13969	0.14079
1,025,000	0.1644	0.16481
1,125,000	0.18749	0.18908
1,225,000	0.20963	0.21165
1,325,000	0.23377	0.23487
1,425,000	0.26048	0.26053
Failure Load: 8744 lbf.		

TABLE F-7. CRACK GROWTH DATA FOR SCG-9

Doubler: 0.120″ Al		
EIFS Spectrum loading		
σ_{max} = 13.4 ksi		
Cycles	Crack Length, c (in)	
	Front	Back
200	0	0.00295
2,000	0	0.00299
4,000	0	0.00402
6,000	0.00187	0.00414
36,000	0.00548	0.00611
186,000	0.02189	0.01679
386,000	0.05851	0.05296
486,000	0.07816	0.0744
600,000	0.10256	0.10008
700,000	0.12498	0.12293
800,000	0.14705	0.14471
900,000	0.16812	0.16516
1,000,000	0.19058	0.18768
1,100,000	0.21513	0.21272
1,200,000	0.24168	0.24313
1,300,000	0.2665	0.26943

TABLE F-8. CRACK GROWTH DATA FOR SCG-11

Doubler: 0.063″ Steel		
Constant amplitude w/marker bands		
σ_{max} = 10 ksi		
Cycles	Crack Length, c (in)	
	Front	Back
200	0.00238	0
2,000	0.00263	0.00307
30,000	0.03332	0.03745
50,000	0.07133	0.07578
60,000	0.08939	0.09237
80,000	0.12131	0.12848
95,000	0.14831	0.15097
110,000	0.17331	0.17662
130,000	0.21122	0.21278
145,000	0.23884	0.23984
160,000	0.26387	0.26814
Failure Load: 8828 lbf.		

TABLE F-9. CRACK GROWTH DATA FOR SCG-12

Doubler: 0.063″ Steel		
Constant amplitude w/marker bands		
σ_{max} = 10 ksi		
Cycles	Crack Length, c (in)	
	Front	Back
200	0	0
2,000	0	0
4,000	0	0
6,000	0	0
11,000	0	0.0054
13,000	0	0.00622
15,000	0	0.00739
17,000	0.00482	0.00913
27,000	0.01572	0.02358
39,000	0.03714	0.04481
49,000	0.0581	0.06125
69,000	0.09089	0.09451
85,000	0.11629	0.12138
100,000	0.14164	0.14368
120,000	0.17571	0.17758
135,000	0.20305	0.20379
150,000	0.23196	0.23088
165,000	0.25889	0.25831

TABLE F-10. CRACK GROWTH DATA FOR SCG-16

No Doubler (open-hole)		
Constant amplitude with marker bands		
σ_{max} = 15 ksi		
Cycles	Crack Length, c (in)	
	Front	Back
0	0	0
100	0	0.00414
500	0	0.00413
2,000	0	0.00412
4,000	0	0.00452
6,000	0	0.00529
8,000	0	0.00632
10,000	0.00178	0.00748
12,000	0.00261	0.00884
17,200	0.00811	0.01414
21,200	0.01684	0.02106
23,200	0.02033	0.0245
33,200	0.04632	0.04857
43,200	0.07583	0.07673
53,400	0.10457	0.10578
63,400	0.13837	0.13564
73,400	0.17371	0.17305
83,400	0.20969	0.21073
95,900	0.26217	0.26075

TABLE F-11. CRACK GROWTH DATA FOR SCG-17s

No Doubler (open-hole)		
Constant amplitude with marker bands		
σ_{max} = 15 ksi		
Cycles	Crack Length, c (in)	
	Front	Back
0	0.02668	0.02715
200	0.02817	0.02726
2,000	0.03258	0.03356
7,000	0.0472	0.04372
13,000	0.0463	0.04956
50,000	0.11166	0.11342
58,500	0.12868	0.13306
65,500	0.14845	0.15311
70,500	0.15961	0.16683
76,500	0.17555	0.1832
82,000	0.18587	0.20002
88,000	0.19936	0.21639
94,000	0.22007	0.23143
99,000	0.23368	0.245
104,500	0.25121	0.26366

TABLE F-12. CRACK GROWTH DATA FOR SCG-18s

No Doubler (open-hole)		
Spectrum loading		
Cycles	Crack Length, c (in)	
	Front	Back
0	0.0045	0.008
100,000	0.019	0.025
200,000	0.046	0.0455
250,000	0.0575	0.0575
300,000	0.068	0.0685
350,000	0.0795	0.081
425,000	0.0985	0.0995
475,000	0.111	0.1105
575,000	0.1365	0.1335
675,000	0.162	0.1595
775,000	0.1905	0.191
875,000	0.222	0.2175
975,000	0.252	0.2495

TABLE F-13. CRACK GROWTH DATA FOR SCG-19s

No Doubler (open-hole)		
Spectrum loading		
Cycles	Crack Length, c (in)	
	Front	Back
0	0.0155	0
50,000	0.0155	0.001
10,000	0.027	0.0165
200,000	0.054	0.043
250,000	0.065	0.0595
300,000	0.077	0.067
350,000	0.09	0.082
450,000	0.1155	0.1075
500,000	0.1315	0.1195
600,000	0.1585	0.1495
700,000	0.191	0.18
800,000	0.2185	0.2165
850,000	0.238	0.231
900,000	0.2565	0.247

TABLE F-14. CRACK GROWTH DATA FOR SCG-20s

No Doubler (open-hole)		
Constant amplitude (no marker bands)		
σ_{max} = 15 ksi		
	Crack Length, c (in)	
Cycles	Front	Back
0	0.0025	0.0015
10,000	0.0240	0.0185
20,000	0.0570	0.0330
30,000	0.0890	0.0905
35,000	0.1155	0.1120
40,000	0.1390	0.1320
45,000	0.1575	0.1570
50,000	0.1830	0.1745
	turned around	
55,000	0.2035	0.2010
60,000	0.2240	0.2260
65,000	0.2545	0.2535
75,000	0.3130	0.3120
85,000	0.3835	0.3880
95,000	0.4720	0.4750
98,000	0.5030	0.5045
108,000	0.6130	0.6130
118,000	0.7530	0.7585
126,562	failed	

TABLE F-15. CRACK GROWTH DATA FOR SCG-21

No Doubler (open-hole)		
Constant amplitude (no marker bands)		
σ_{max} = 15 ksi		
	Crack Length, c (in)	
Cycles	Front	Back
0	0.0000	0.0020
5,000	0.0000	0.0100
10,000	0.0000	0.0120
15,000	0.0000	0.0135
25,000	0.0000	0.0190
35,000	0.0000	0.0255
45,000	0.0030	0.0370
55,000	0.0065	0.0390
65,000	0.0065	0.0530
75,000	0.0065	0.0675
85,000	0.0140	0.0880
95,000	0.1125	0.1220
105,000	0.1685	0.1705
115,000	0.2320	0.2325
125,000	0.3225	0.3210
135,000	0.4620	0.4560
145,000	0.6780	0.6685

F.1 SMALL CRACK GROWTH SPECIMEN STRAIN SURVEY DATA.

Figures F-4 through F-14 are plots of calibration and periodic strain surveys. Calibration surveys, done before testing, used a split specimen to get 100% load transfer through the doublers. The strain surveys were taken at intervals during the crack growth testing.

F.2 SPECIMEN SCG-1s STRAIN GAGE DATA.

Specimen SCG-1s has a 0.063″ aluminum doubler and was cycled at a constant amplitude of 15 ksi, R = 0.1. Strain surveys were taken before and after the specimen was disassembled for periodic inspection. This data came from the Air Force Research Laboratory.

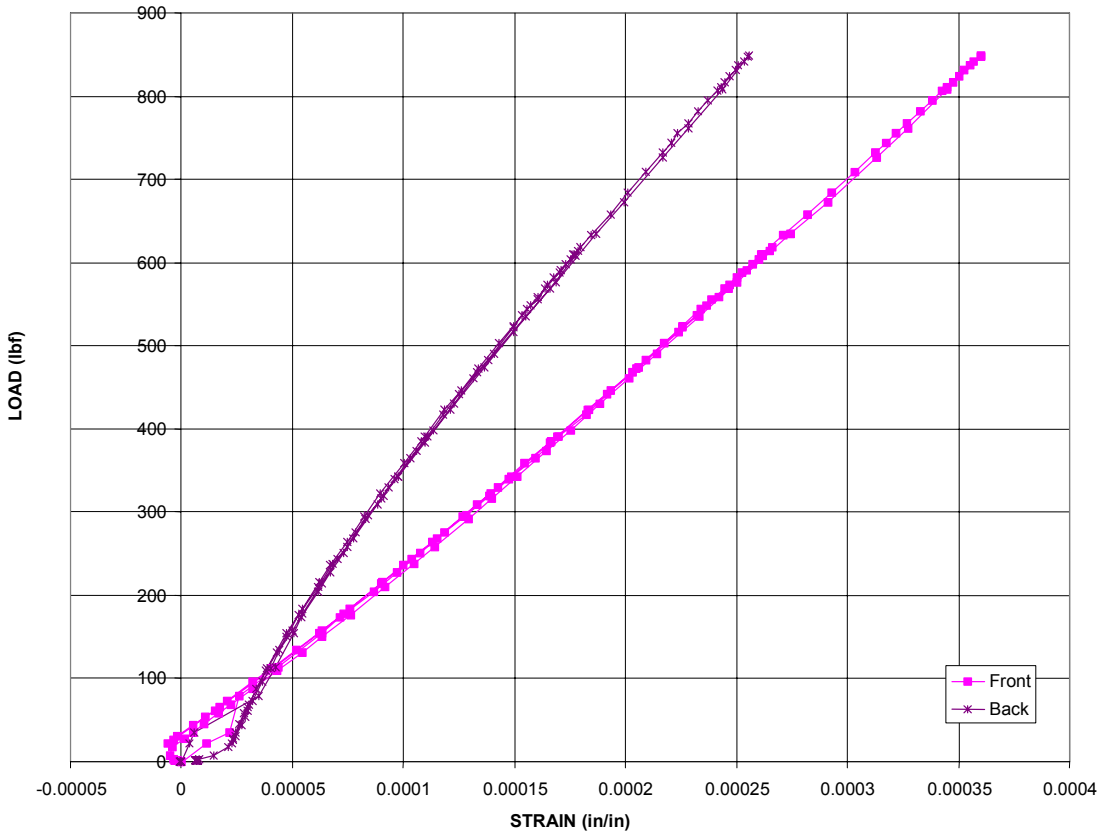

FIGURE F-4. STRAIN GAGE DATA, SCG-1s, CALIBRATION #1

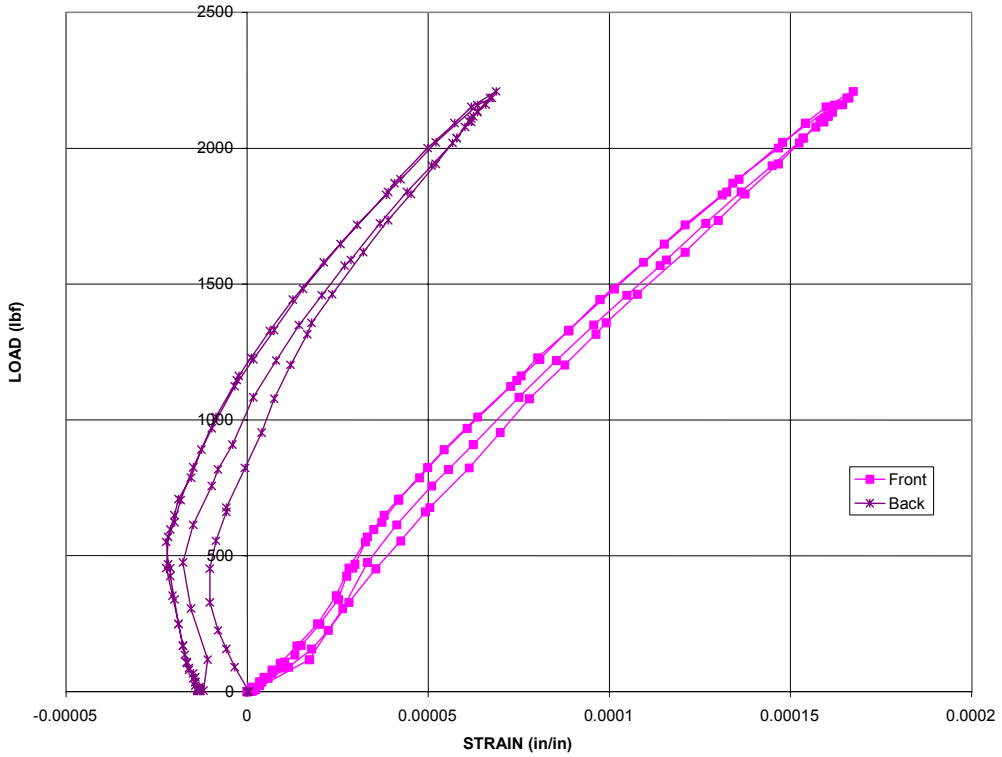

FIGURE F-5. STRAIN GAGE DATA, SCG-1s, 0 CYCLES NEW

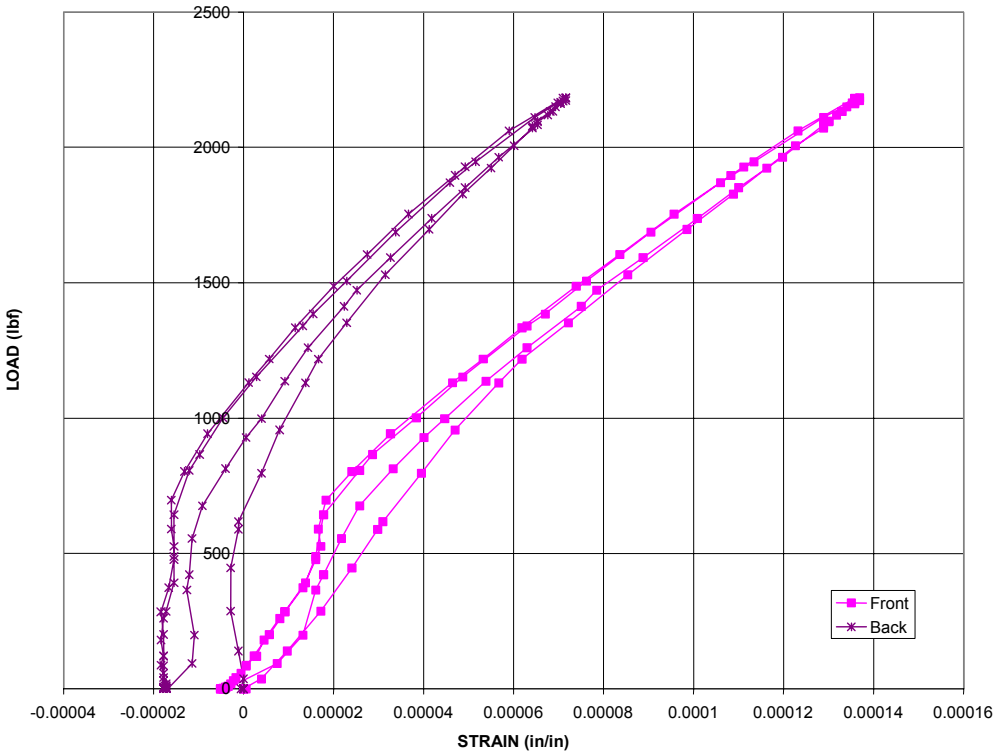

FIGURE F-6. STRAIN GAGE DATA, SCG-1s, 2200 CYCLES AFTER INSPECTION

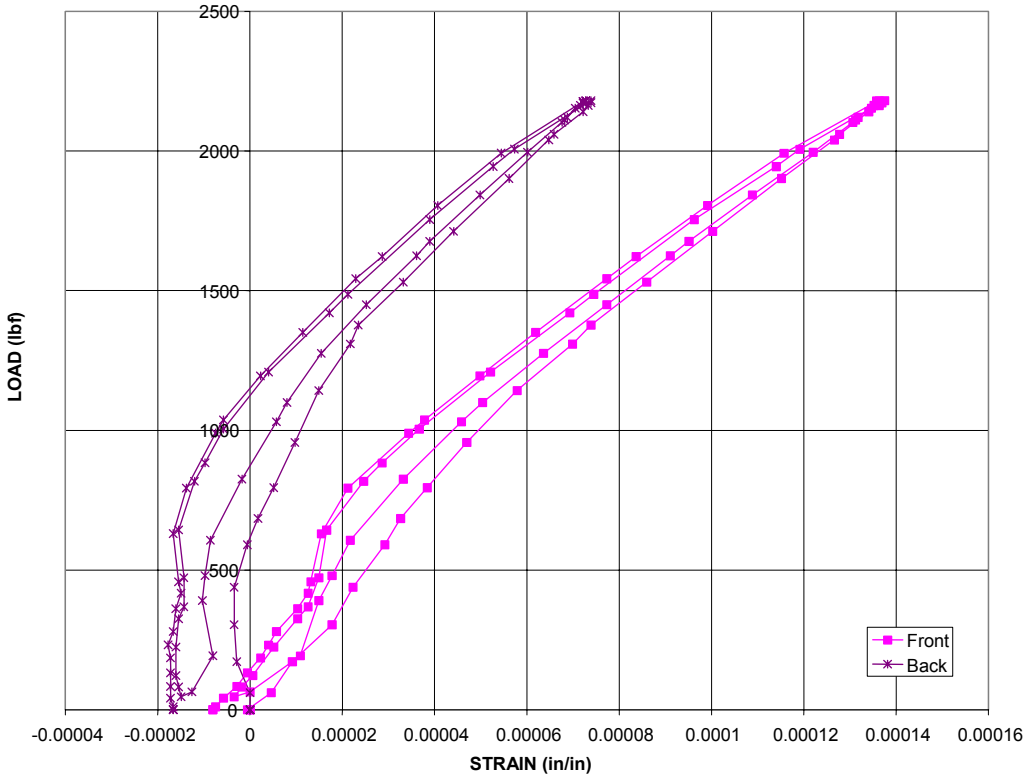

FIGURE F-7. STRAIN GAGE DATA, SCG-1s, 4200 CYCLES

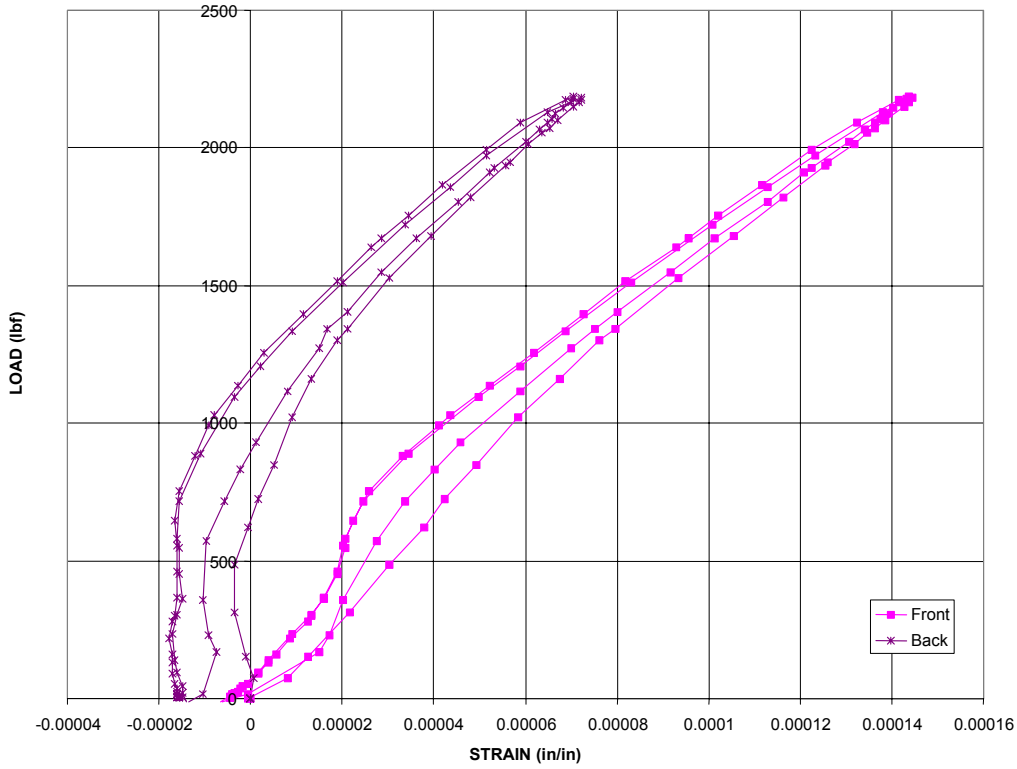

FIGURE F-8. STRAIN GAGE DATA, SCG-1s, 9400 CYCLES

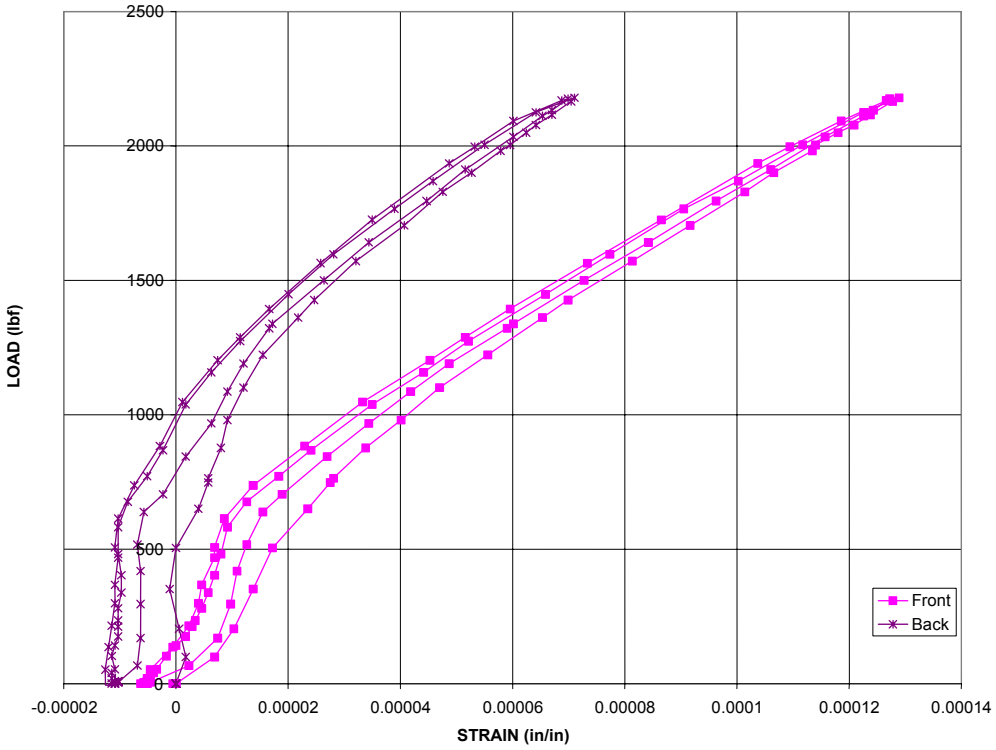

FIGURE F-9. STRAIN GAGE DATA, SCG-1s, 19,800 CYCLES

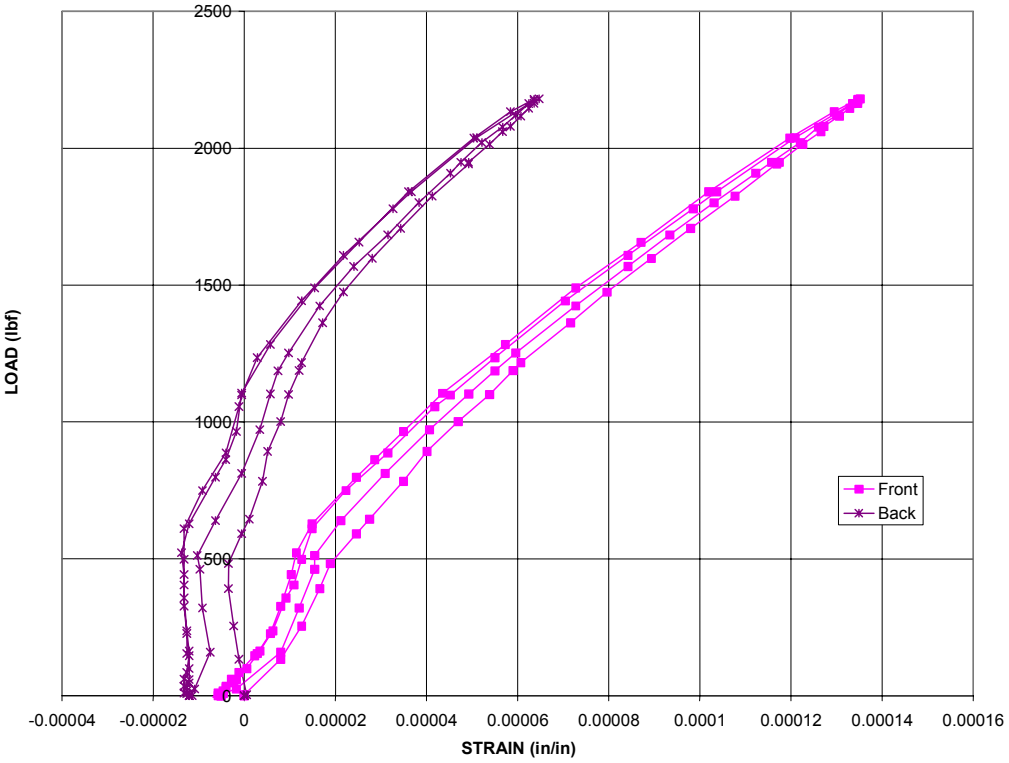

FIGURE F-10. STRAIN GAGE DATA, SCG-1s, 25,800 CYCLES

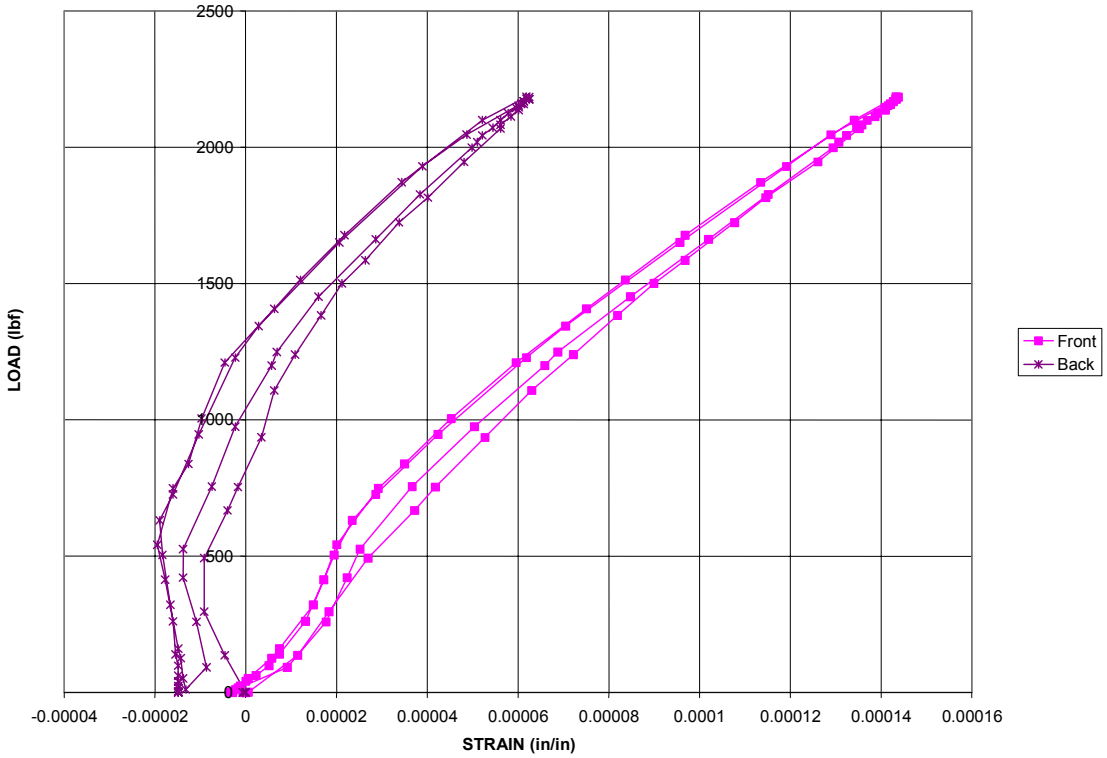

FIGURE F-11. STRAIN GAGE DATA, SCG-1s, 31,800 CYCLES

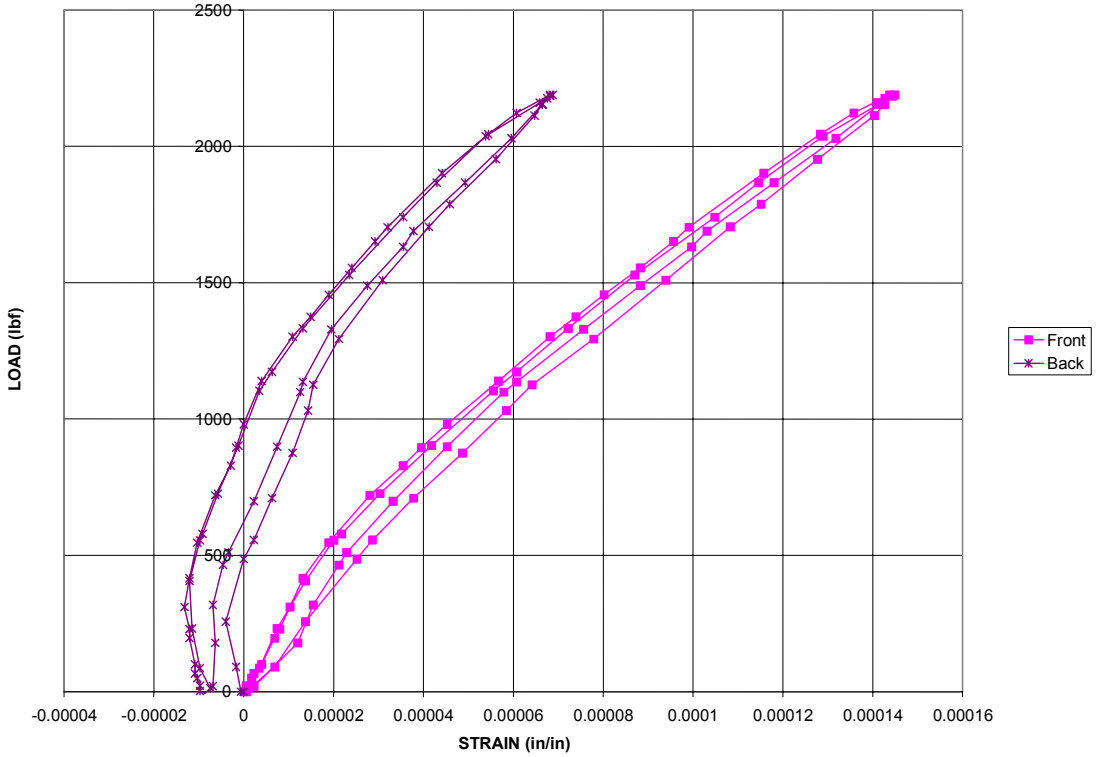

FIGURE F-12. STRAIN GAGE DATA, SCG-1s, 37,800 CYCLES

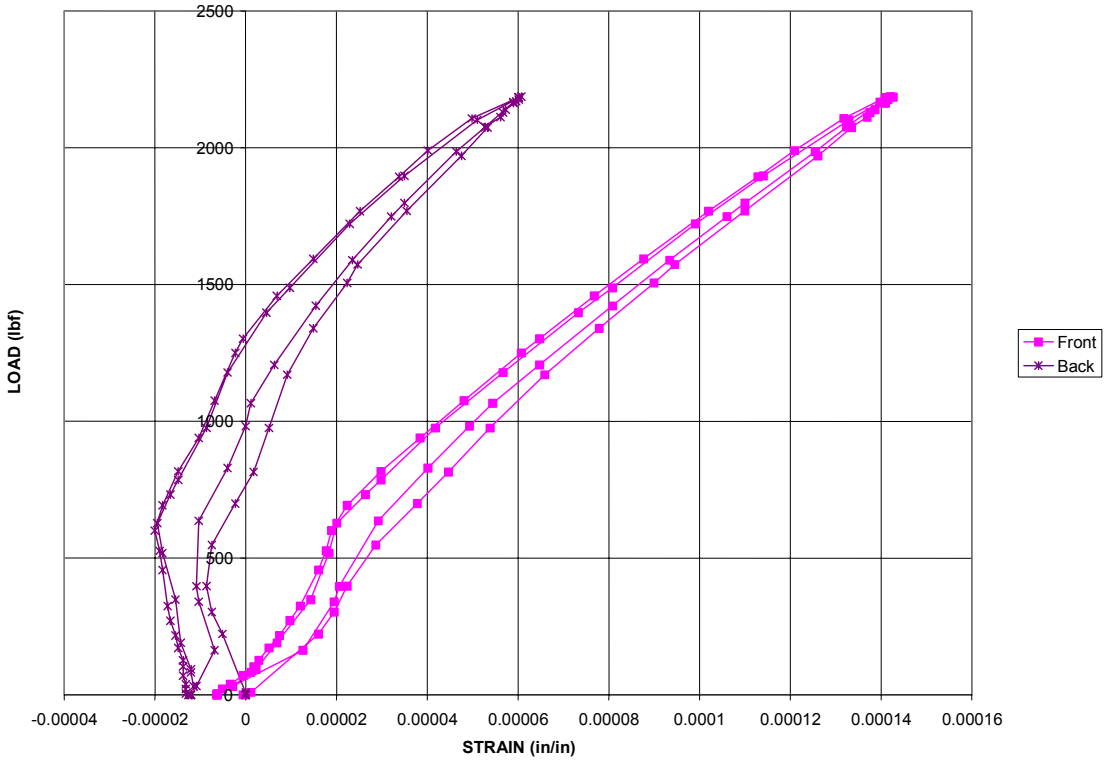

FIGURE F-13. STRAIN GAGE DATA, SCG-1s, 43,800 CYCLES

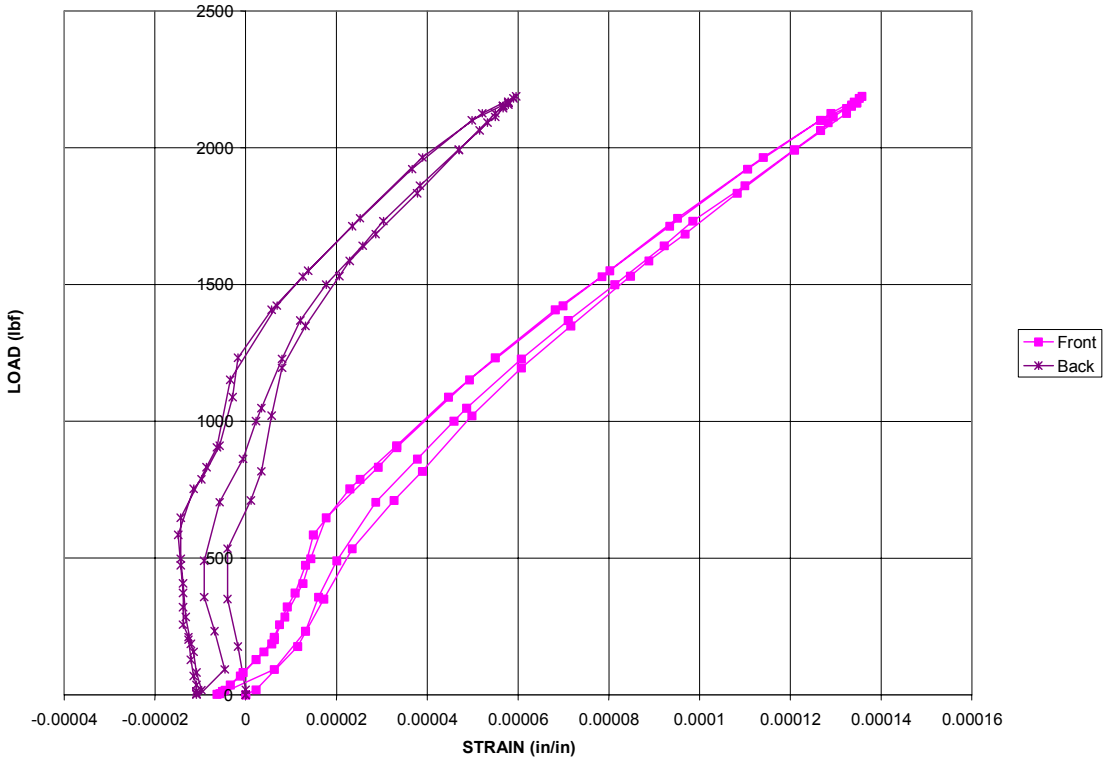

FIGURE F-14. STRAIN GAGE DATA, SCG-1s, 51,800 CYCLES

F.3 SPECIMEN SCG-2 STRAIN GAGE DATA.

Specimen SCG-2 has 0.063″ aluminum doublers and was cycled at a constant amplitude of 15 ksi, R = 0.1. Strain surveys were taken before and after the specimen was disassembled for periodic inspection, which is noted in the figure title.

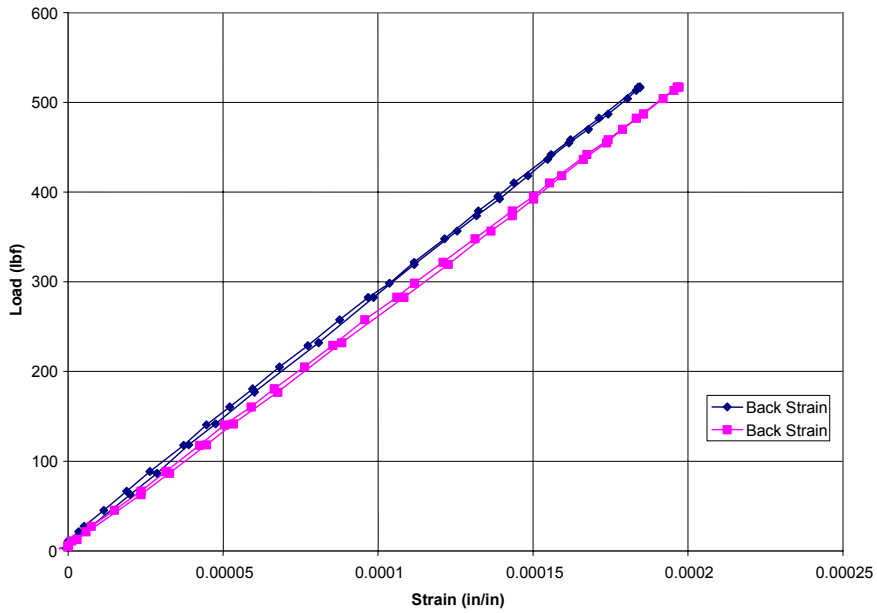

FIGURE F-15. STRAIN GAGE DATA, SCG-2 STRAIN CALIBRATION

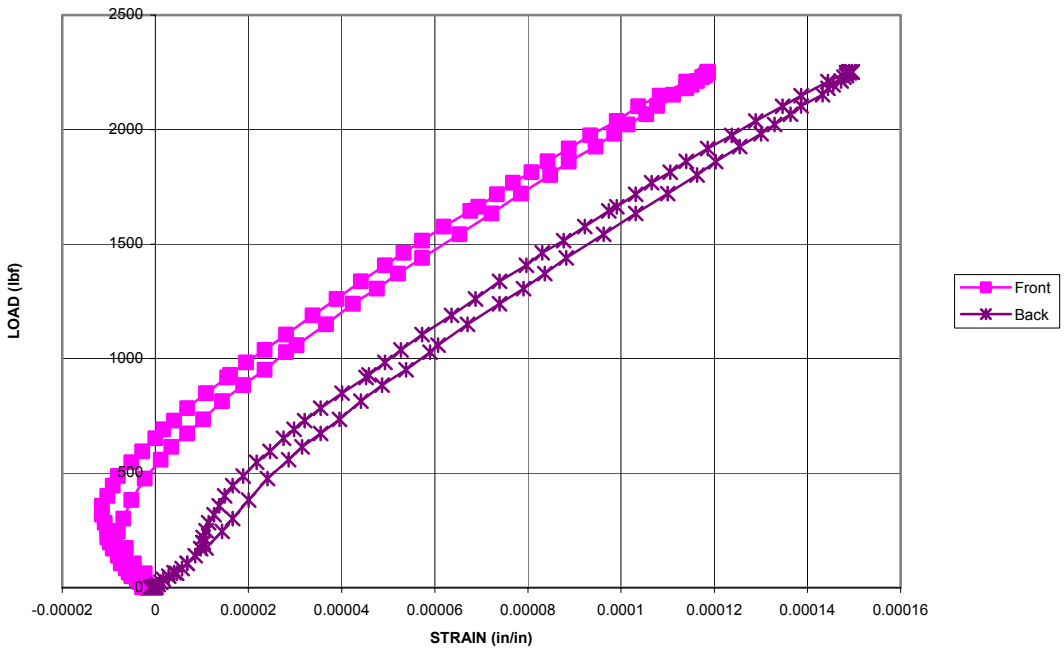

FIGURE F-16. STRAIN GAGE DATA, SCG-2, 12 ksi 0 CYCLES NEW

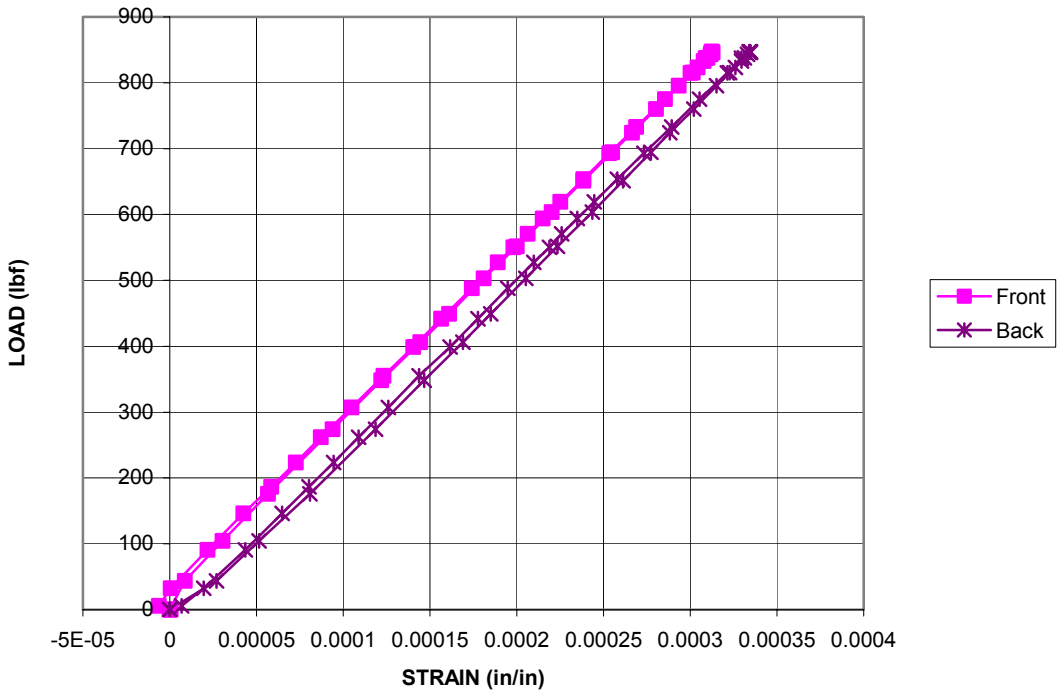

FIGURE F-17. STRAIN GAGE DATA, SCG-2 CALIBRATION #2

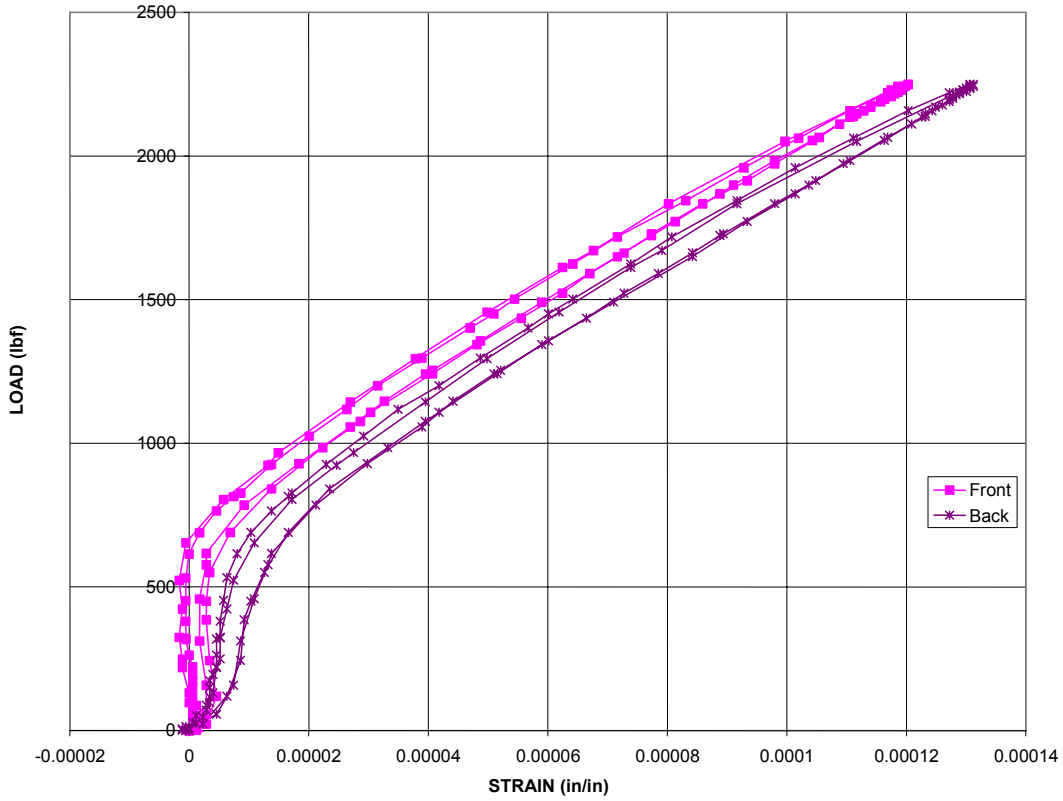

FIGURE F-18. STRAIN GAGE DATA, SCG-2, 2000 CYCLES AFTER

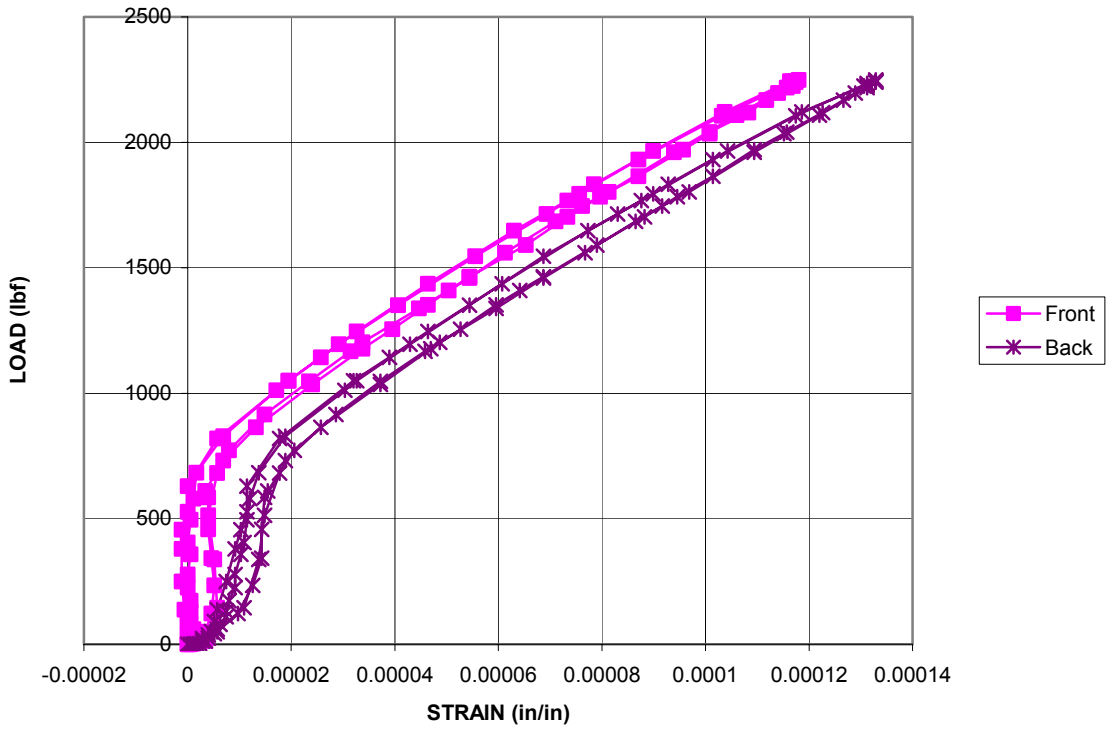

FIGURE F-19. STRAIN GAGE DATA, SCG-2, 4000 CYCLES BEFORE

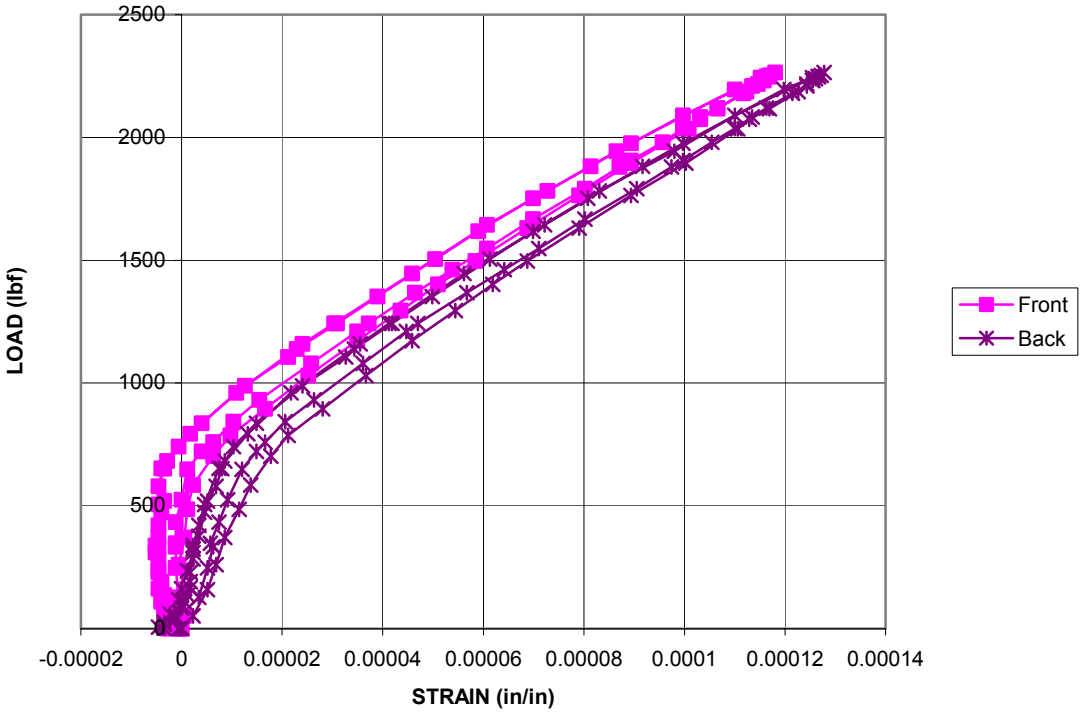

FIGURE F-20. STRAIN GAGE DATA, SCG-2, 4000 CYCLES AFTER

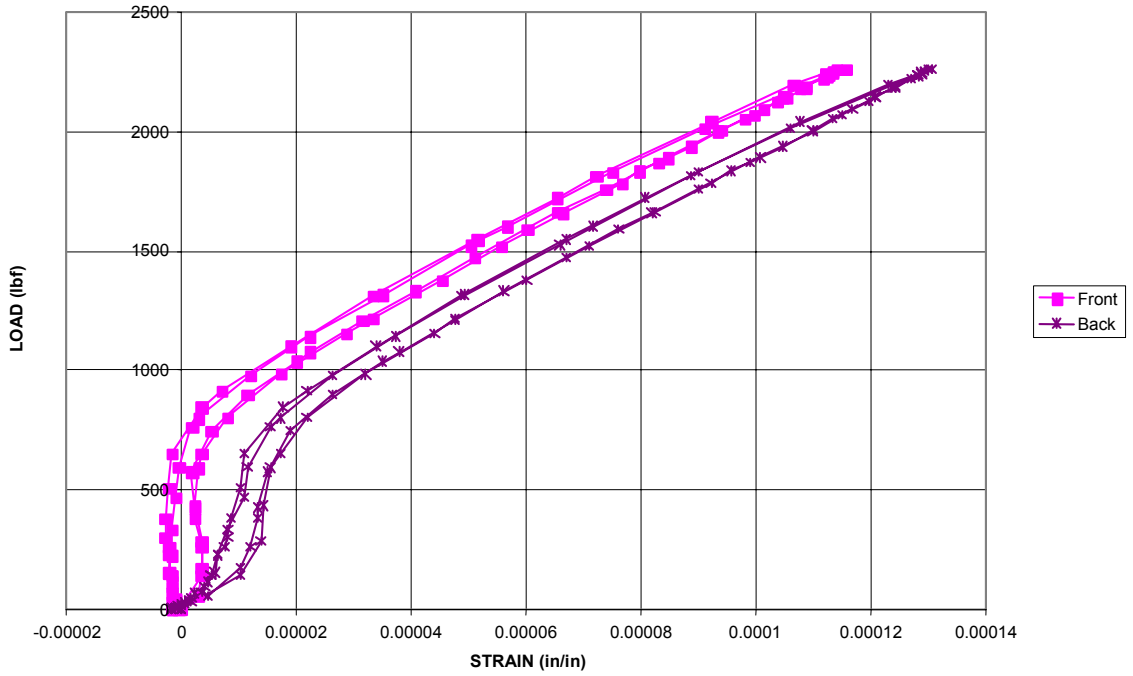

FIGURE F-21. STRAIN GAGE DATA, SCG-2, 6000 CYCLES BEFORE

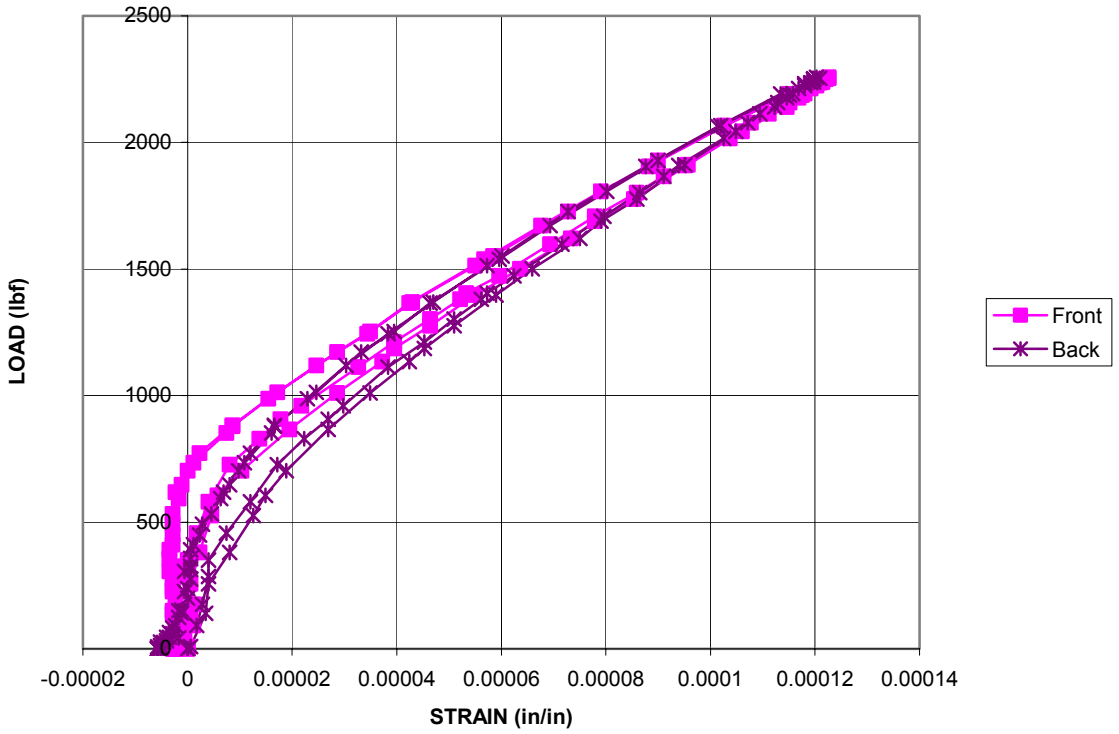

FIGURE F-22. STRAIN GAGE DATA, SCG-2, 6000 CYCLES AFTER

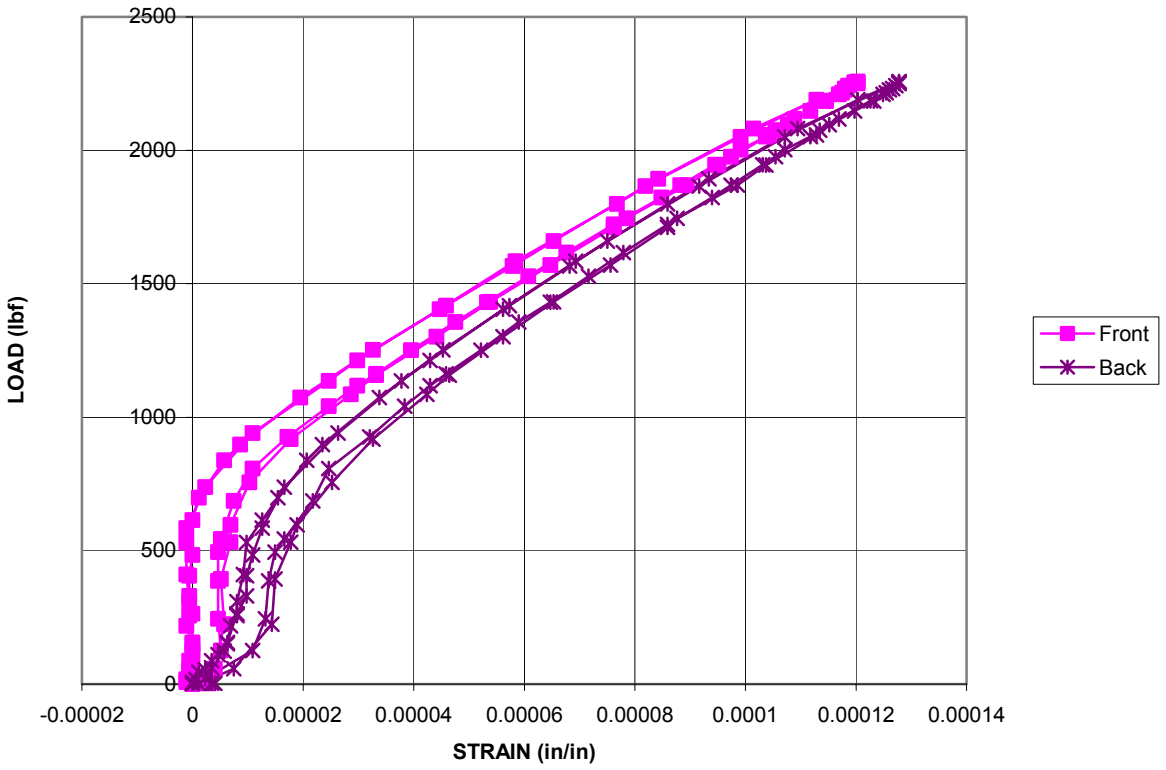

FIGURE F-23. STRAIN GAGE DATA, SCG-2, 8000 CYCLES BEFORE

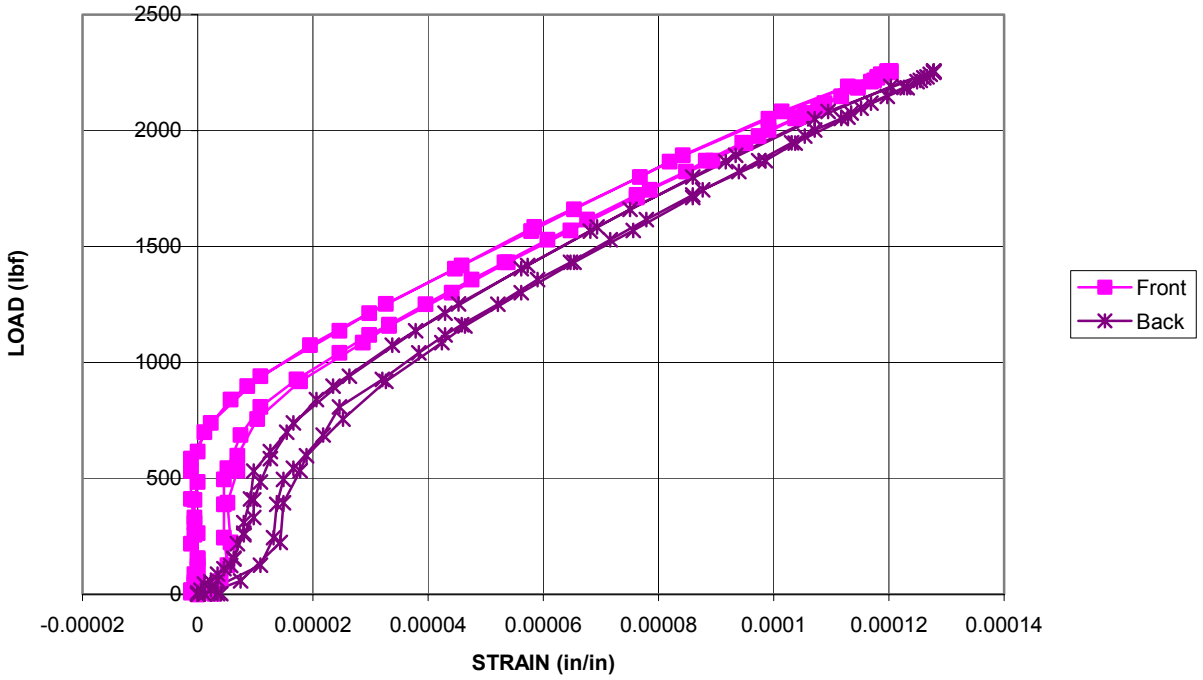

FIGURE F-24. STRAIN GAGE DATA, SCG-2, 8000 CYCLES AFTER

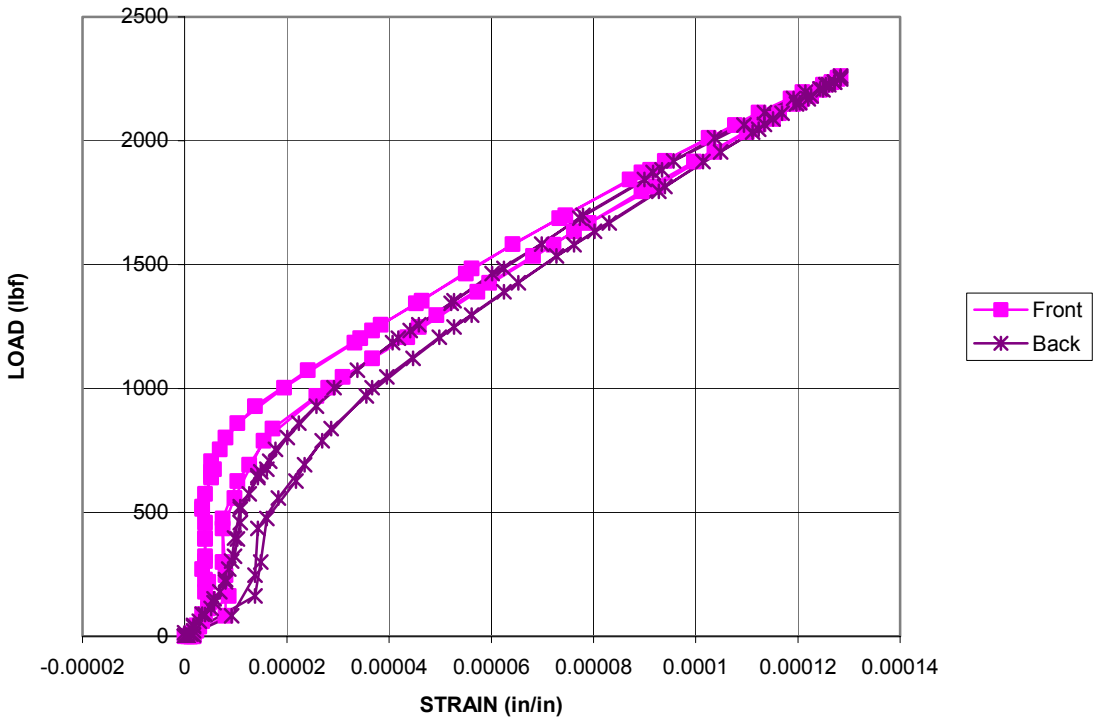

FIGURE F-25. STRAIN GAGE DATA, SCG-2, 10,000 CYCLES BEFORE

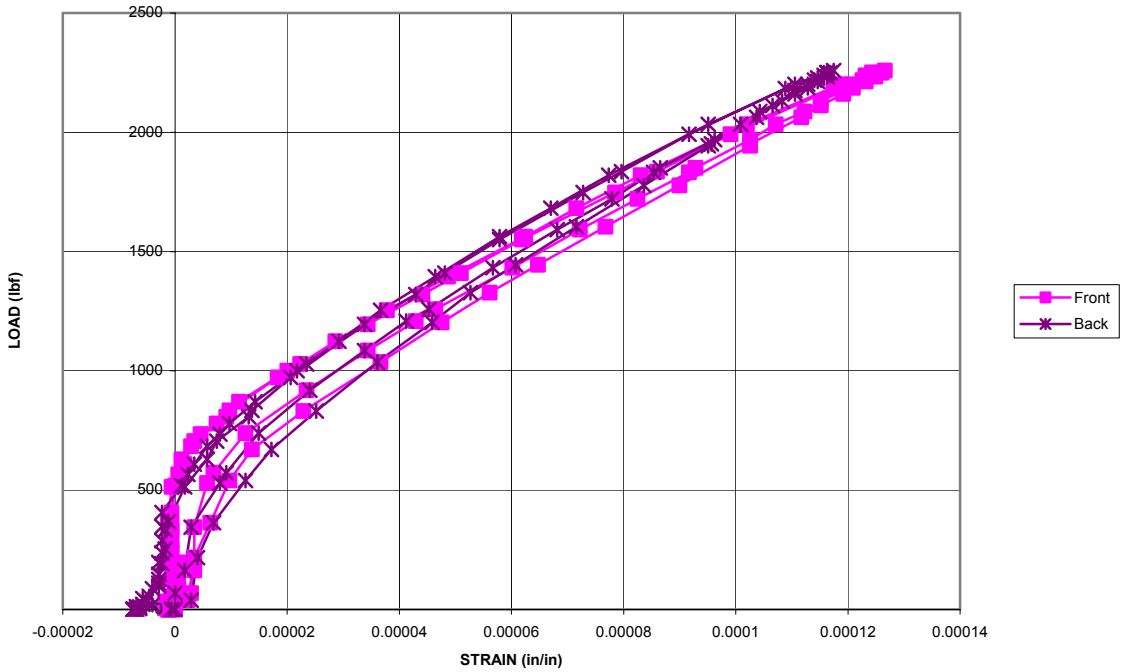

FIGURE F-26. STRAIN GAGE DATA, SCG-2, 10,000 CYCLES AFTER

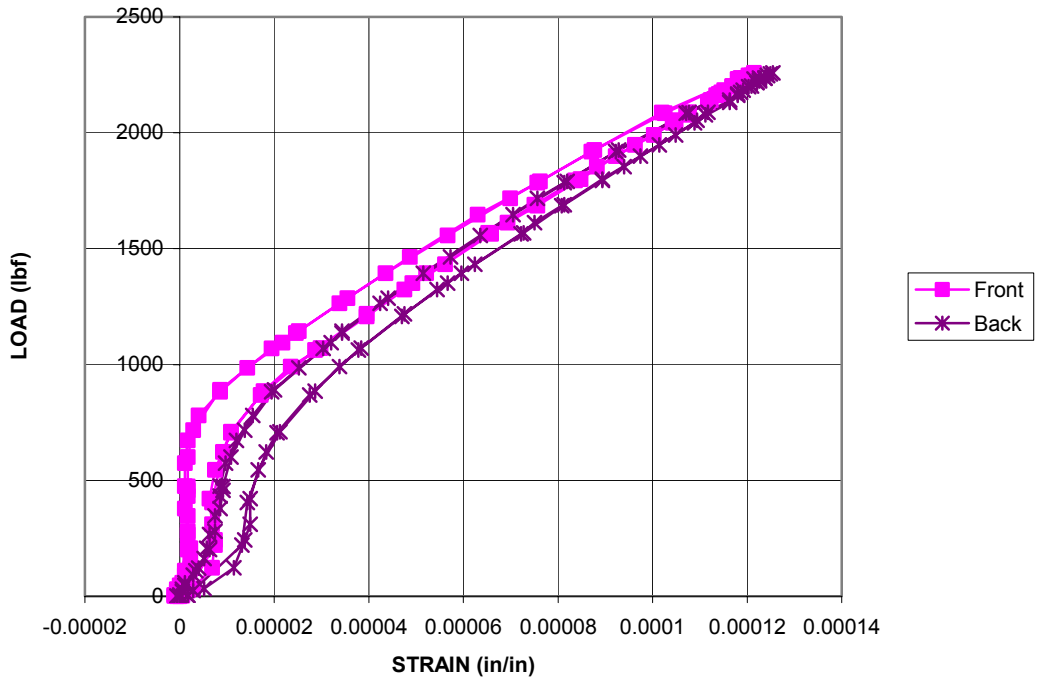

FIGURE F-27. STRAIN GAGE DATA, SCG-2, 12,000 CYCLES BEFORE

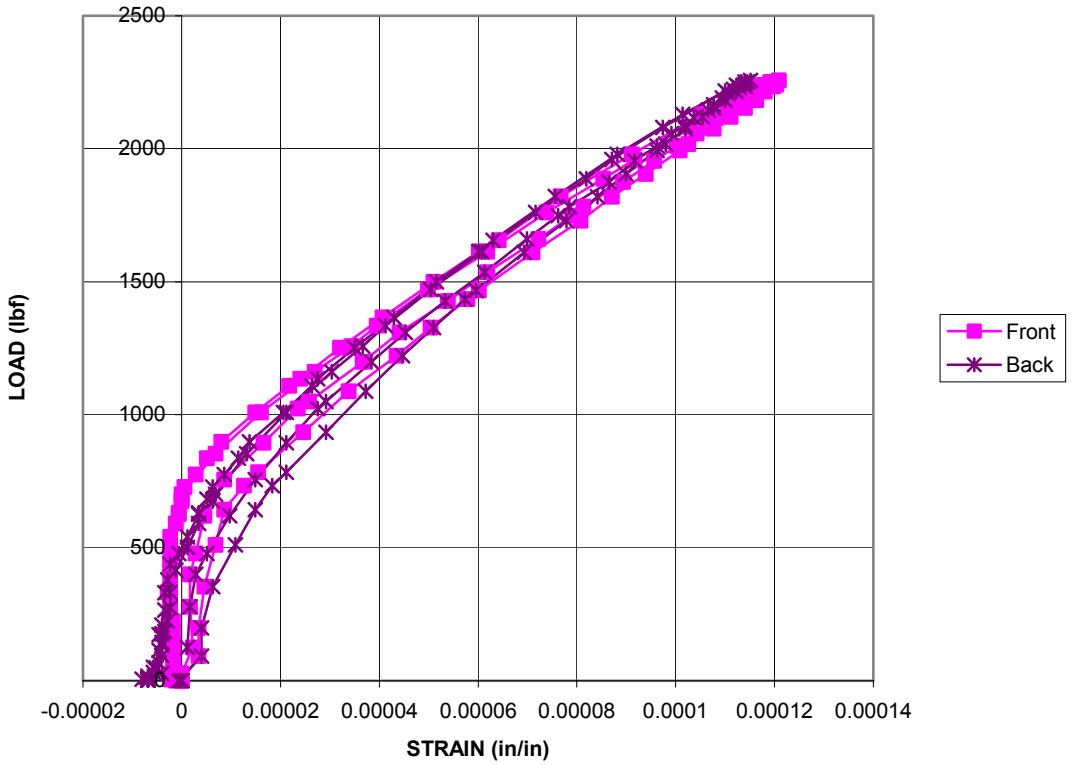

FIGURE F-28. STRAIN GAGE DATA, SCG-2, 12,000 CYCLES AFTER

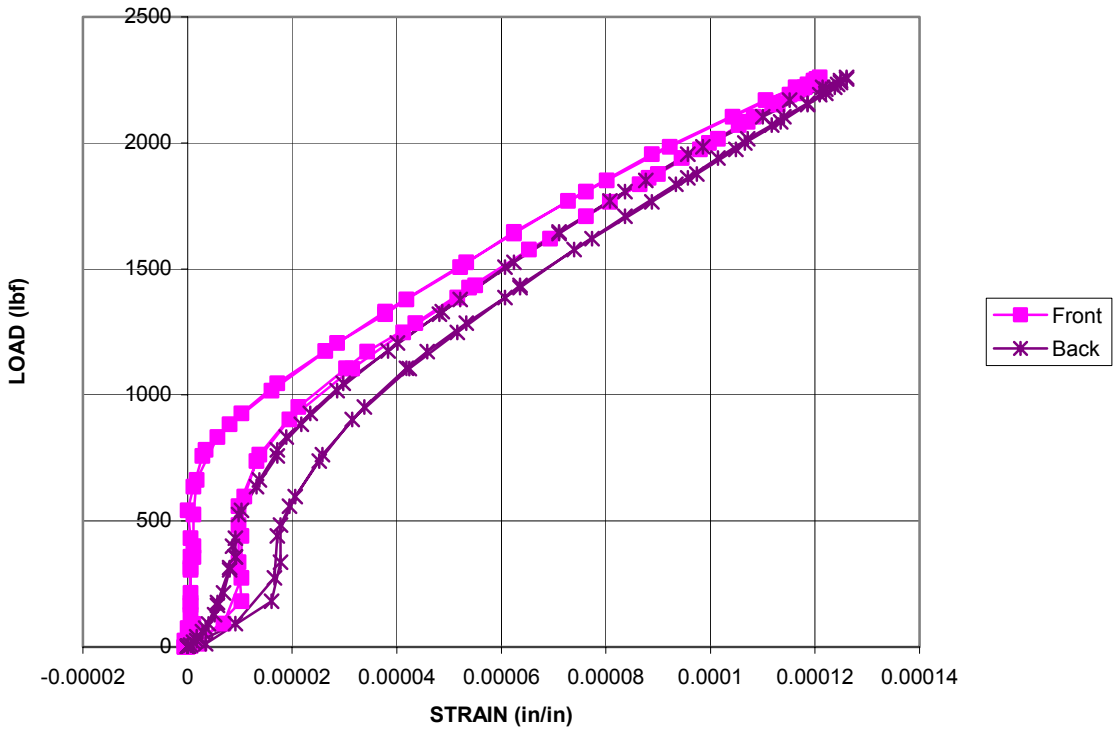

FIGURE F-29. STRAIN GAGE DATA, SCG-2, 14,000 CYCLES BEFORE

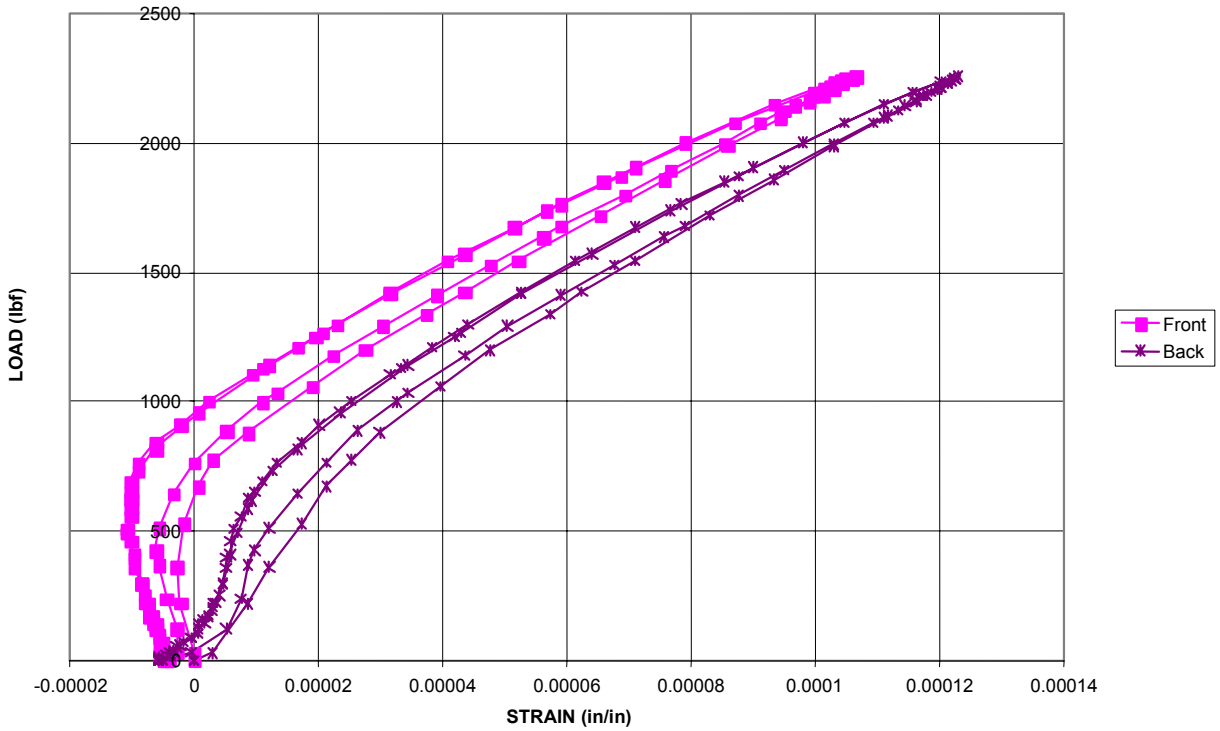

FIGURE F-30. STRAIN GAGE DATA, SCG-2, 14,000 CYCLES AFTER

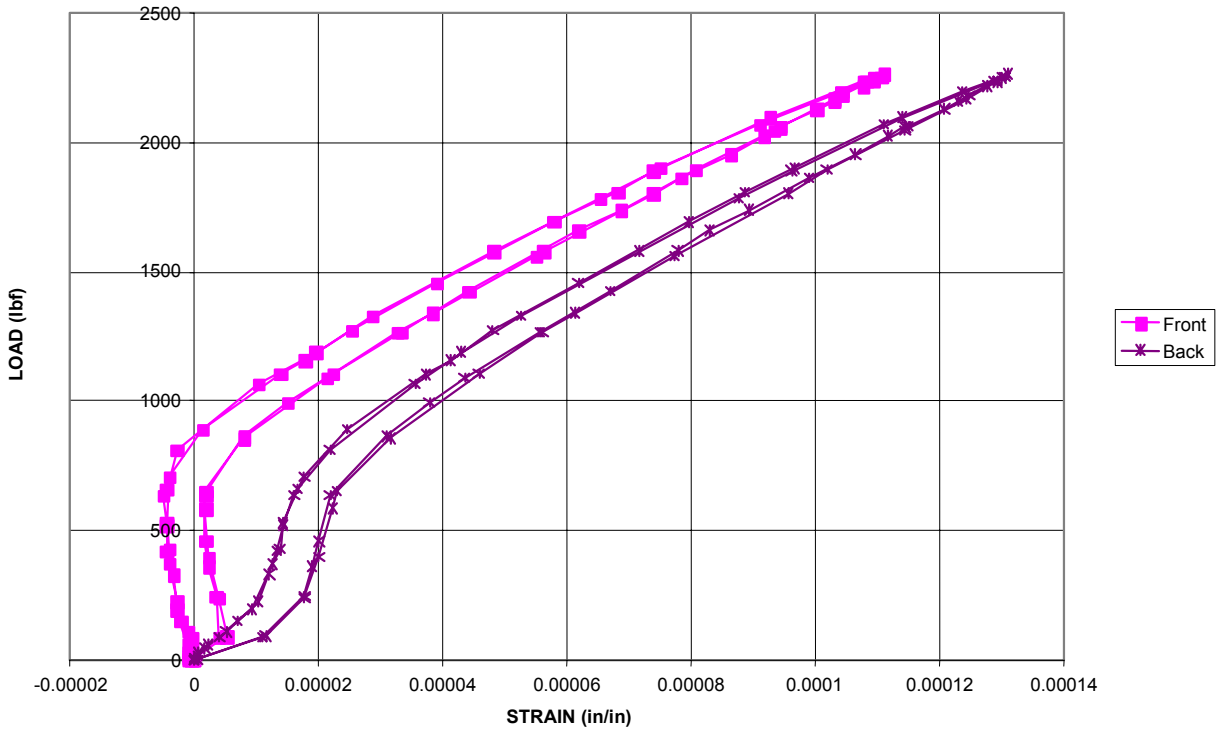

FIGURE F-31. STRAIN GAGE DATA, SCG-2, 20,000 CYCLES BEFORE

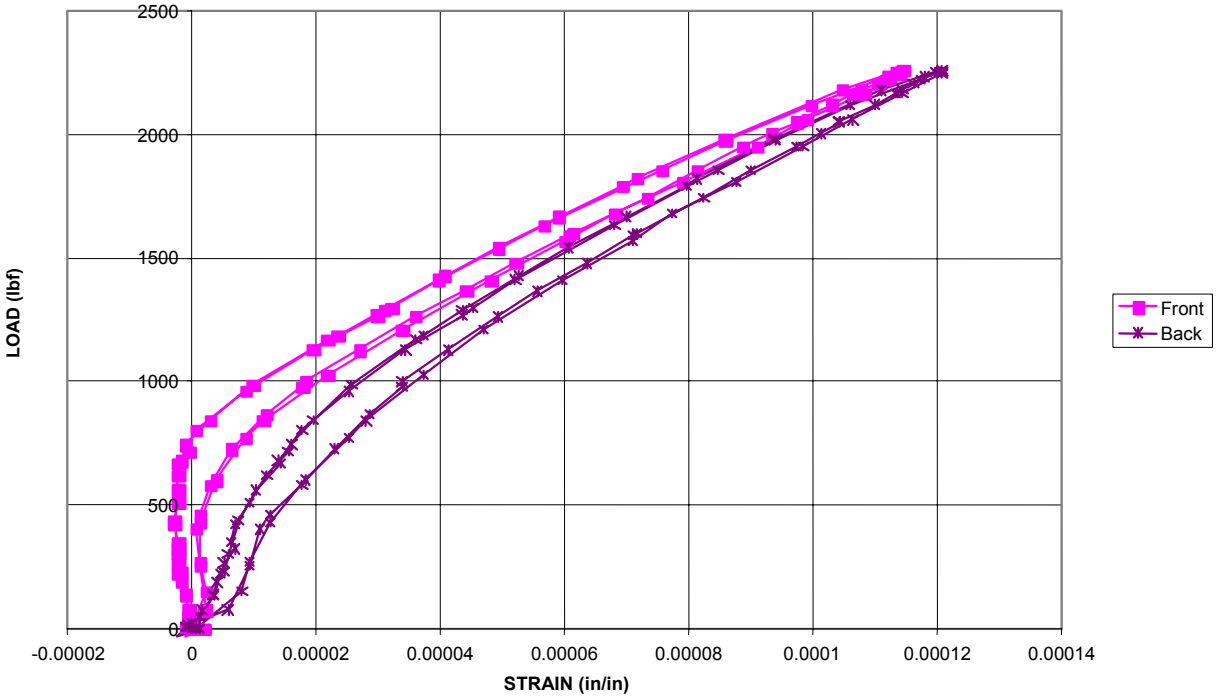

FIGURE F-32. STRAIN GAGE DATA, SCG-2, 20,000 CYCLES AFTER

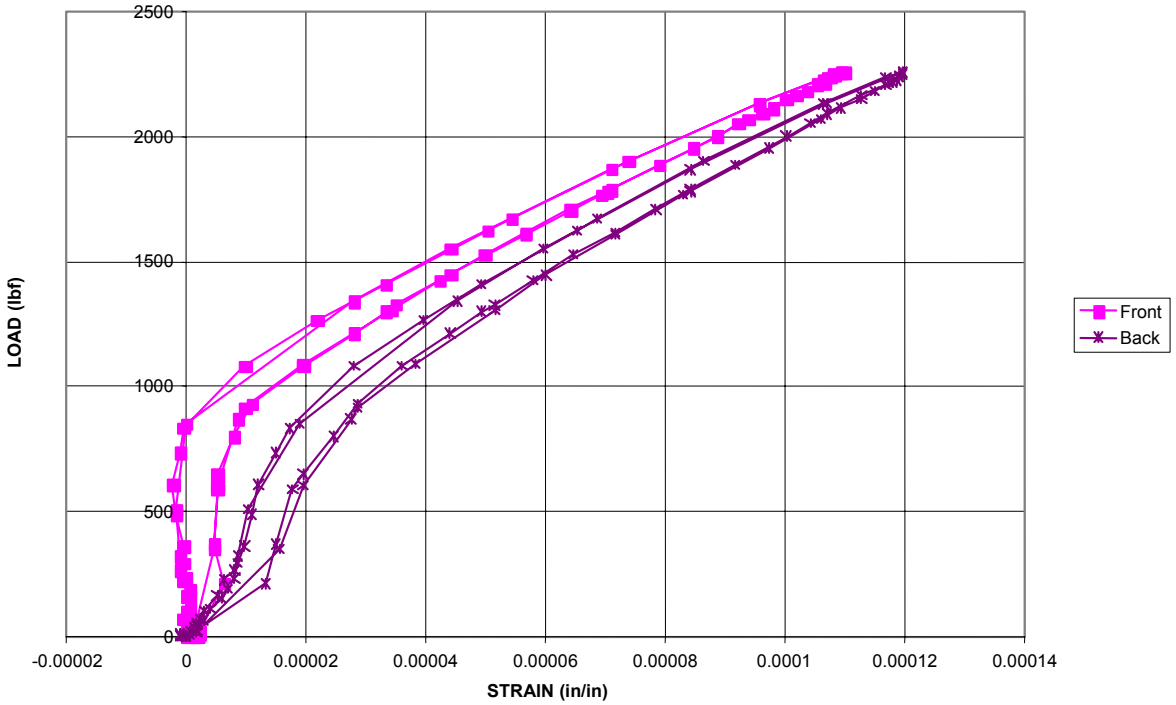

FIGURE F-33. STRAIN GAGE DATA, SCG-2, 26,000 CYCLES BEFORE

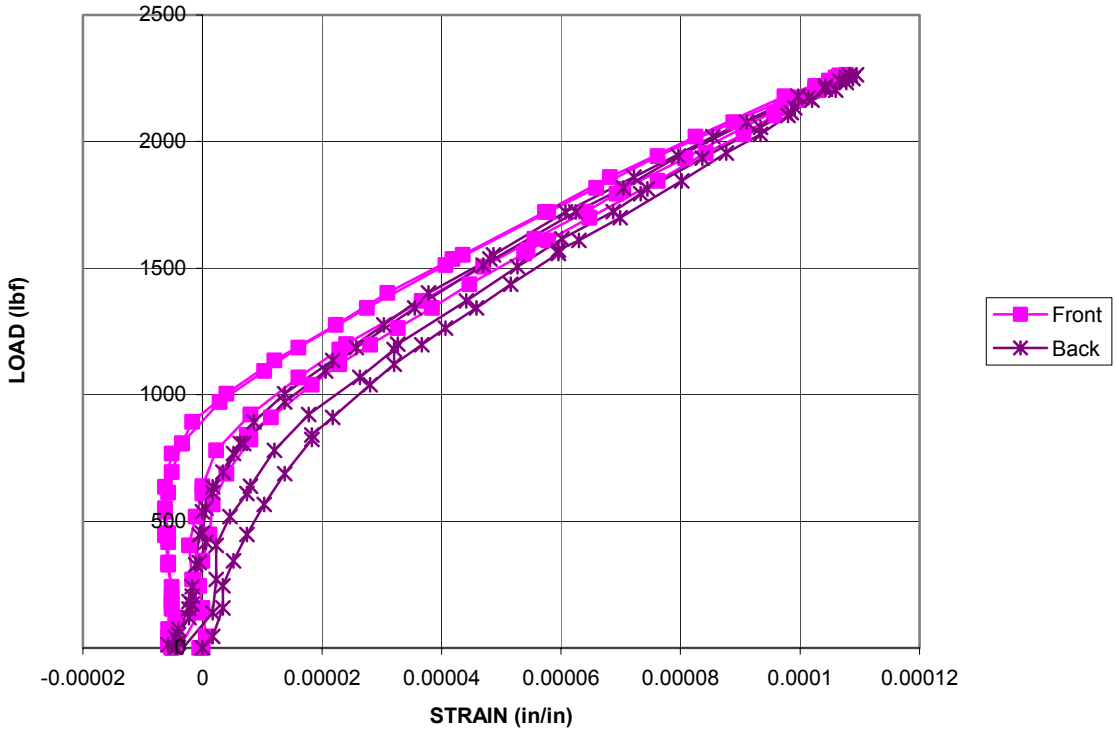

FIGURE F-34. STRAIN GAGE DATA, SCG-1, 26,000 CYCLES AFTER

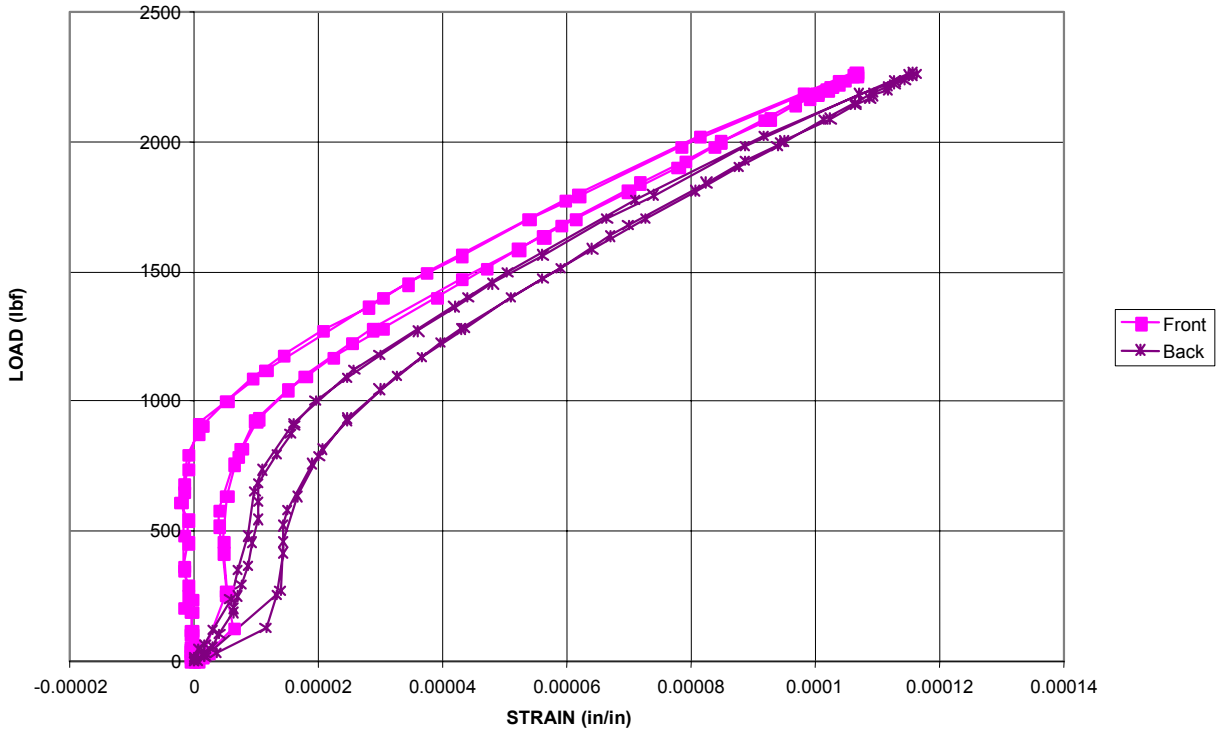

FIGURE F-35. STRAIN GAGE DATA, SCG-2, 32,000 CYCLES BEFORE

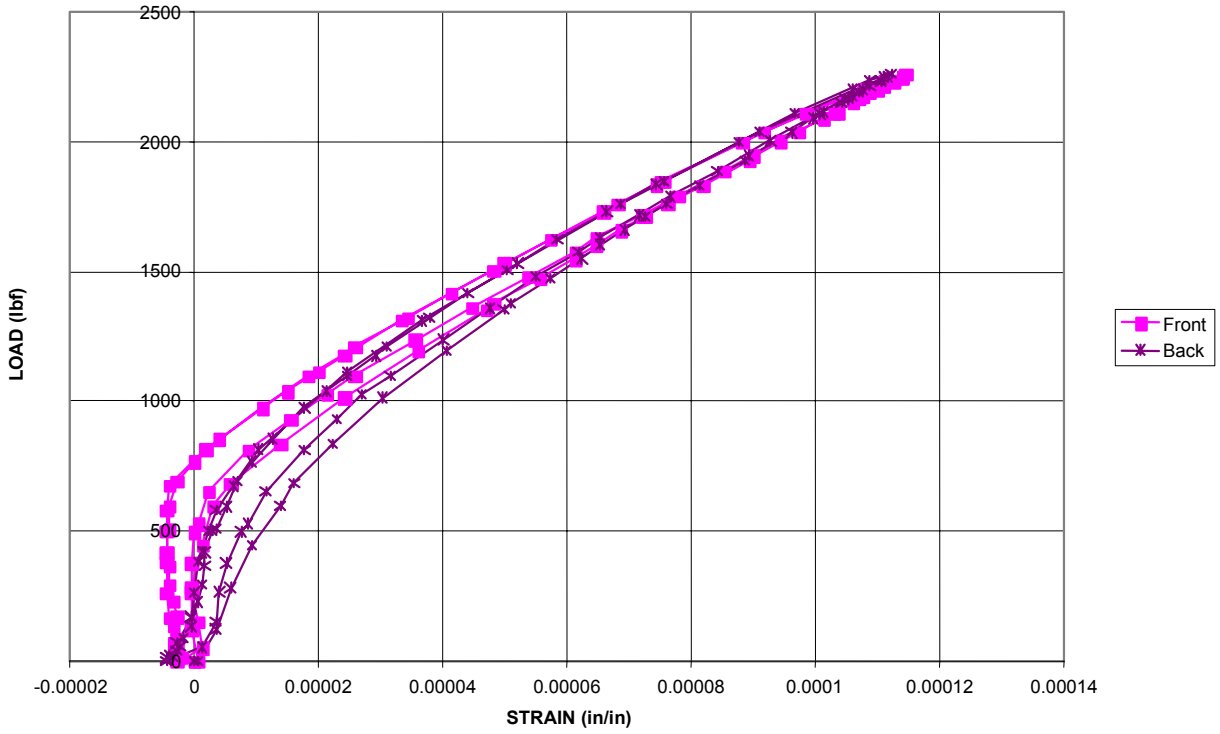

FIGURE F-36. STRAIN GAGE DATA, SCG-2, 32,000 CYCLES AFTER

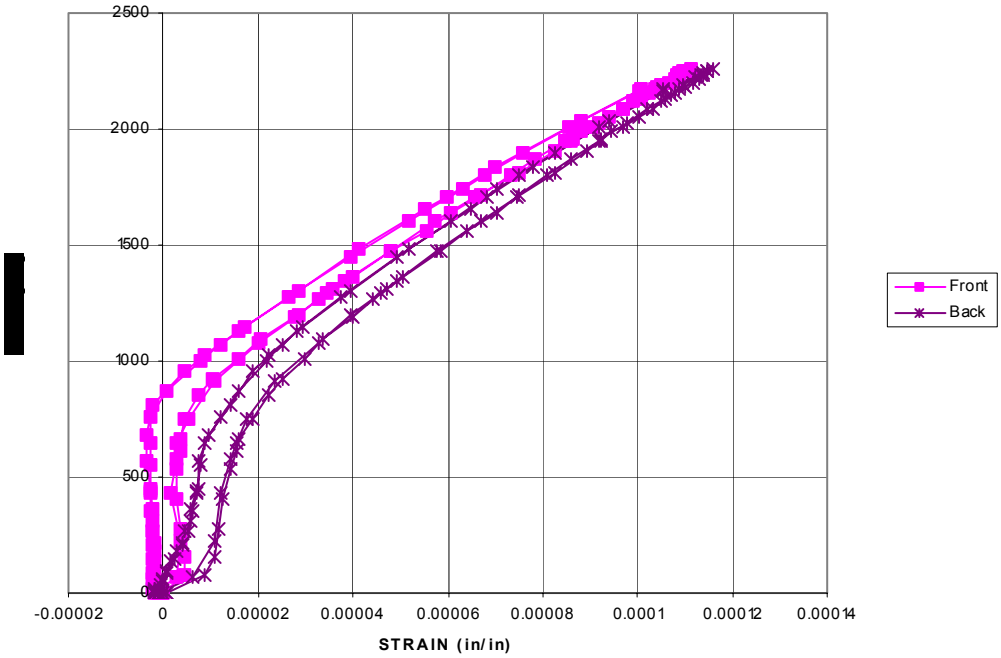

FIGURE F-37. STRAIN GAGE DATA, SCG-2, 38,000 CYCLES BEFORE

F.4 SPECIMEN SCG-5 STRAIN GAGE DATA.

Specimen SCG-5 has 0.063″ aluminum doublers and was cycled at a constant amplitude of 15 ksi, R = 0.1. Strain surveys were taken before and after the specimen was disassembled for periodic inspection, which is noted in the figure title.

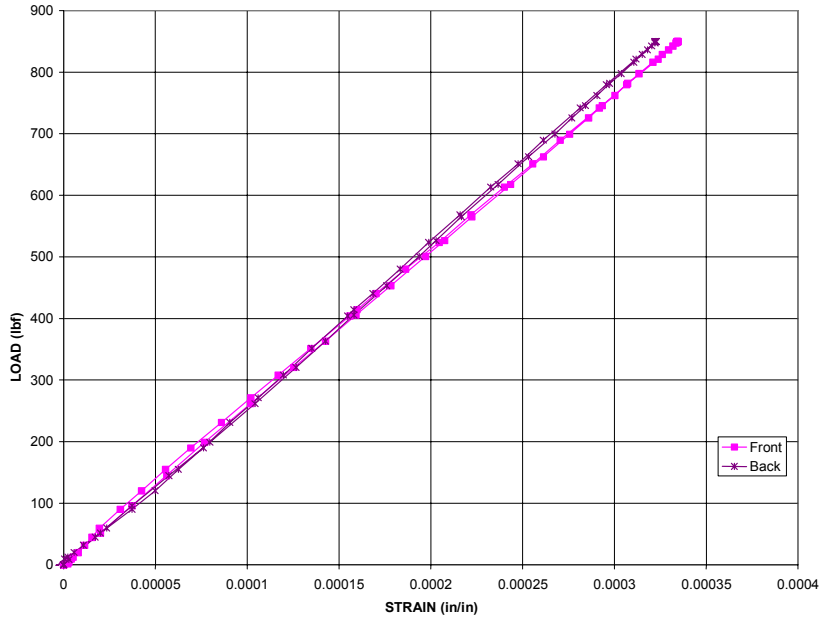

FIGURE F-38. STRAIN GAGE DATA, SCG-5, CALIBRATION #1

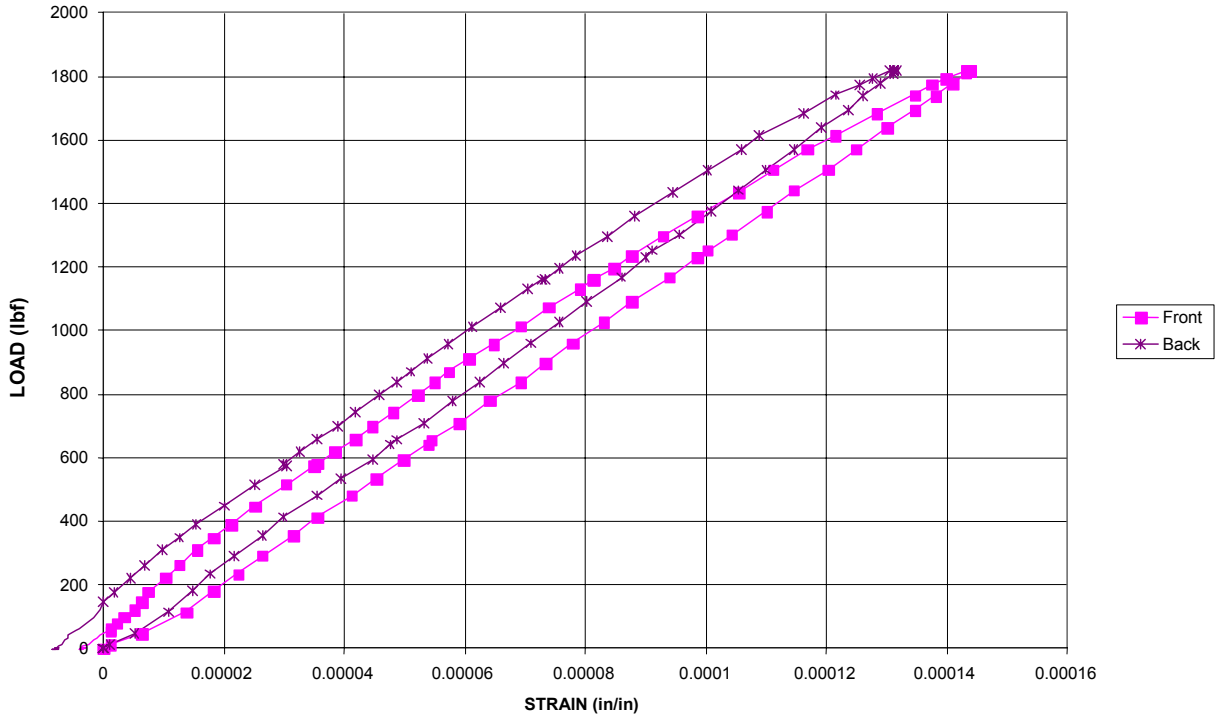

FIGURE F-39. STRAIN GAGE DATA, SCG-5, 0 CYCLES NEW

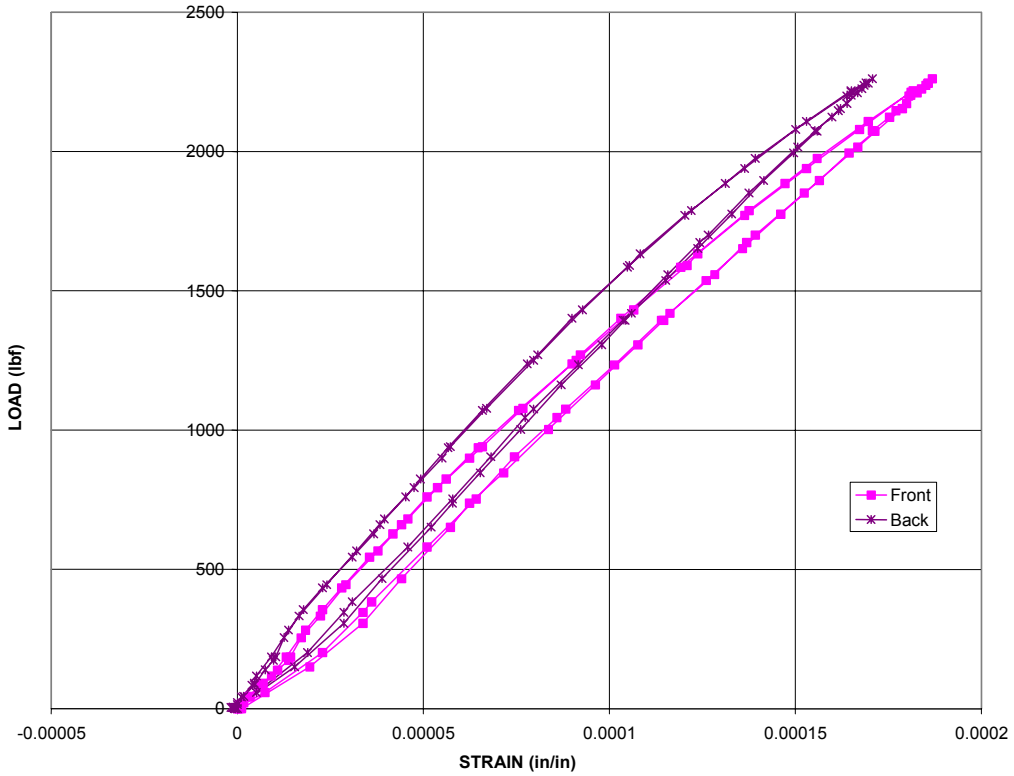

FIGURE F-40. STRAIN GAGE DATA, SCG-5, 500 CYCLES BEFORE

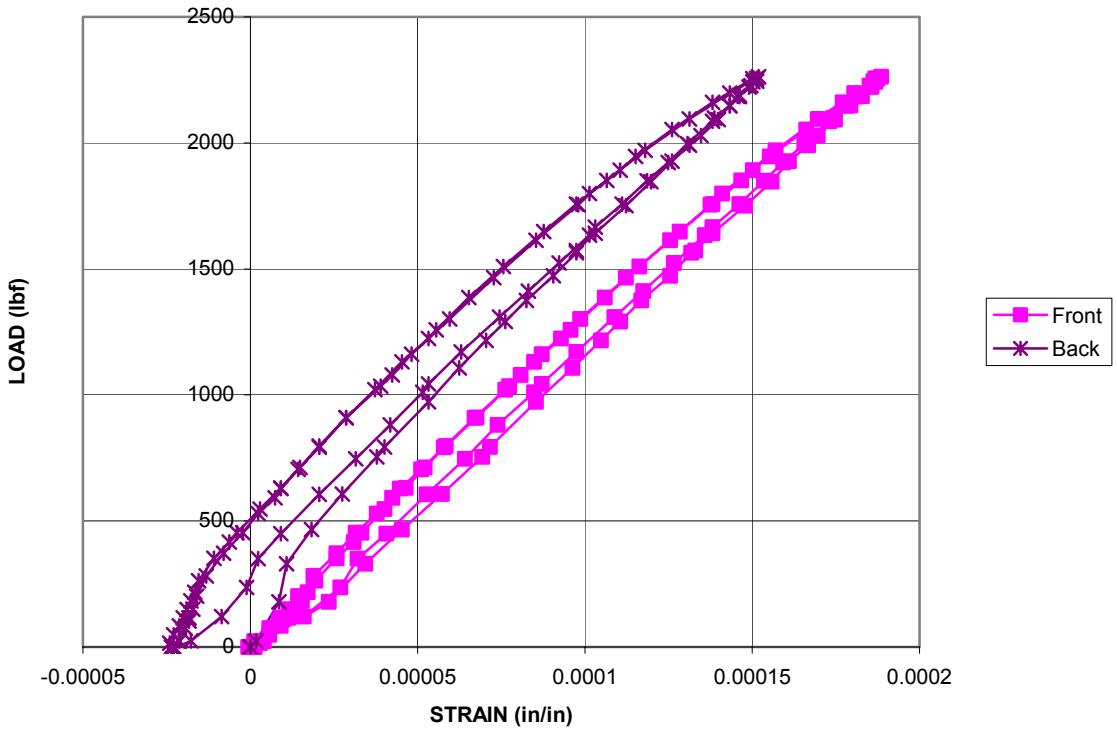

FIGURE F-41. STRAIN GAGE DATA, SCG-5, 500 CYCLES AFTER

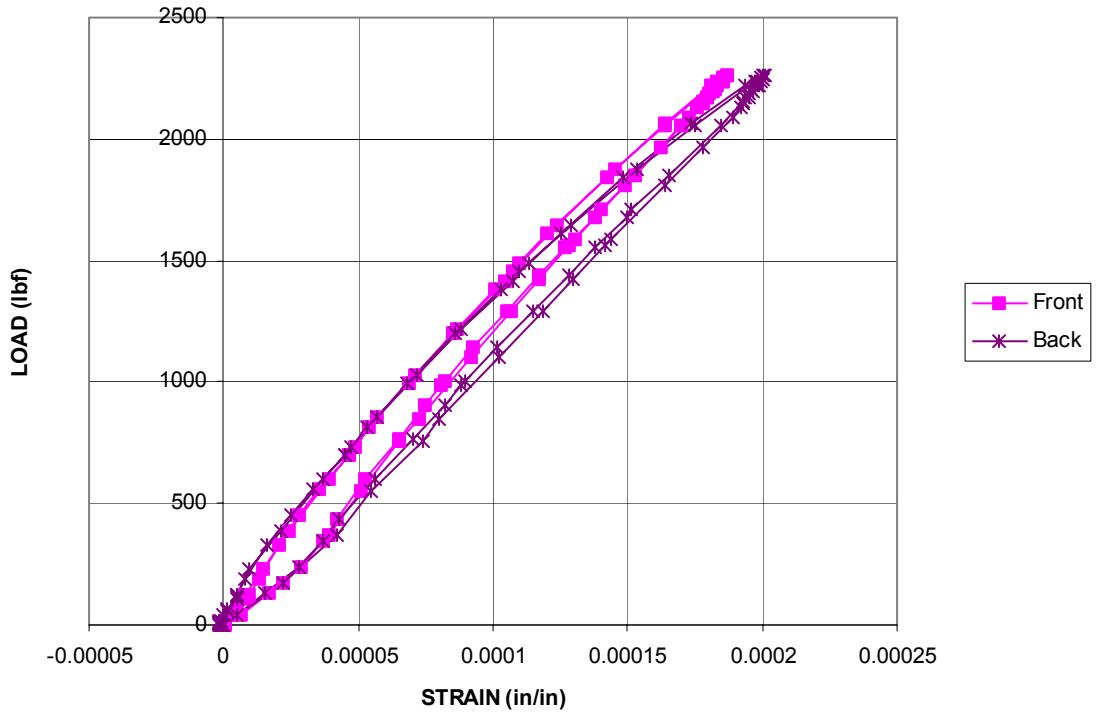

FIGURE F-42. STRAIN GAGE DATA, SCG-5, 5700 CYCLES BEFORE

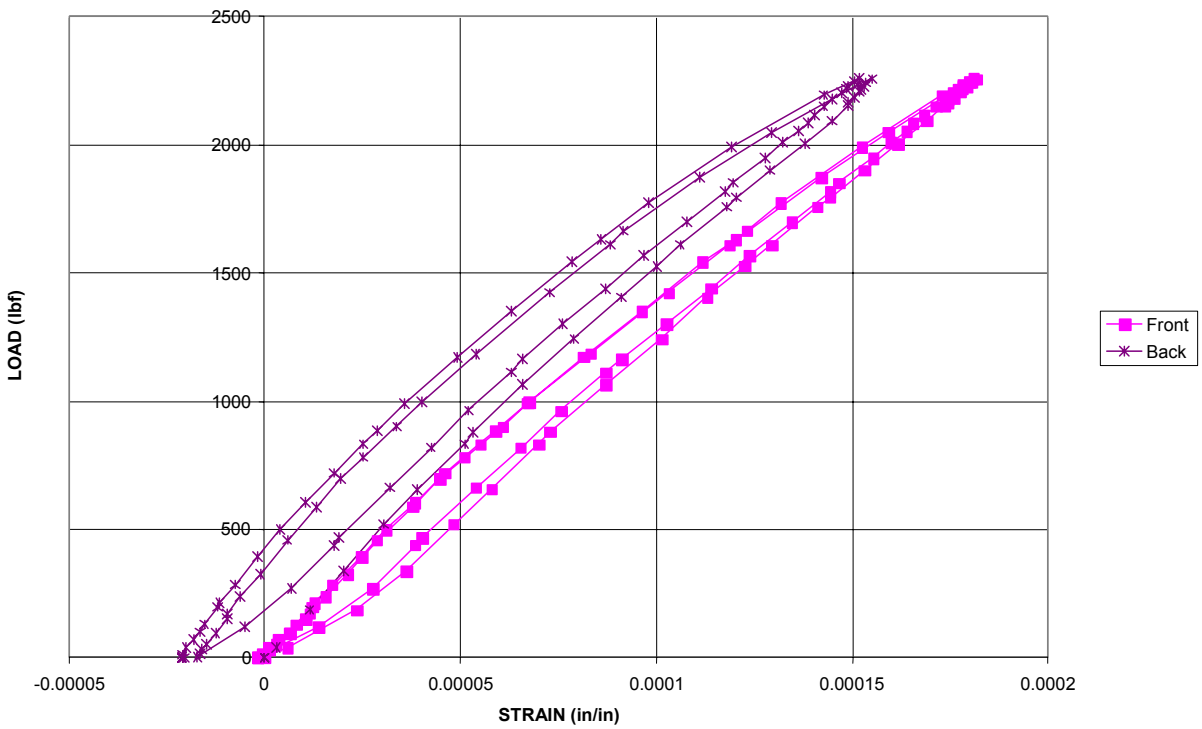

FIGURE F-43. STRAIN GAGE DATA, SCG-5, 5700 CYCLES AFTER

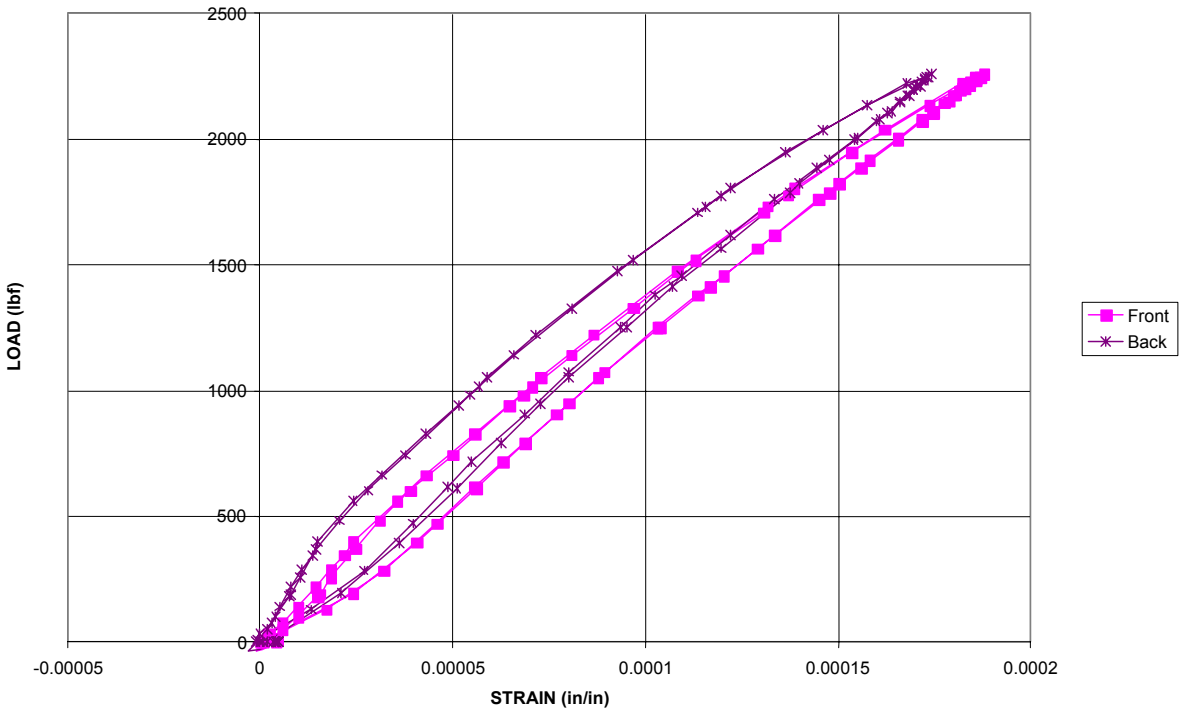

FIGURE F-44. STRAIN GAGE DATA, SCG-5, 10,900 CYCLES BEFORE

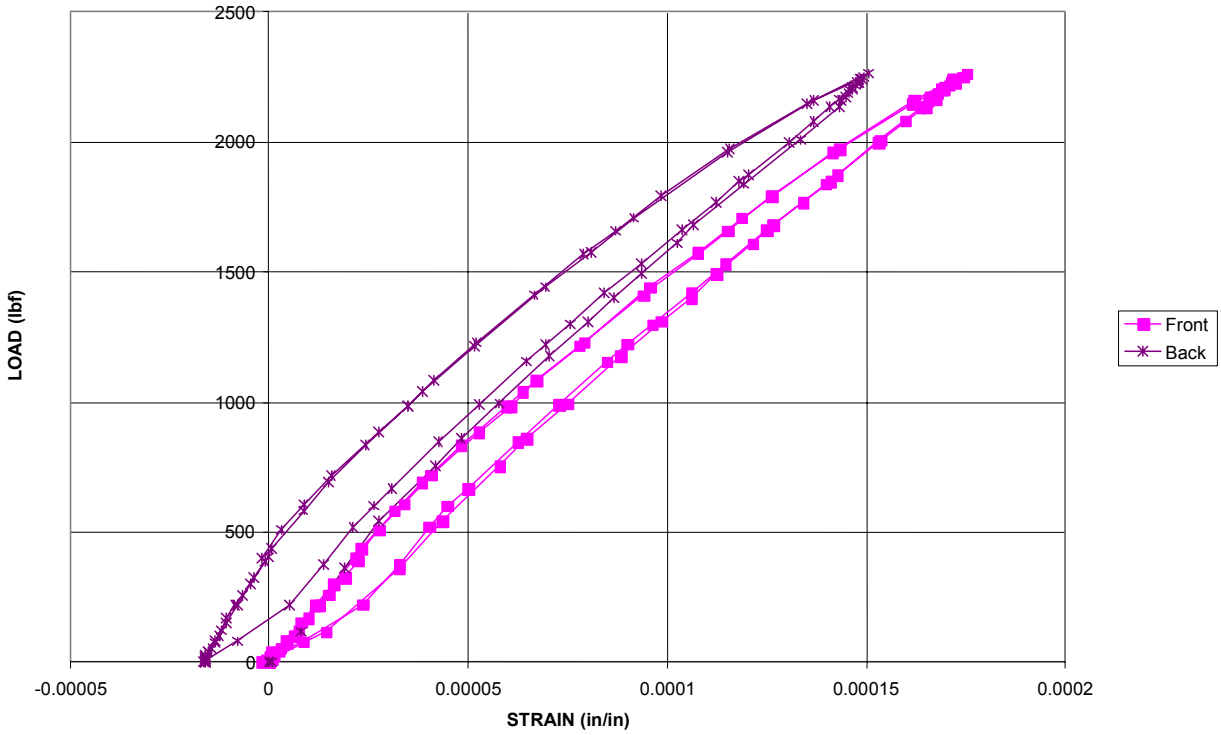

FIGURE F-45. STRAIN GAGE DATA, SCG-5, 10,900 CYCLES AFTER

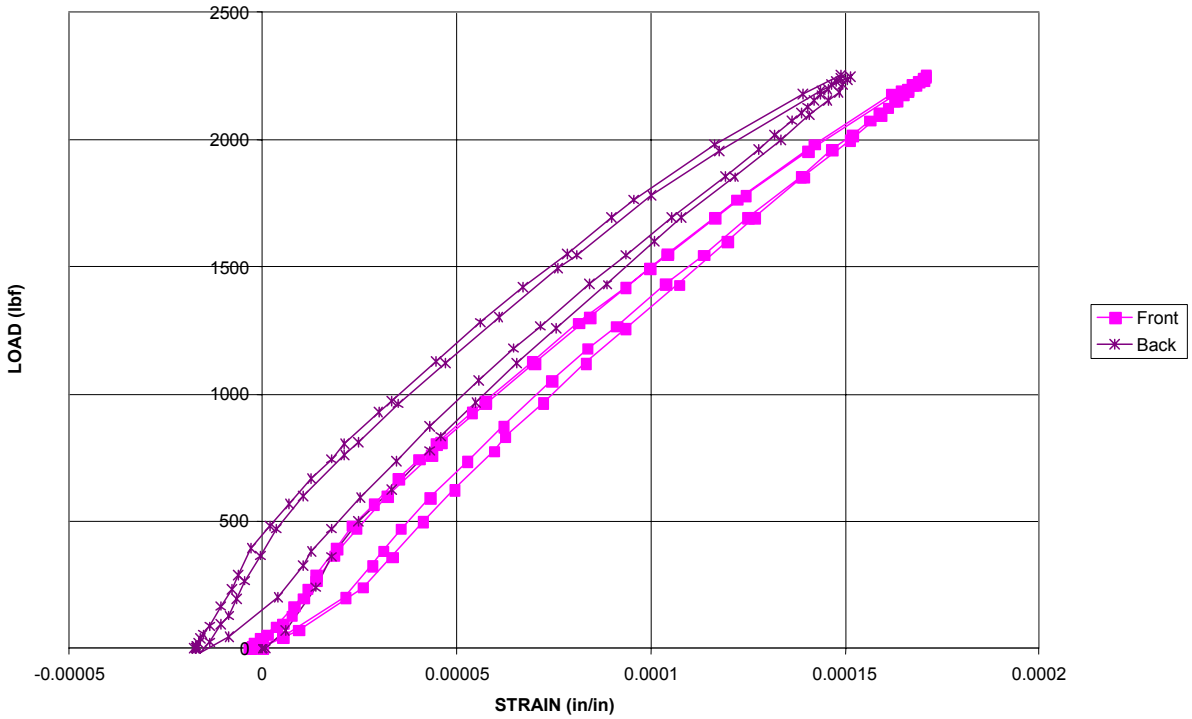

FIGURE F-46. STRAIN GAGE DATA, SCG-5, 16,100 CYCLES

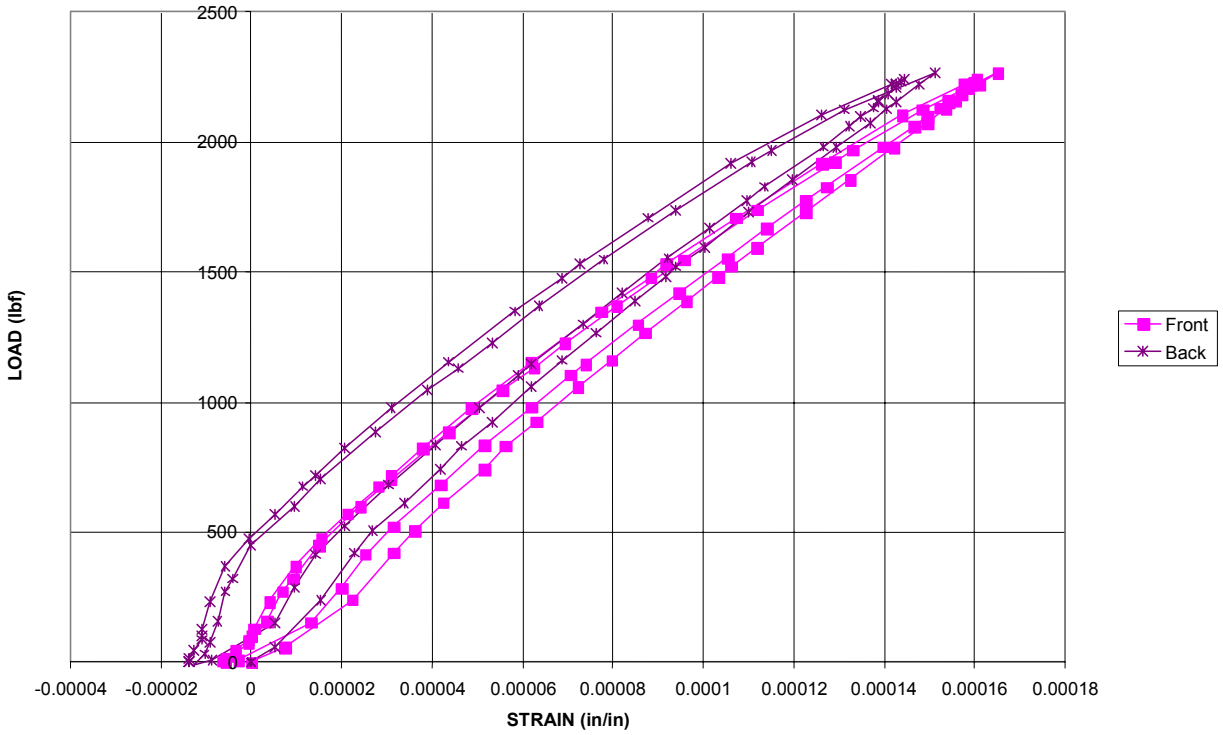

FIGURE F-47. STRAIN GAGE DATA, SCG-5, 21,300 CYCLES

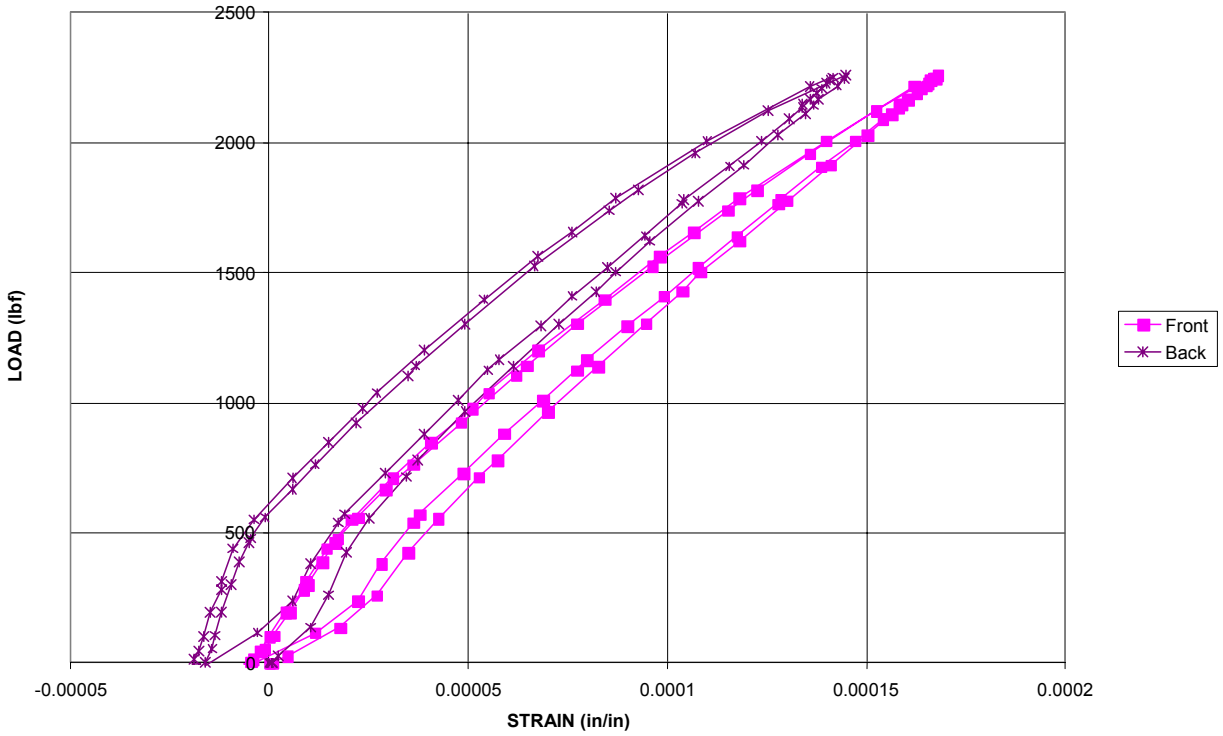

FIGURE F-48. STRAIN GAGE DATA, SCG-5, 26,500 CYCLES

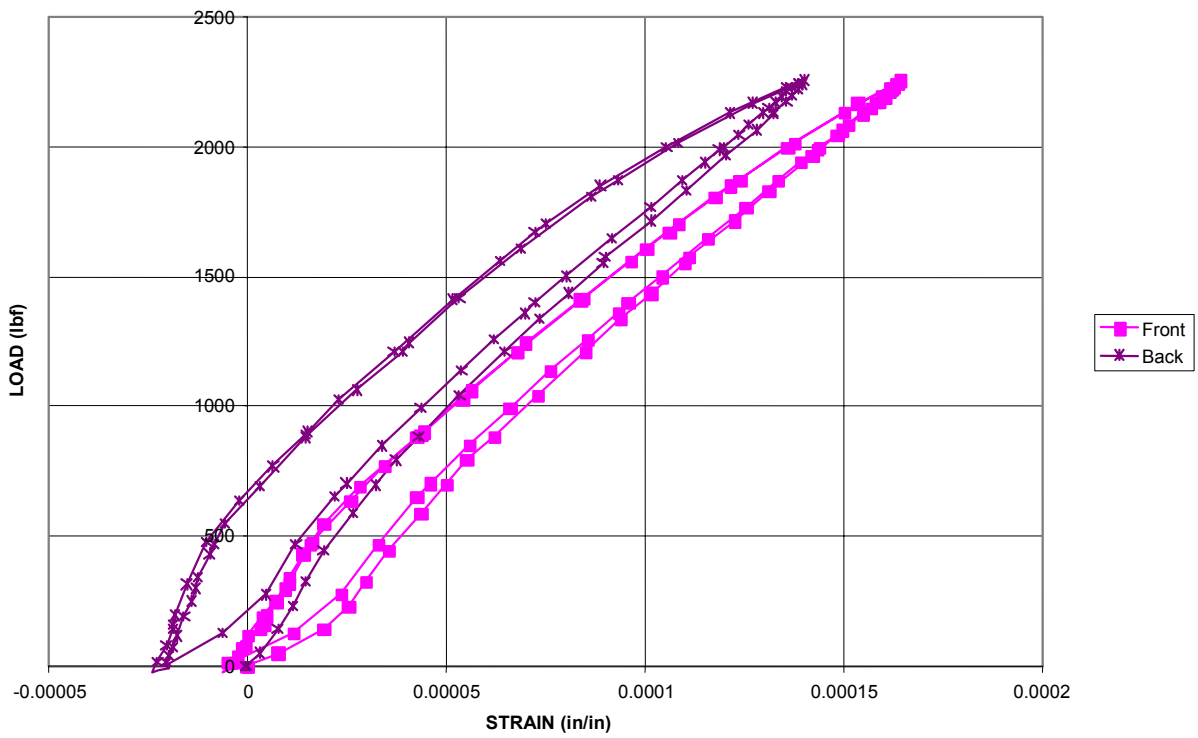

FIGURE F-49. STRAIN GAGE DATA, SCG-5, 31,700 CYCLES

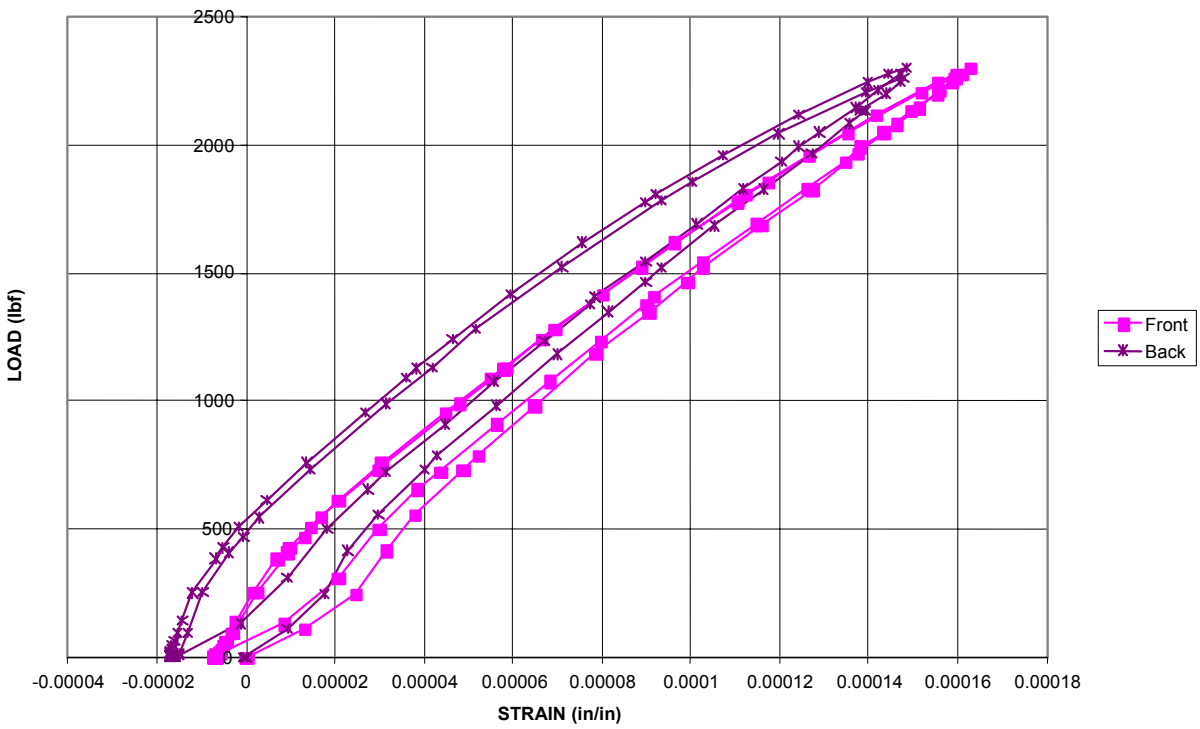

FIGURE F-50. STRAIN GAGE DATA, SCG-5, 36,900 CYCLES

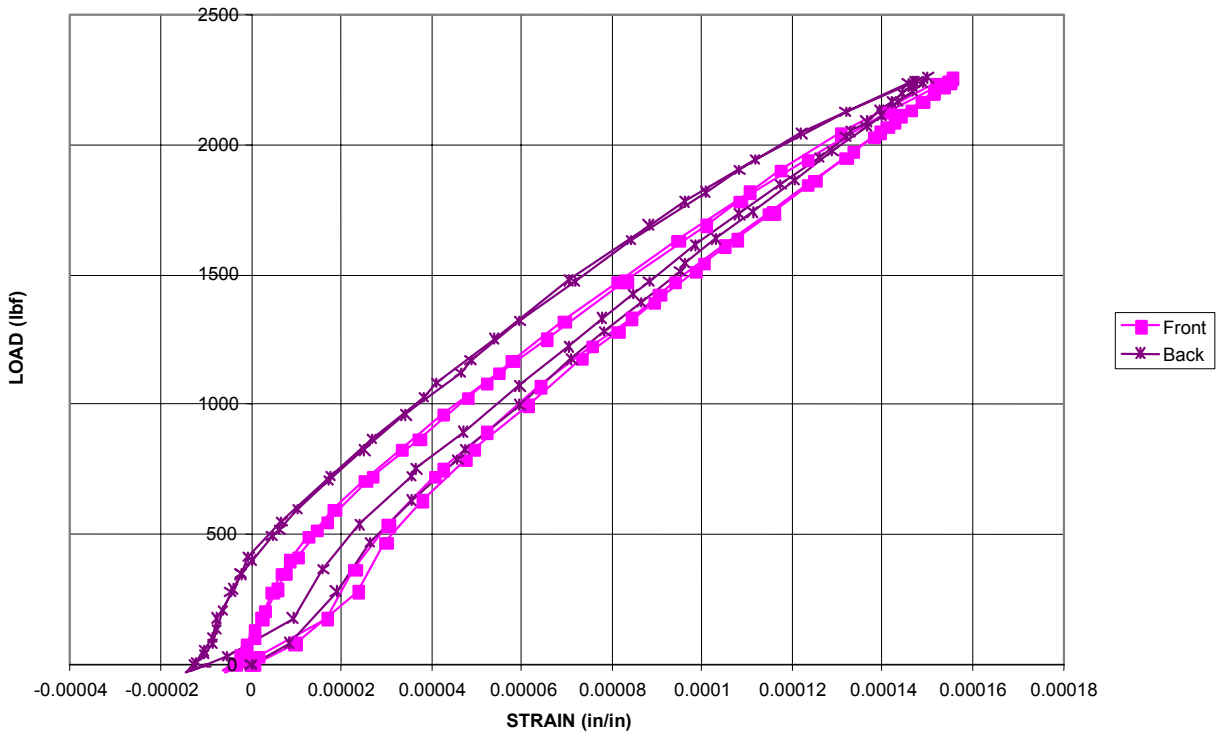

FIGURE F-51. STRAIN GAGE DATA, SCG-5, 42,100 CYCLES

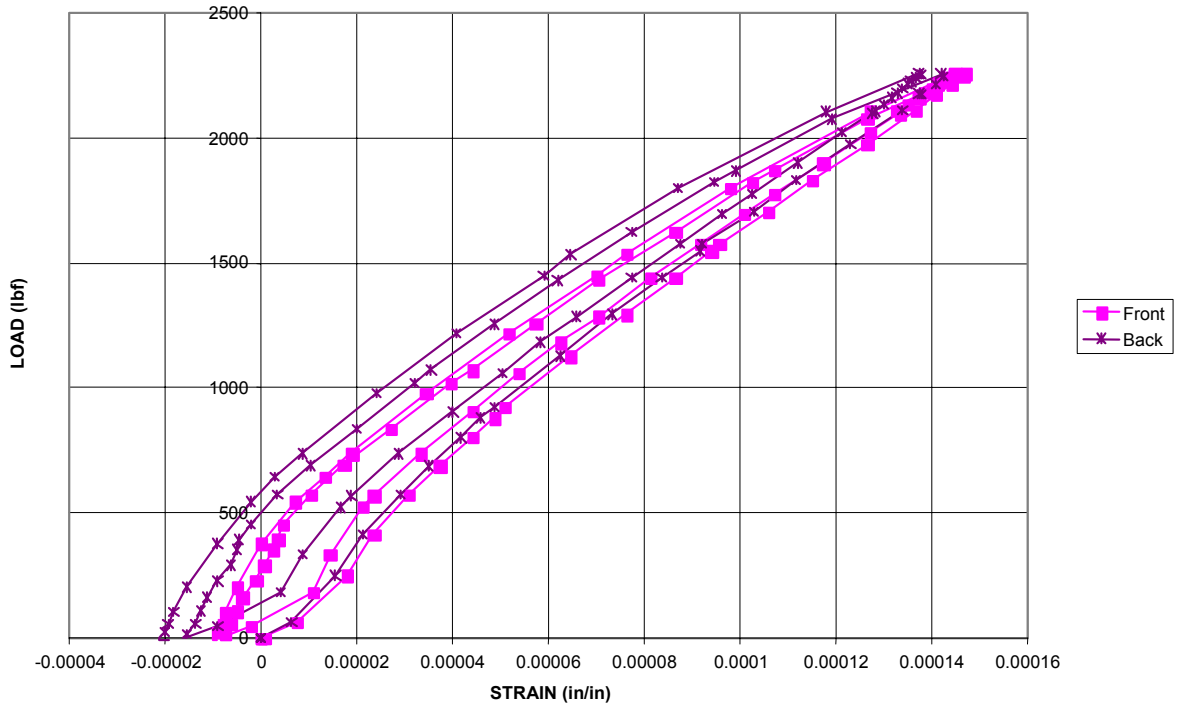

FIGURE F-52. STRAIN GAGE DATA, SCG-5, 47,300 CYCLES

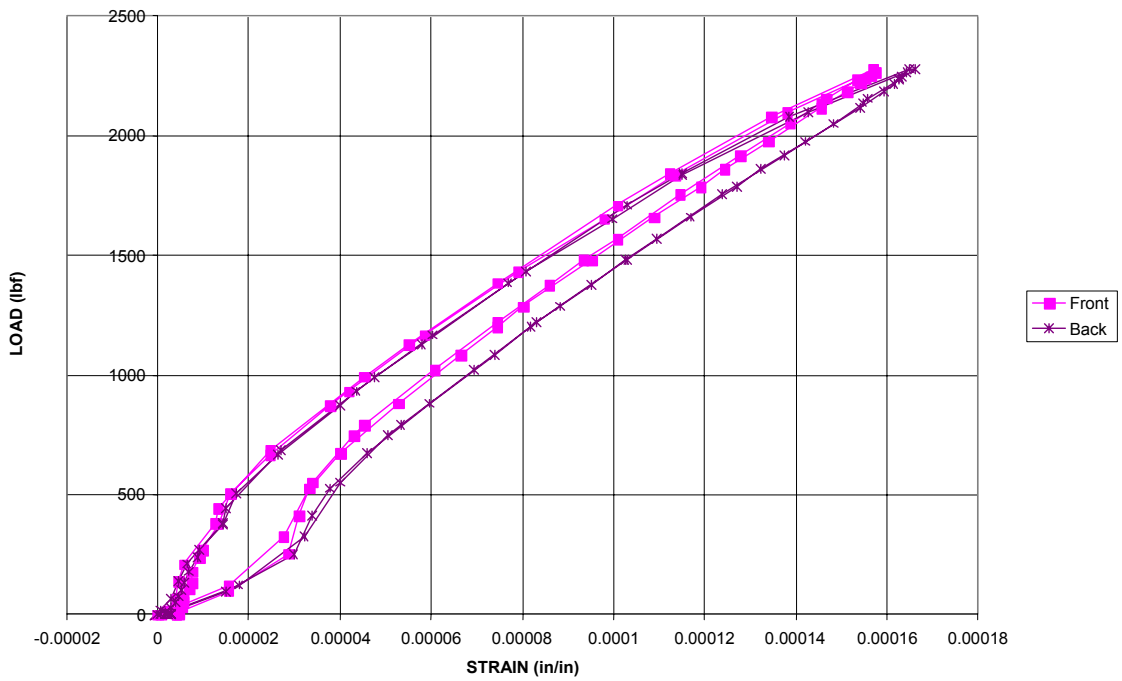

FIGURE F-53. STRAIN GAGE DATA, SCG-5, 52,500 CYCLES BEFORE

F.5 SPECIMEN SCG-6 CALIBRATION DATA.

Specimen SCG-6 has 0.120″ aluminum doublers and was cycled at a constant amplitude of 12.5 ksi, R = 0.1. Strain surveys were taken before and after the specimen was disassembled for periodic inspection.

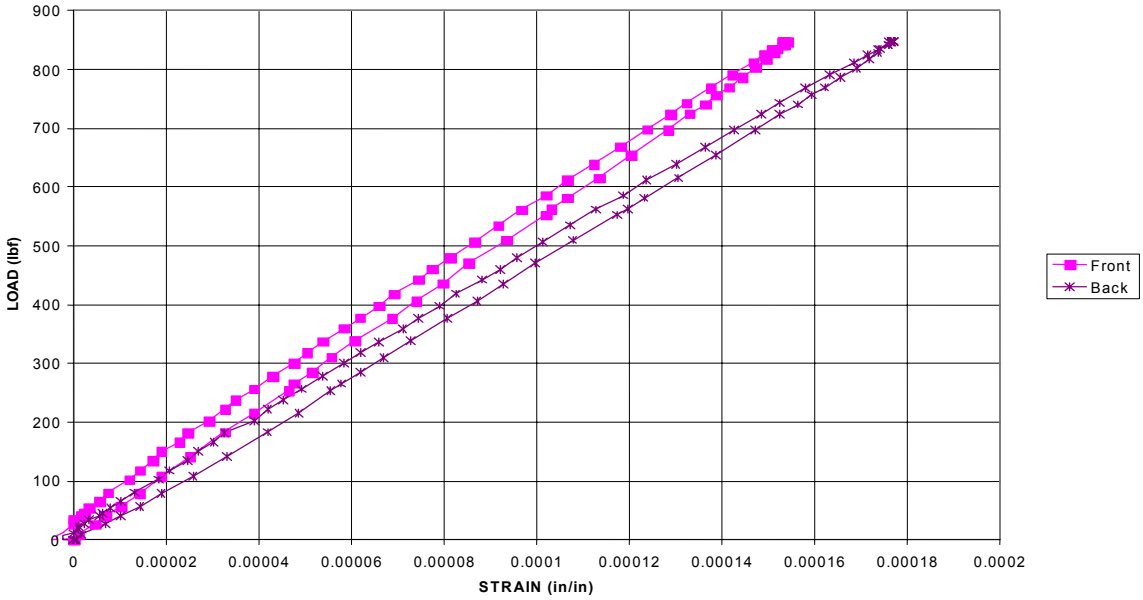

FIGURE F-54. STRAIN GAGE DATA, SCG-6, CALIBRATION #1

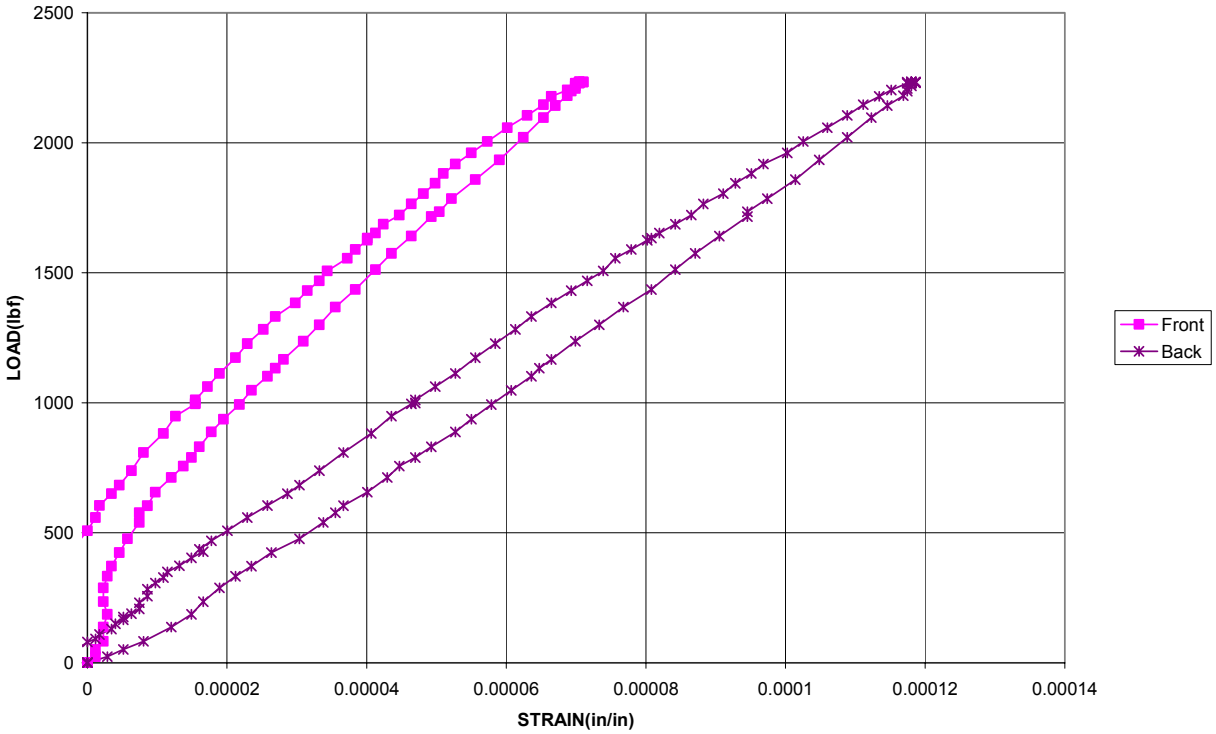

FIGURE F-55. STRAIN GAGE DATA, SCG-6, 0 CYCLES NEW

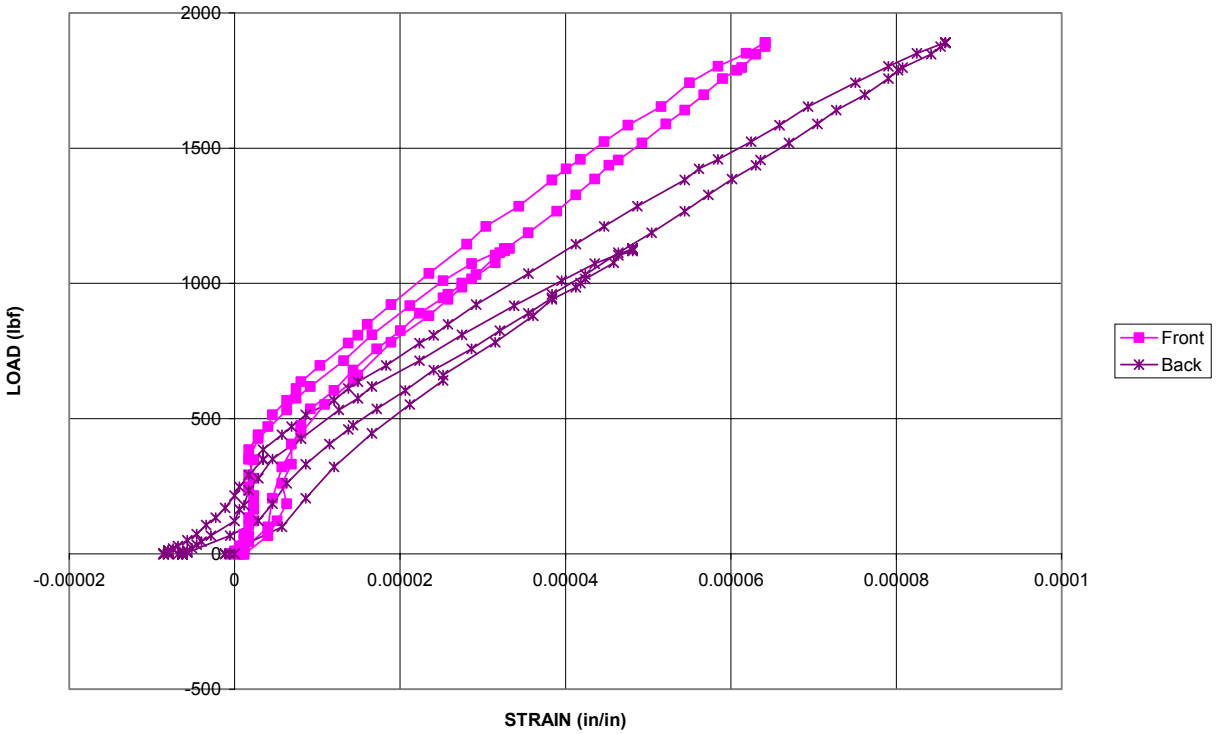

FIGURE F-56. STRAIN GAGE DATA, SCG-6, 0 CYCLES REDO

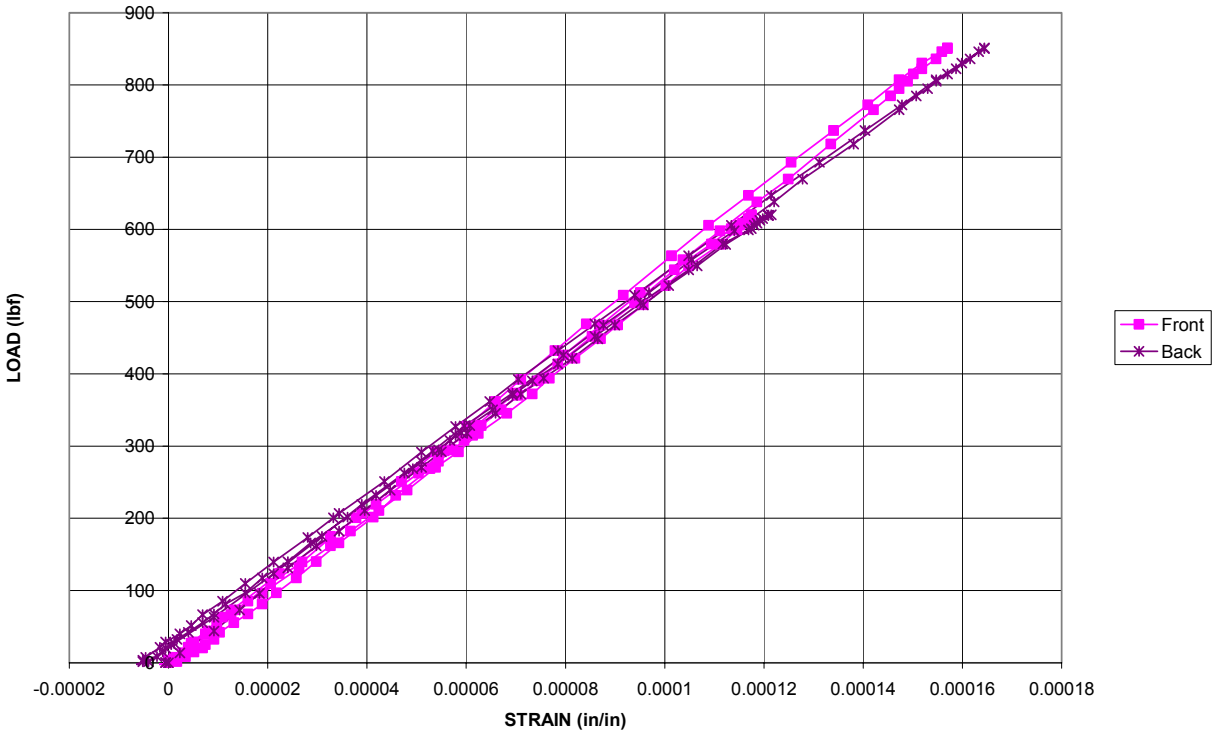

FIGURE F-57. STRAIN GAGE DATA, SCG-6, CALIBRATION #2

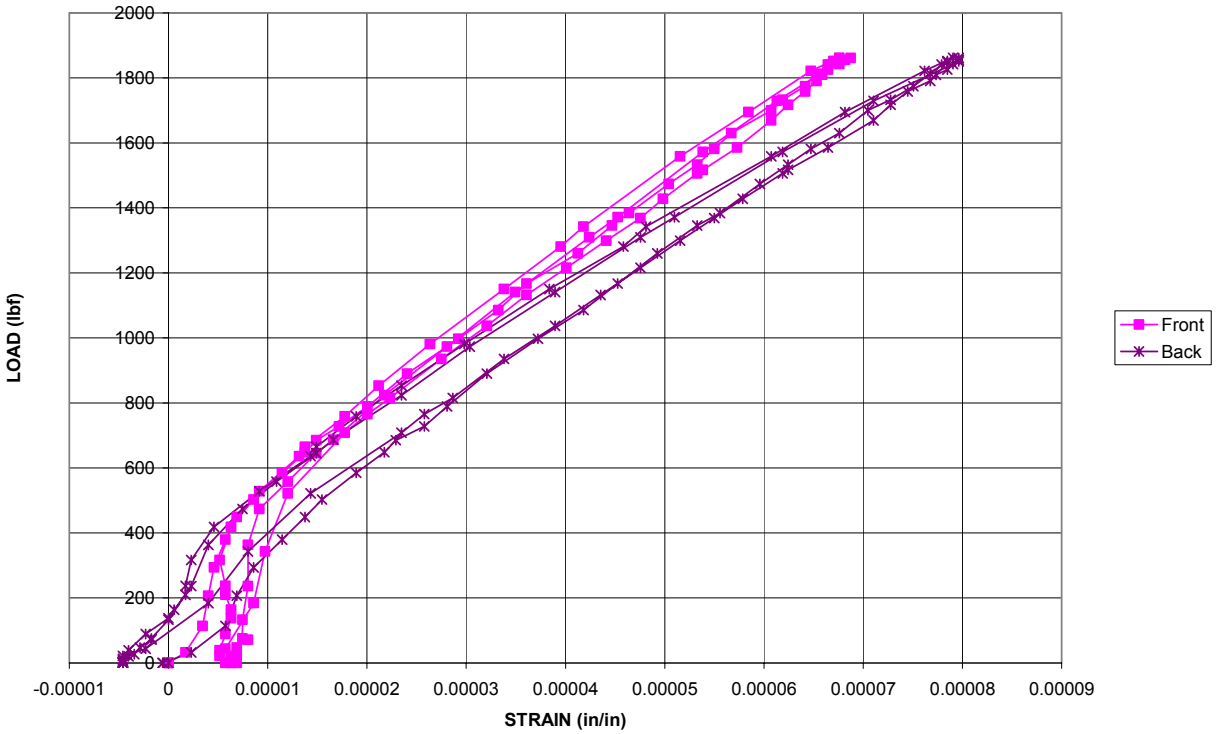

FIGURE F-58. STRAIN GAGE DATA, SCG-6, 0 CYCLES

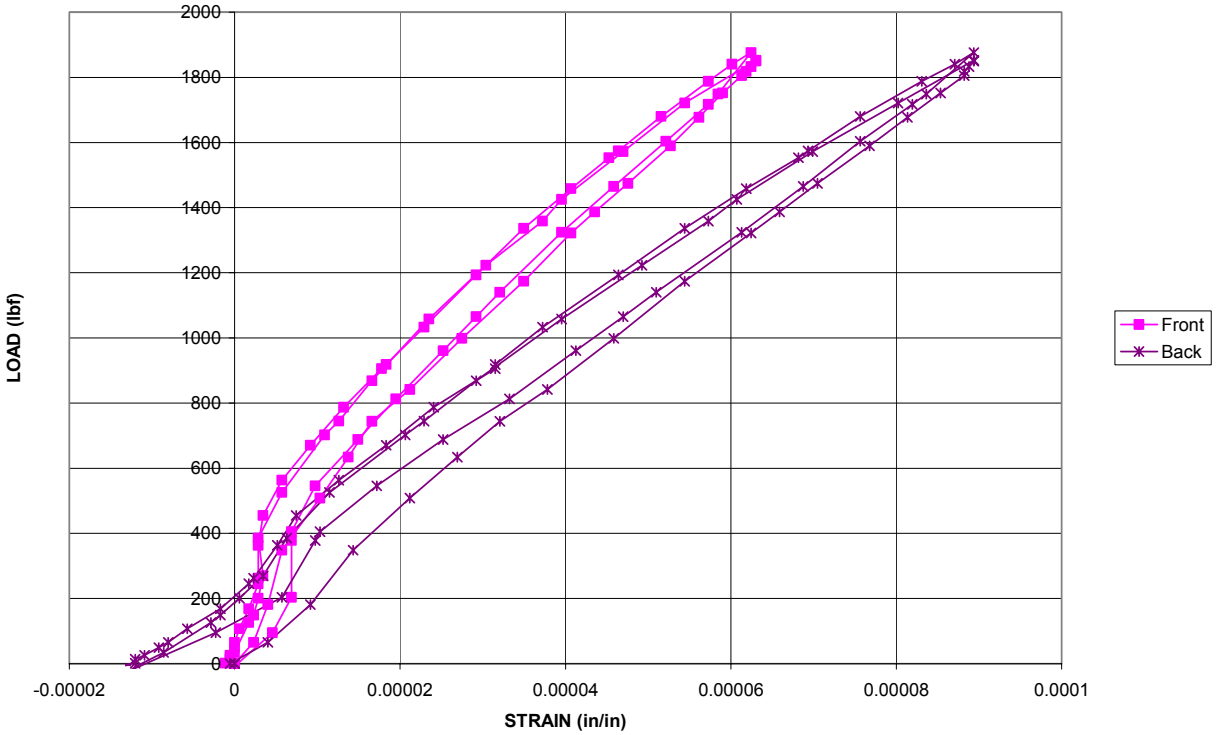

FIGURE F-59. STRAIN GAGE DATA, SCG-6, 5200 CYCLES

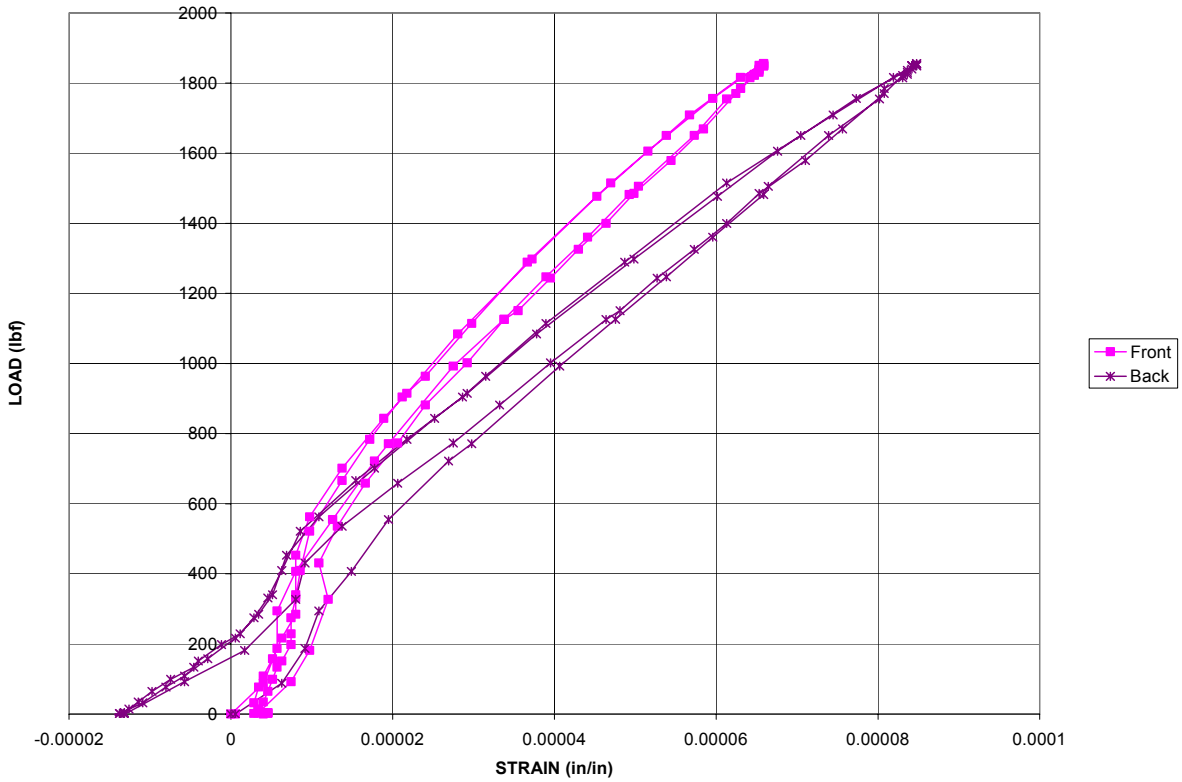

FIGURE F-60. STRAIN GAGE DATA, SCG-6, 10,400 CYCLES

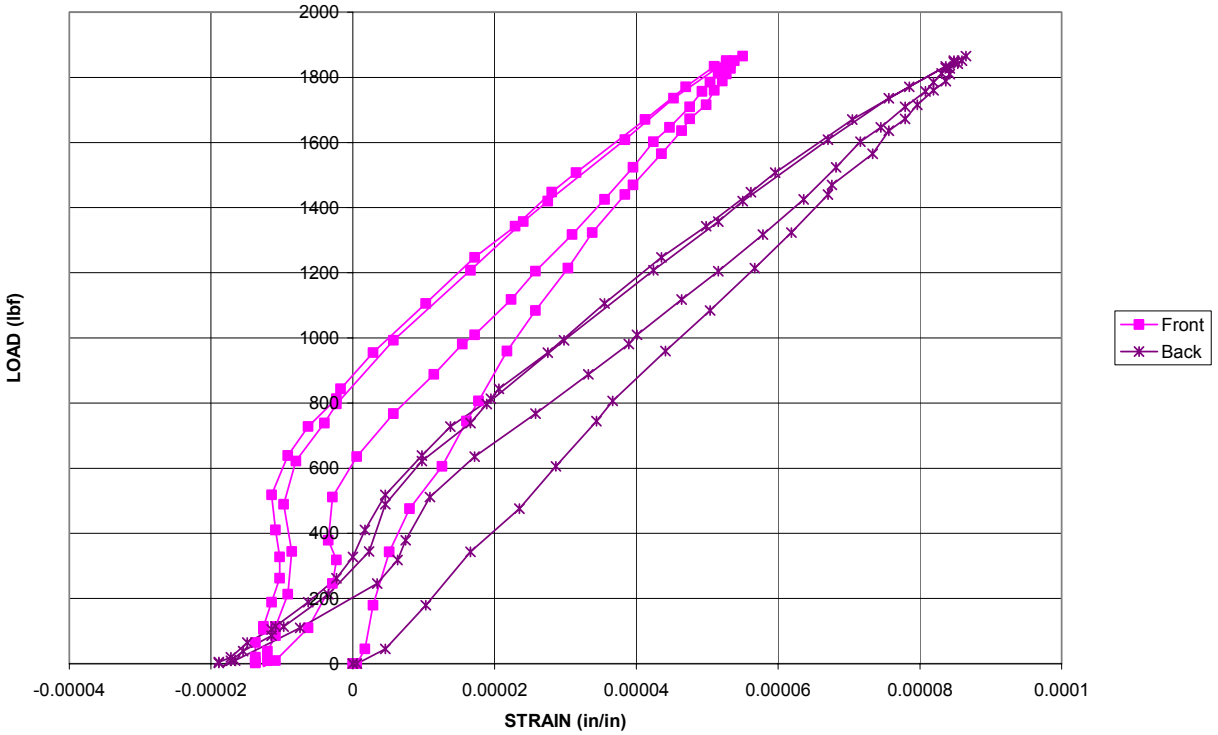

FIGURE F-61. STRAIN GAGE DATA, SCG-6, 20,800 CYCLES

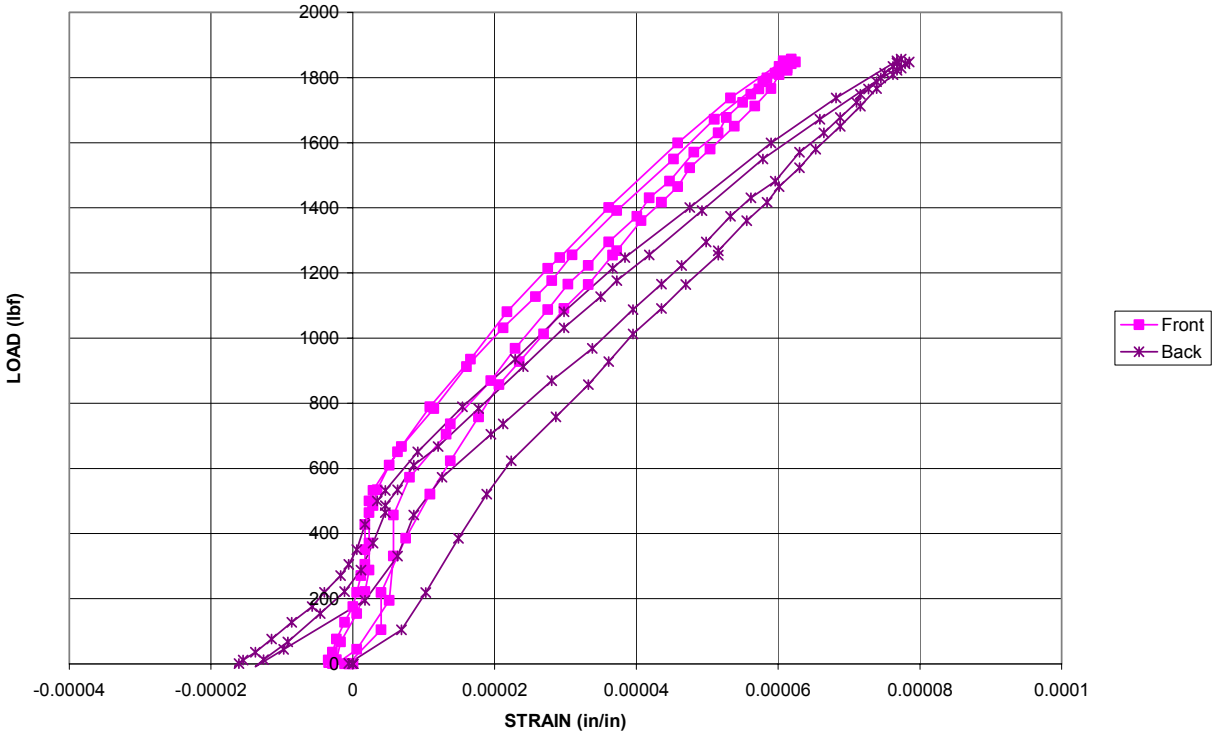

FIGURE F-62. STRAIN GAGE DATA, SCG-6, 28,600 CYCLES

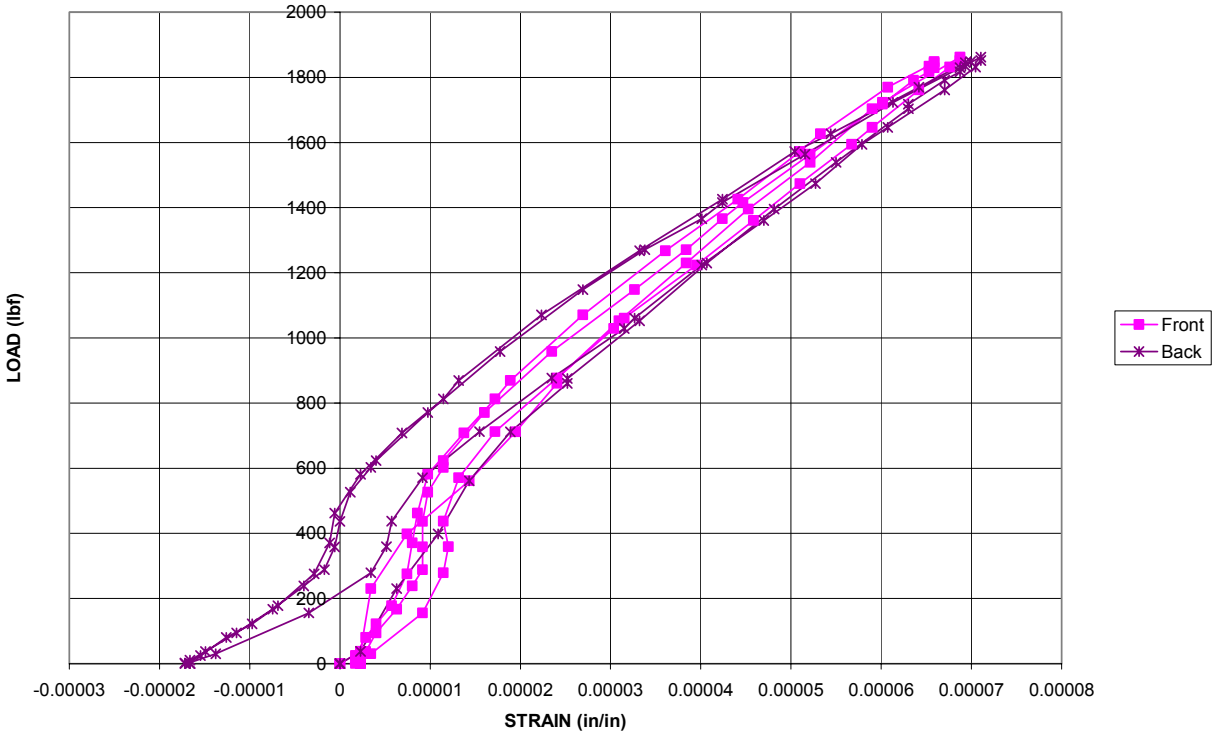

FIGURE F-63. STRAIN GAGE DATA, SCG-6, 36,600 CYCLES

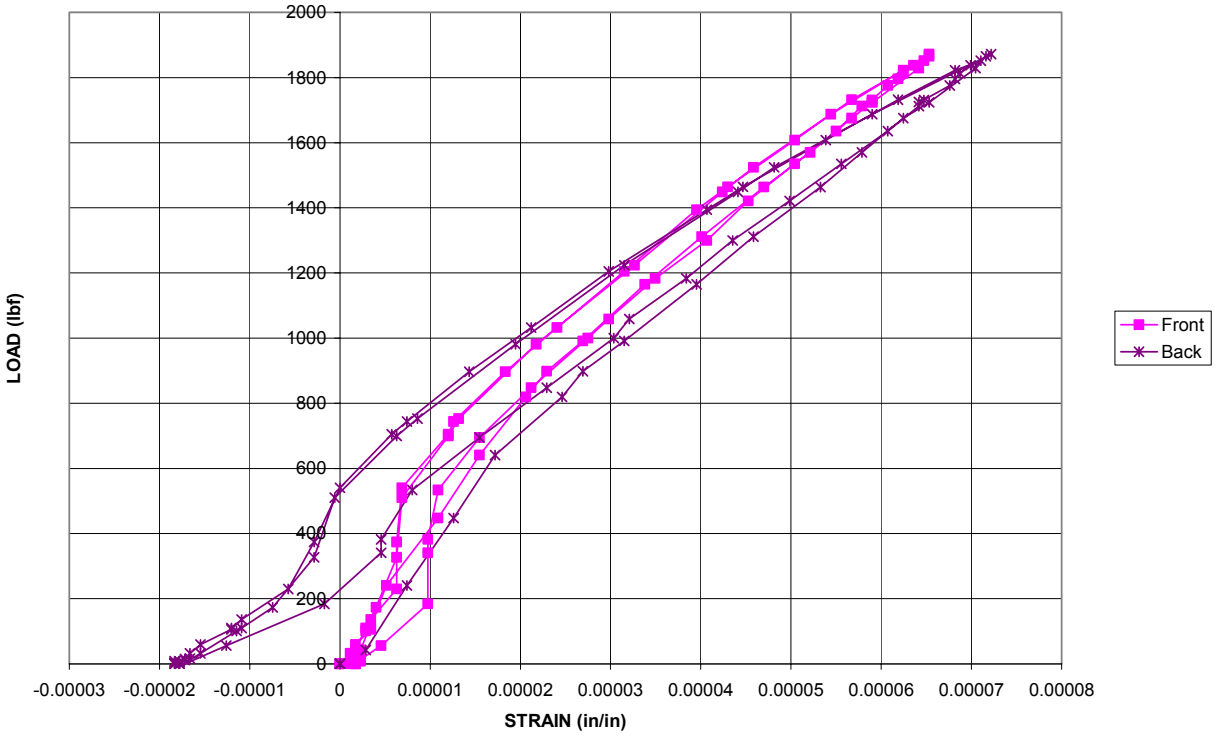

FIGURE F-64. STRAIN GAGE DATA, SCG-6, 44,000 CYCLES

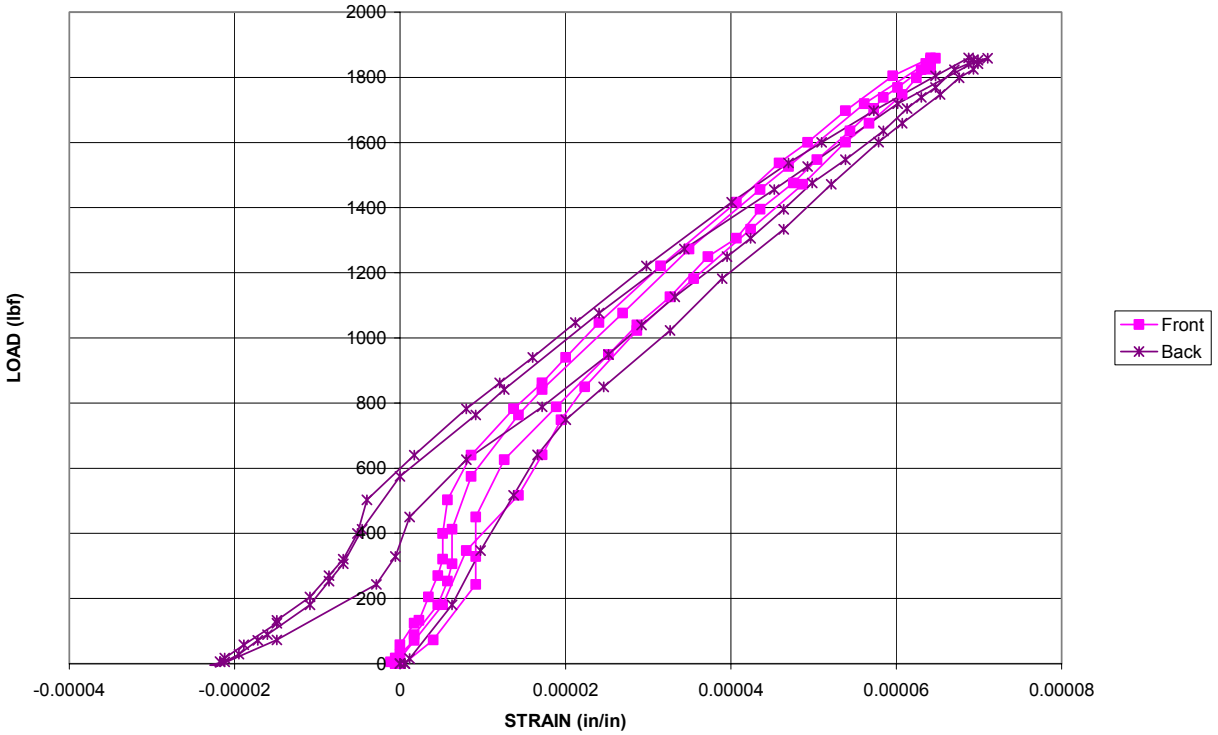

FIGURE F-65. STRAIN GAGE DATA, SCG-6, 52,200 CYCLES

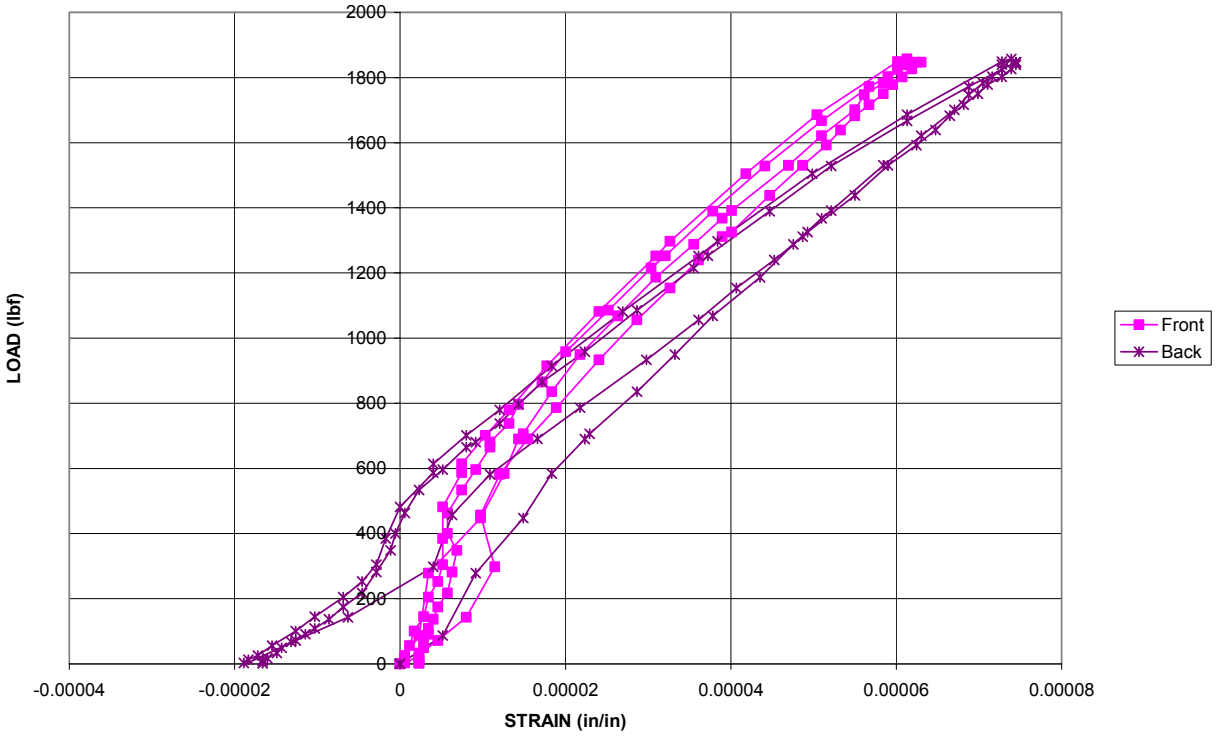

FIGURE F-66. STRAIN GAGE DATA, SCG-6, 62,600 CYCLES

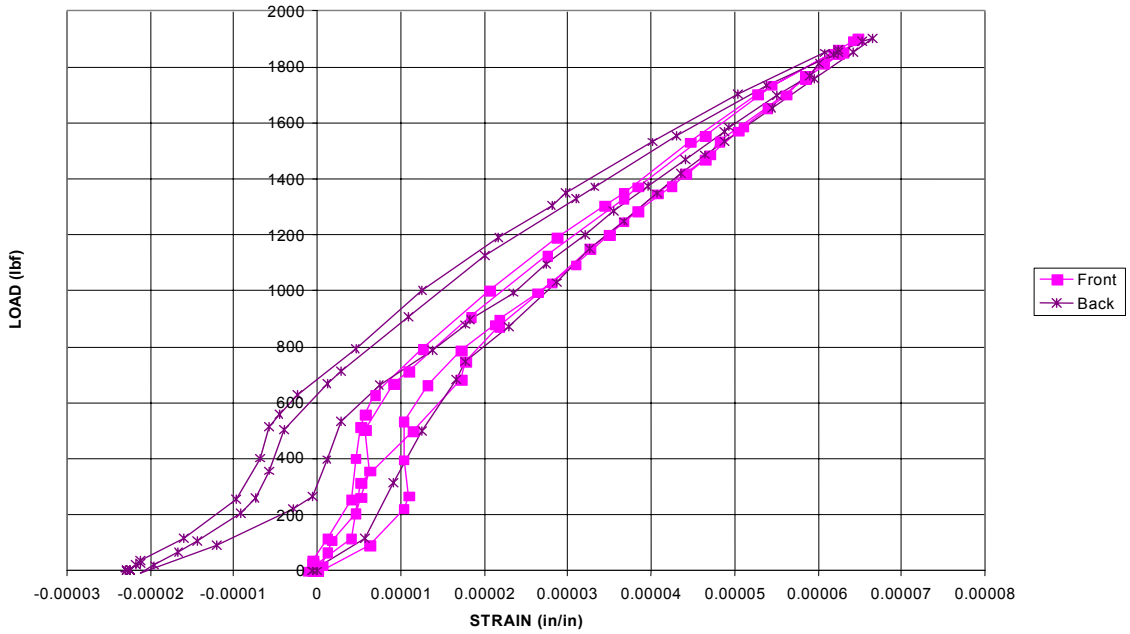

FIGURE F-67. STRAIN GAGE DATA, SCG-6, 73,000 CYCLES

F.6 SPECIMEN SCG-7 CALIBRATION DATA.

Specimen SCG-7 has 0.120″ aluminum doublers and was cycled at a constant amplitude of 12.5 ksi, R = 0.1. Strain surveys were taken before and after the specimen was disassembled for periodic inspection.

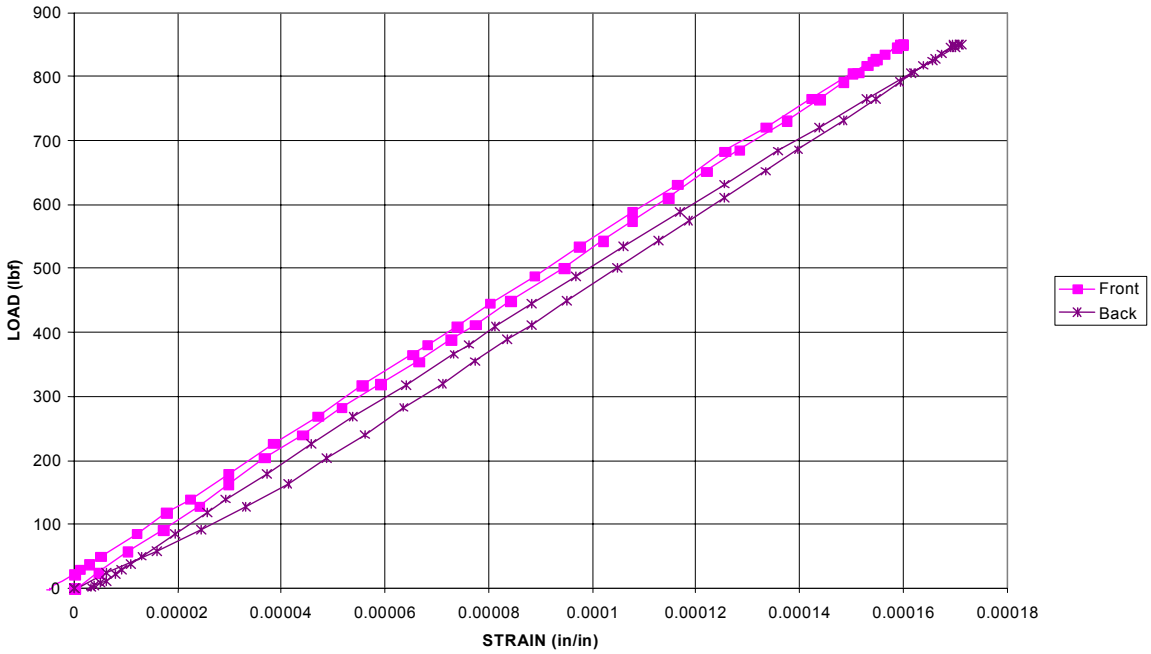

FIGURE F-68. STRAIN GAGE DATA, SCG-7, CALIBRATION #1

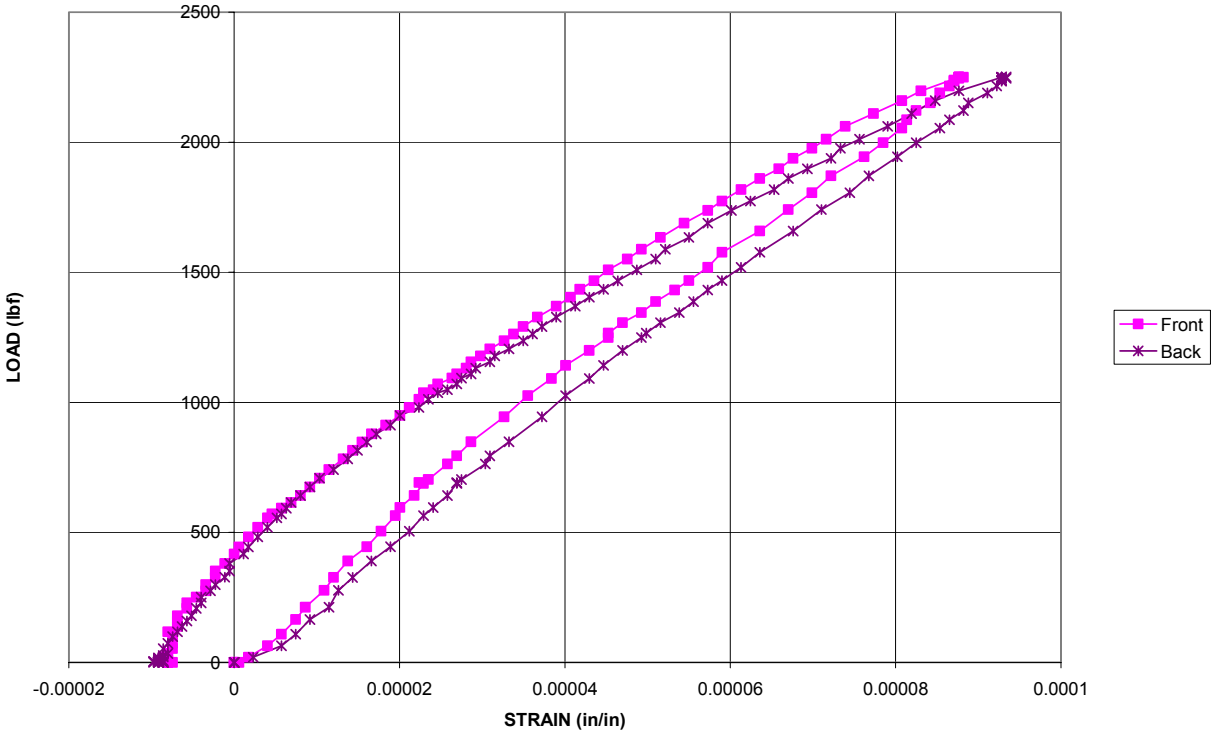

FIGURE F-69. STRAIN GAGE DATA, SCG-7, 0 CYCLES NEW

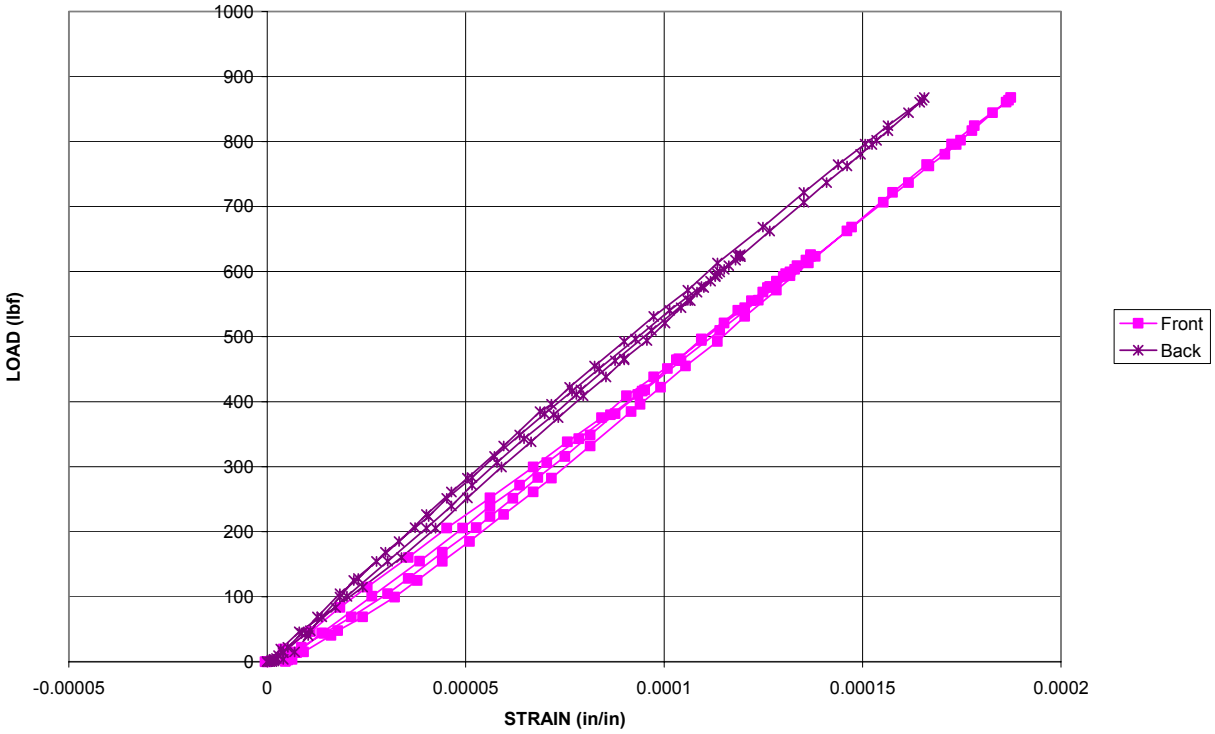

FIGURE F-70. STRAIN GAGE DATA, SCG-7, CALIBRATION #2

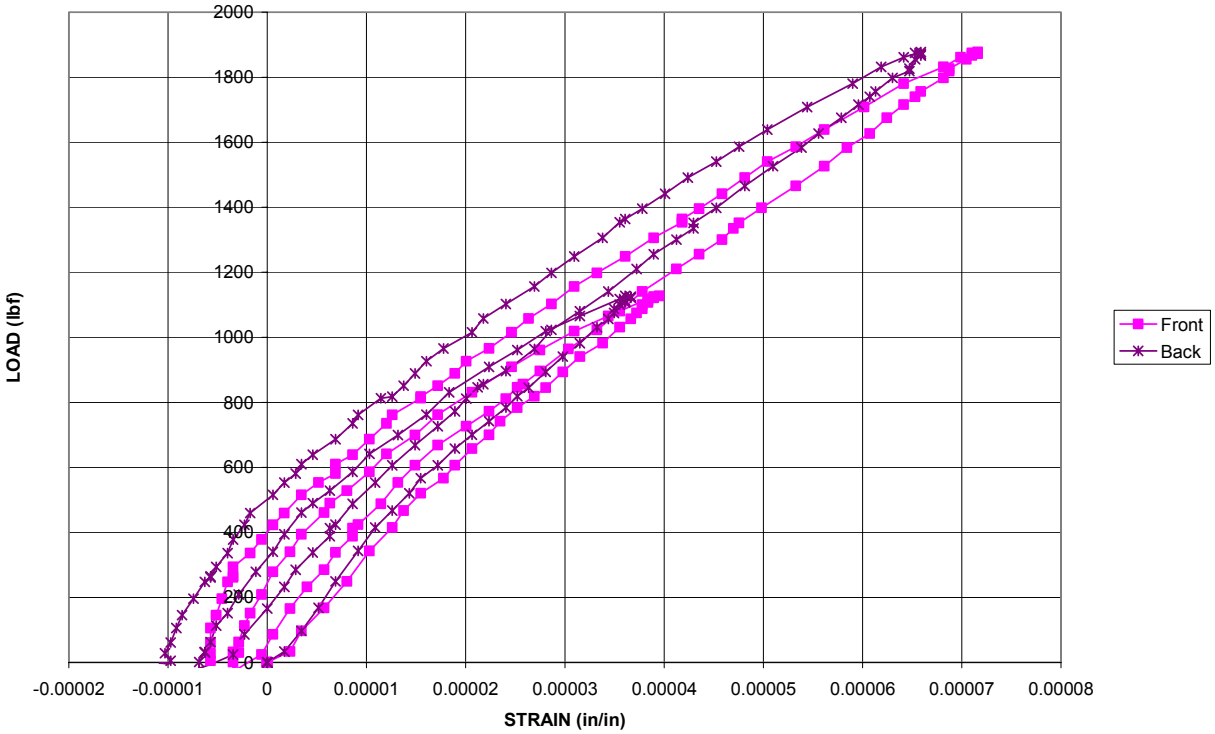

FIGURE F-71. STRAIN GAGE DATA, SCG-7, 0 CYCLES REDO

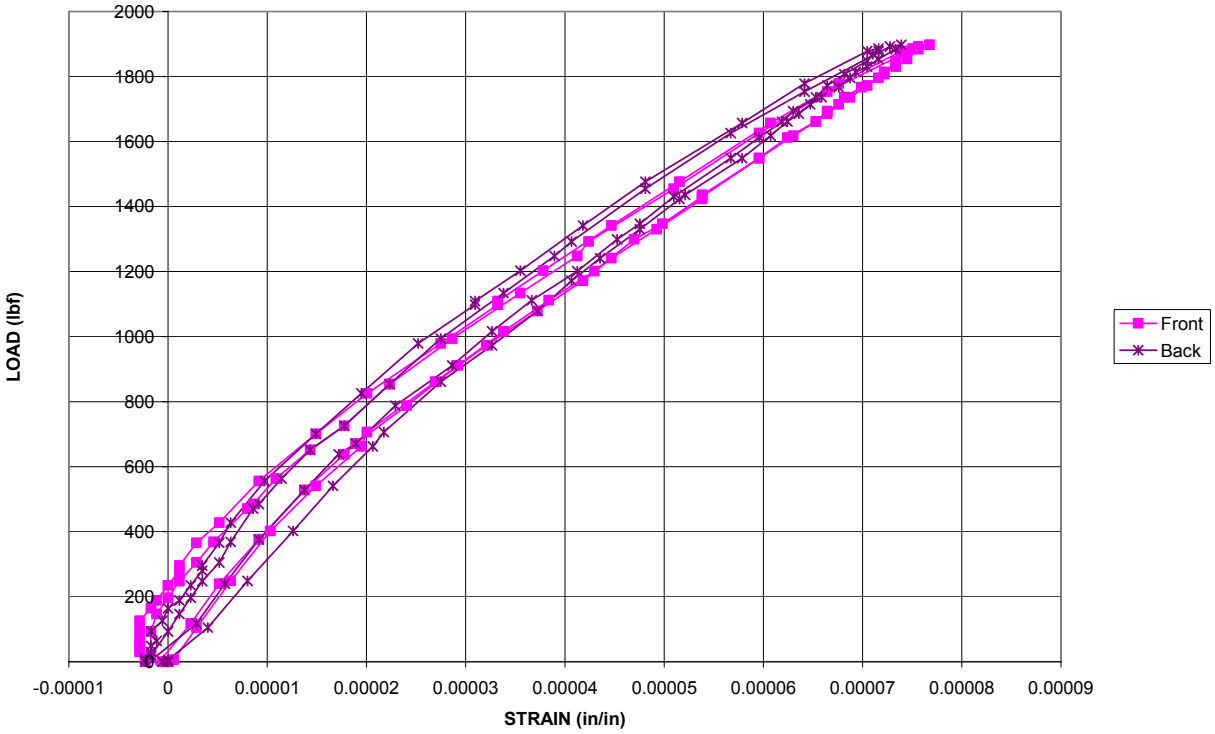

FIGURE F-72. STRAIN GAGE DATA, SCG-7, 0 CYCLES NEW STRAIN SURVEY

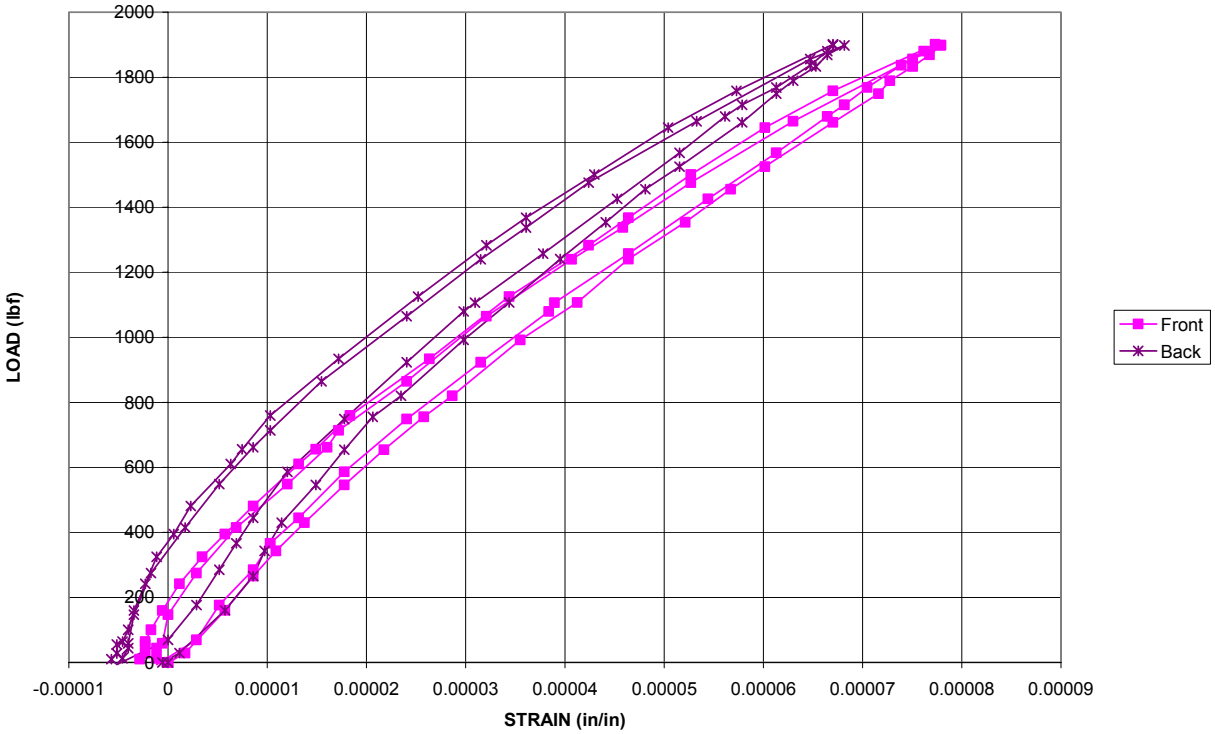

FIGURE F-73. STRAIN GAGE DATA, SCG-7, 2000 CYCLES

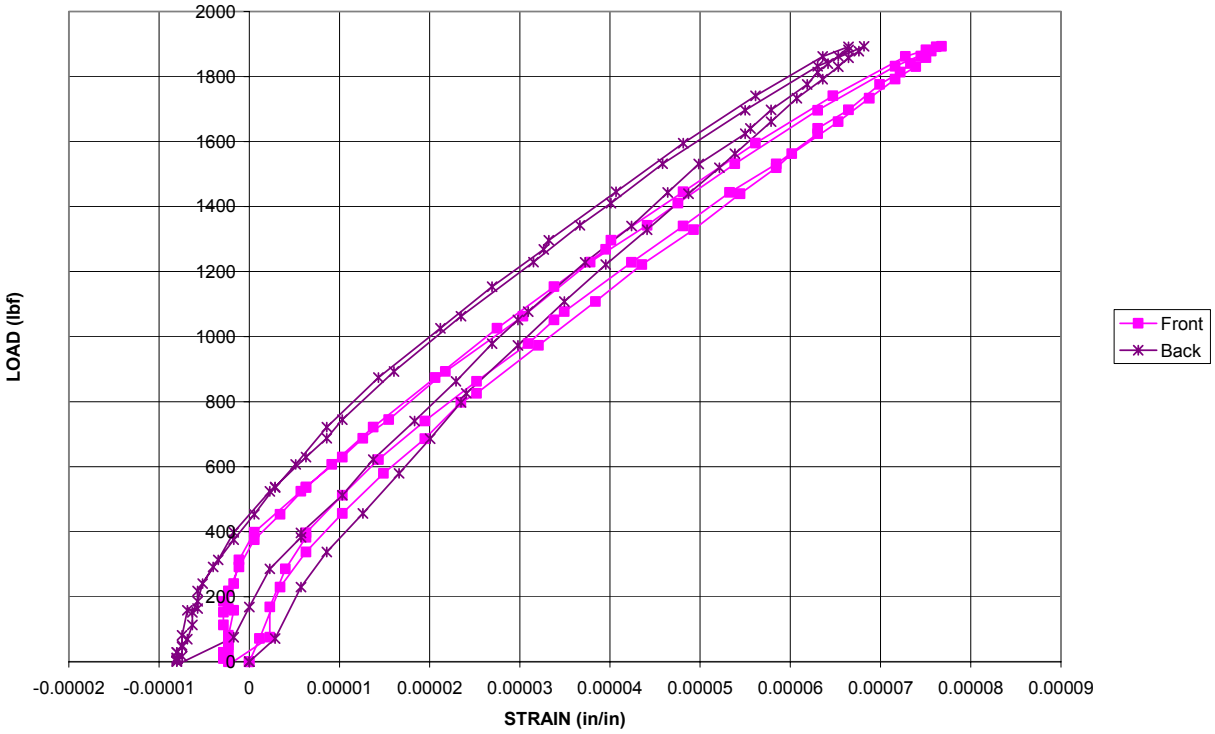

FIGURE F-74. STRAIN GAGE DATA, SCG-7, 7200 CYCLES

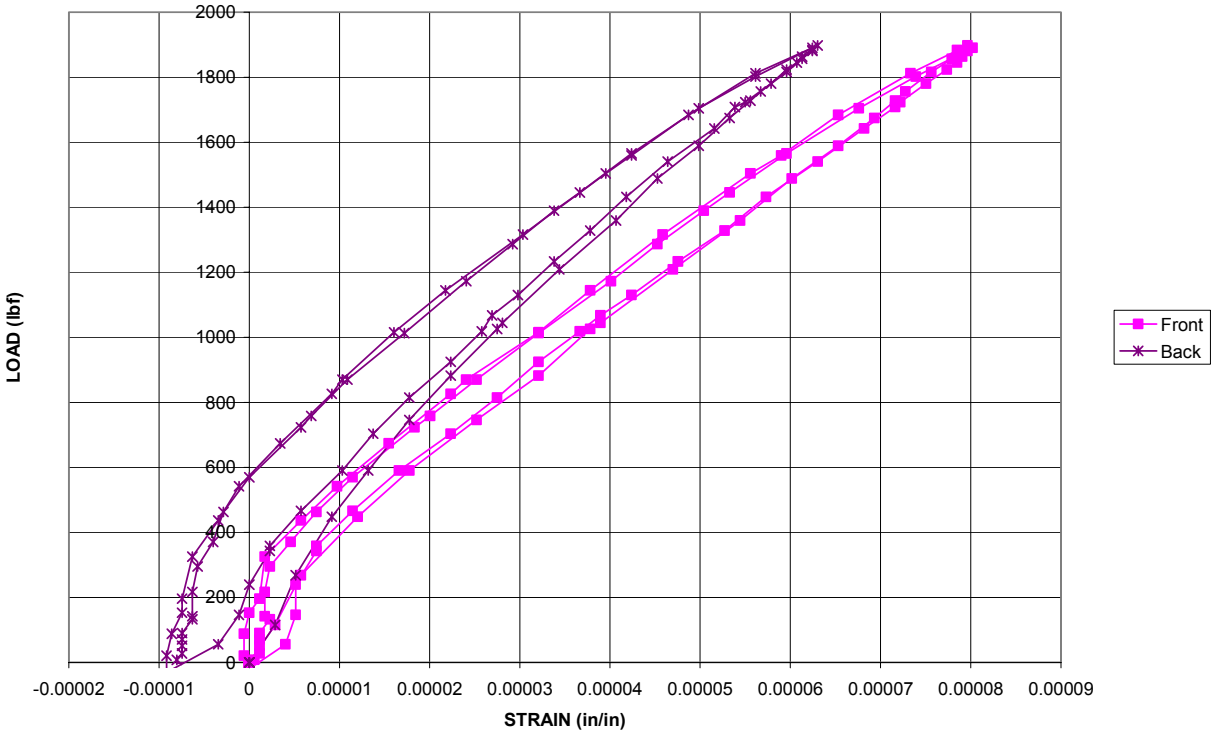

FIGURE F-75. STRAIN GAGE DATA, SCG-7, 12,400 CYCLES

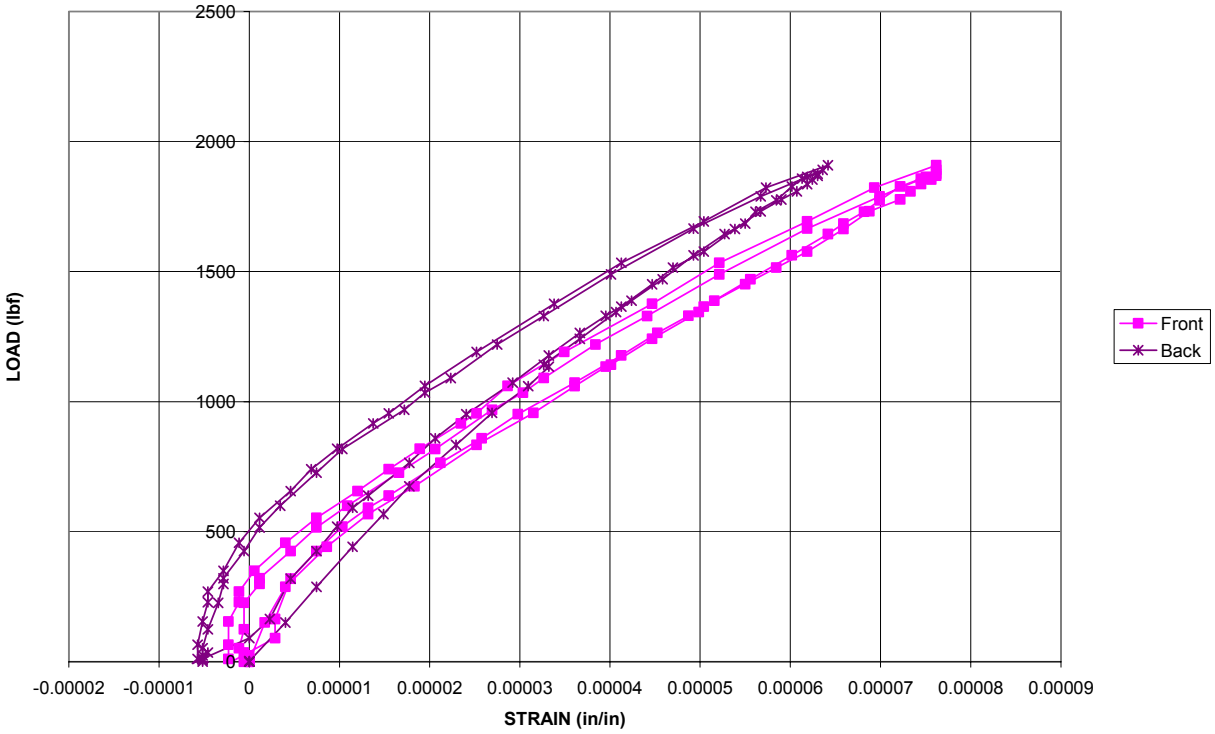

FIGURE F-76. STRAIN GAGE DATA, SCG-7, 22,800 CYCLES

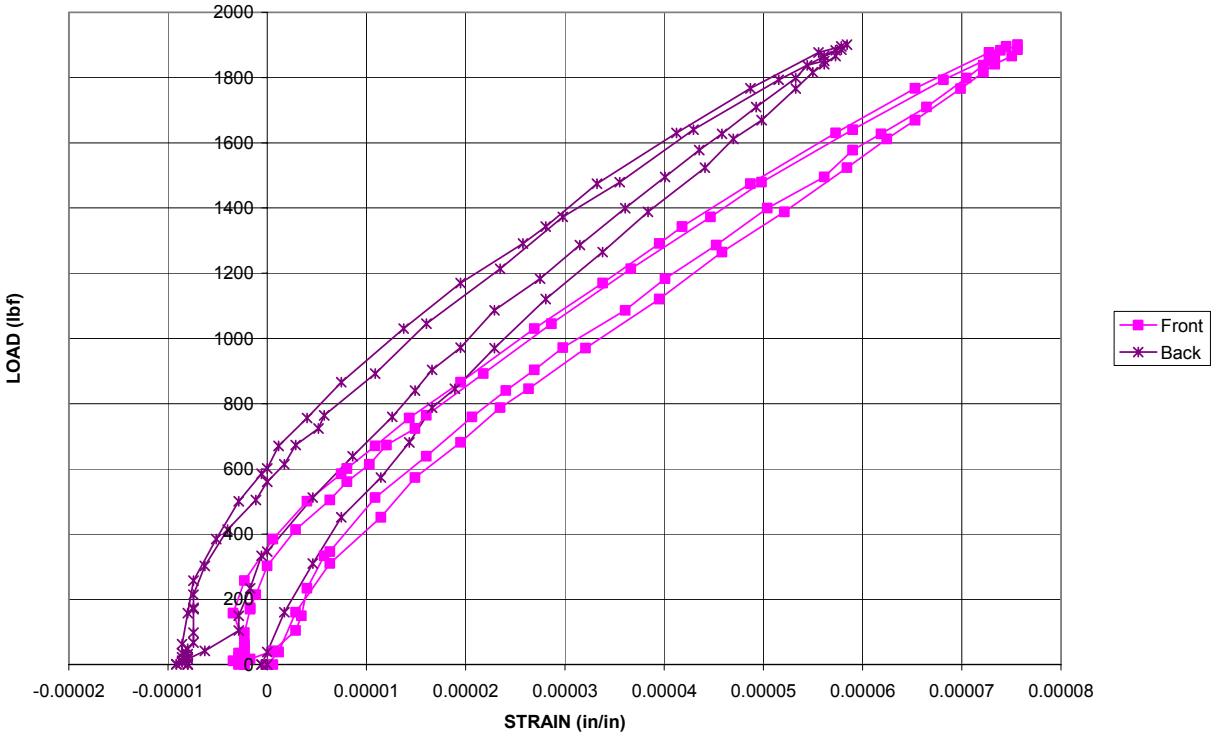

FIGURE F-77. STRAIN GAGE DATA, SCG-7, 30,300 CYCLES

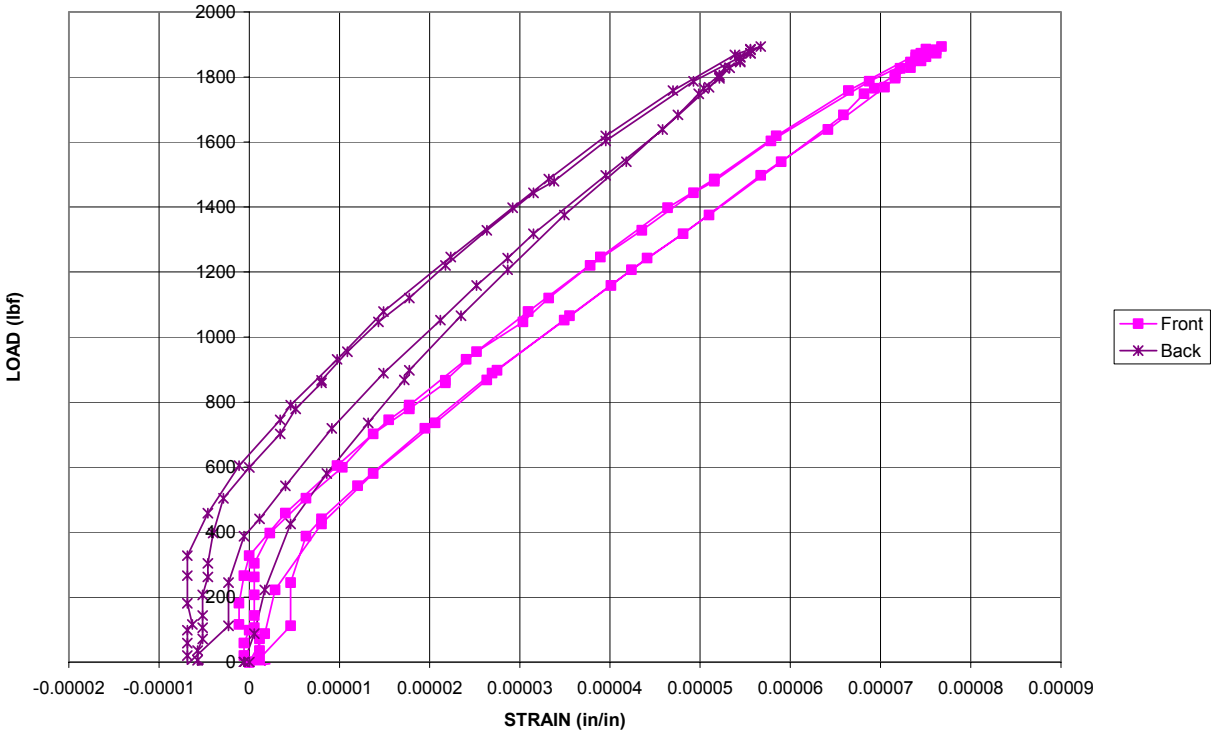

FIGURE F-78. STRAIN GAGE DATA, SCG-7, 37,800 CYCLES

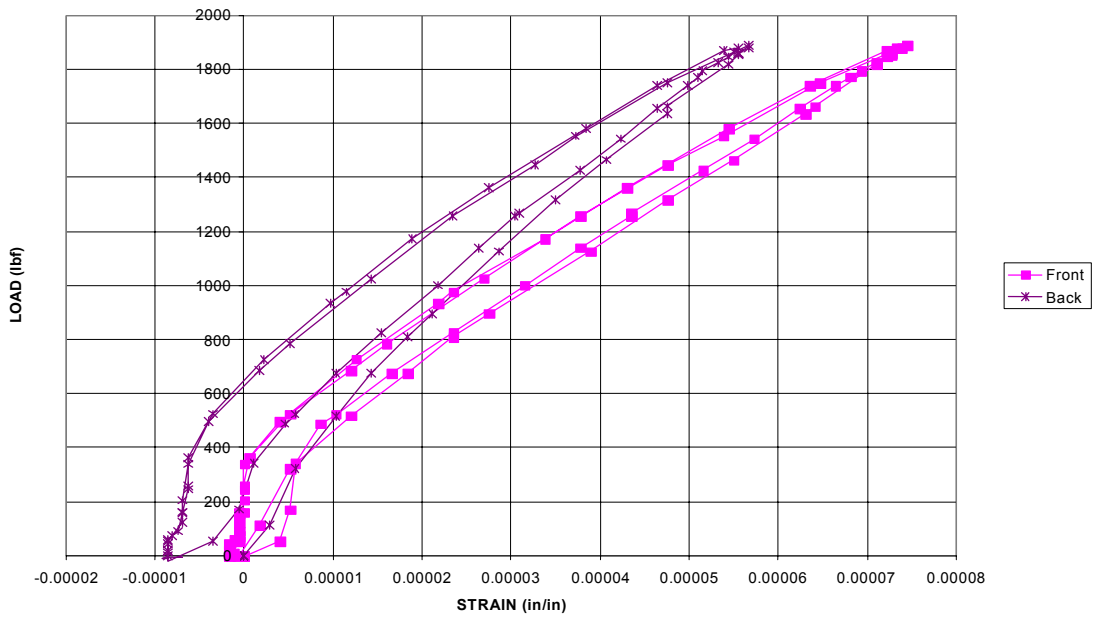

FIGURE F-79. STRAIN GAGE DATA, SCG-7, 45,300 CYCLES

F.7 SPECIMEN SCG-8 CALIBRATION DATA.

Specimen SCG-8 has 0.120″ aluminum doublers; the EIFS spectrum was applied with a maximum stress of 13.4 ksi. Strain surveys were taken before and after the specimen was disassembled for periodic inspection.

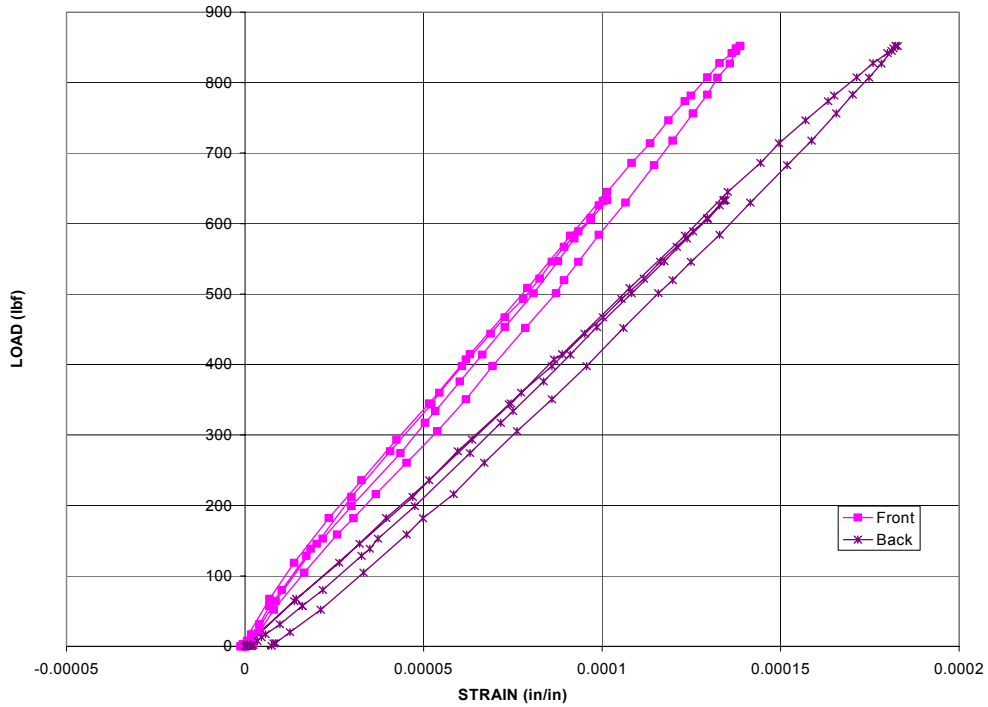

FIGURE F-80. STRAIN GAGE DATA, SCG-8, CALIBRATION

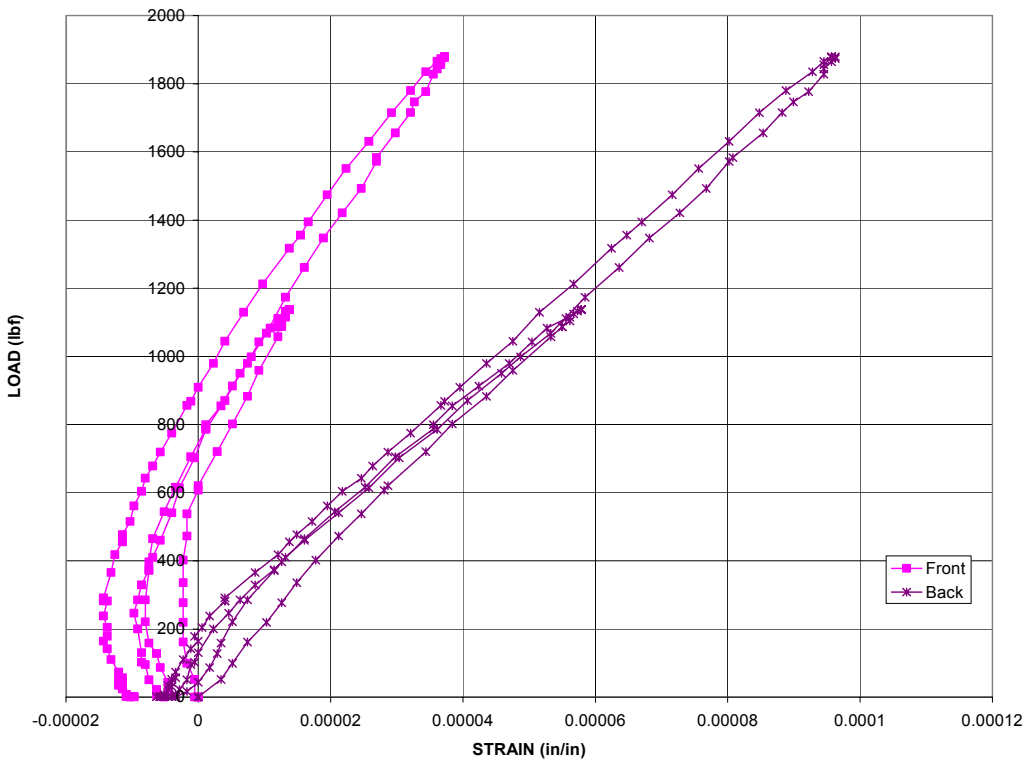

FIGURE F-81. STRAIN GAGE DATA, SCG-8, 0 CYCLES

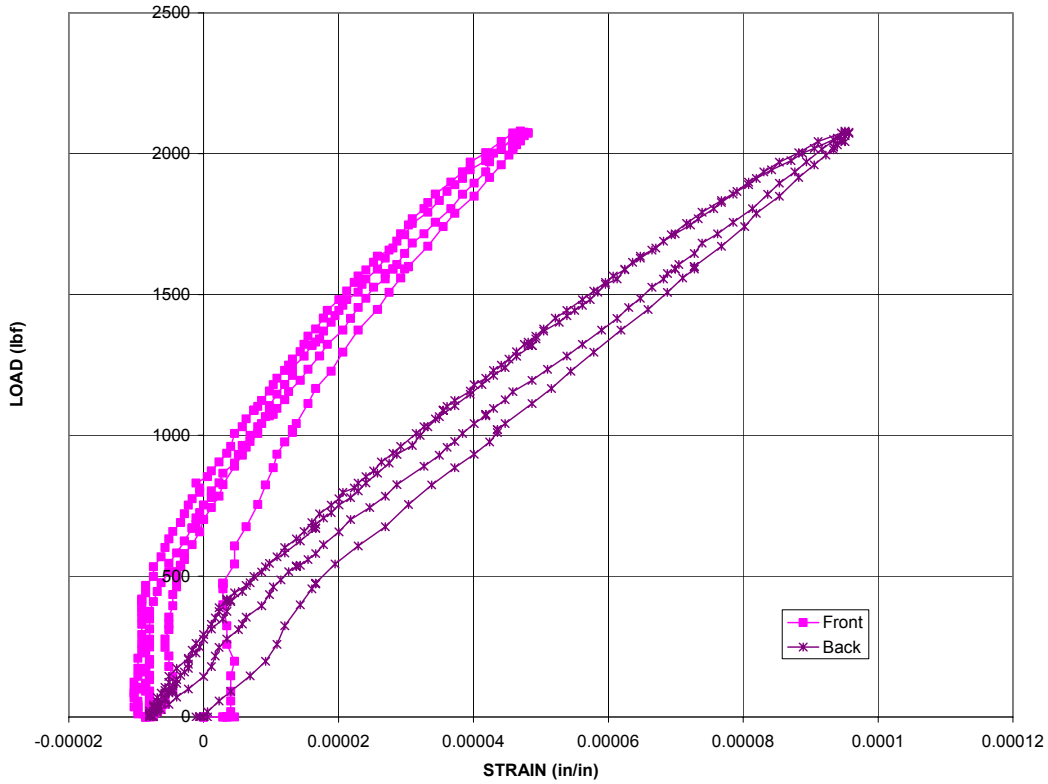

FIGURE F-82. STRAIN GAGE DATA, SCG-8, 325,000 CYCLES

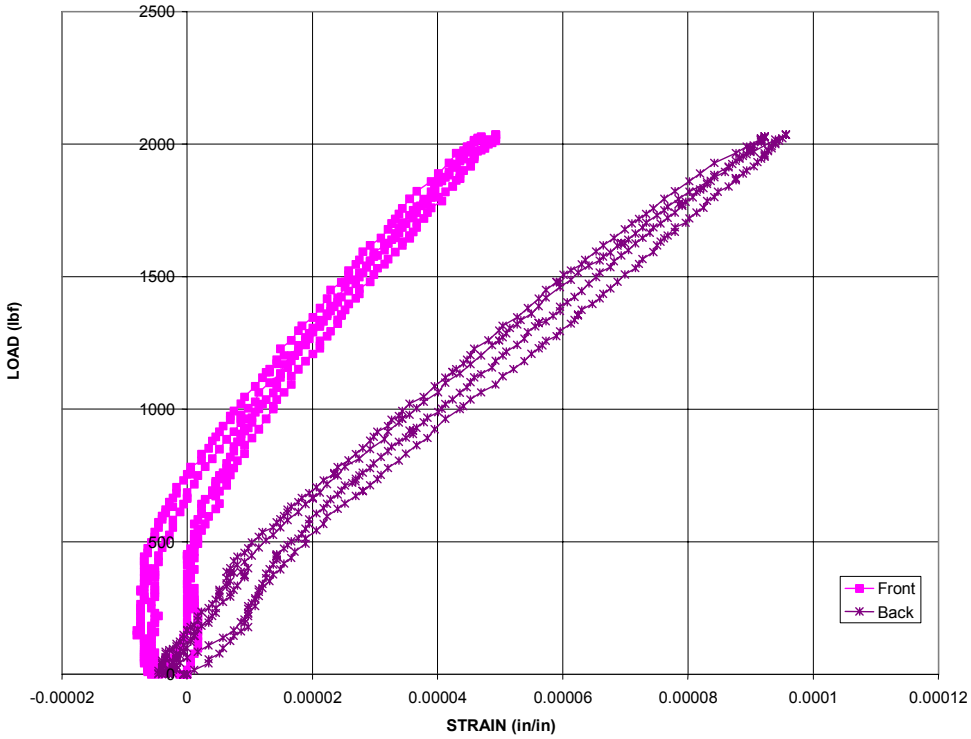

FIGURE F-83. STRAIN GAGE DATA, SCG-8, 725,000 CYCLES

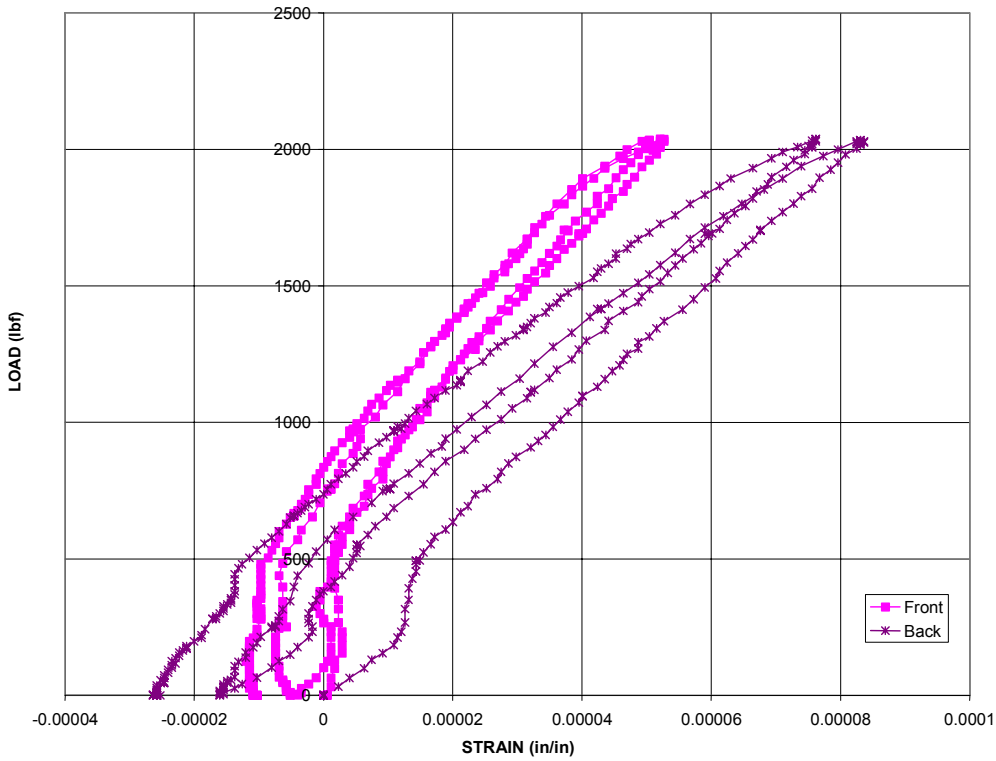

FIGURE F-84. STRAIN GAGE DATA, SCG-8, 825,000 CYCLES

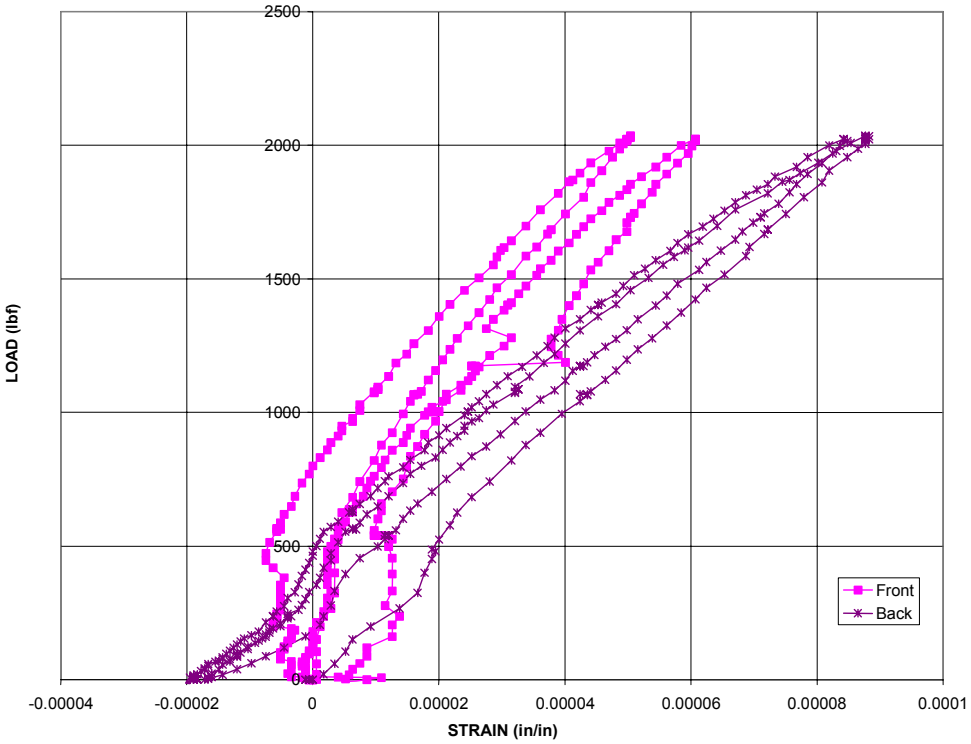

FIGURE F-85. STRAIN GAGE DATA, SCG-8, 925,000 CYCLES

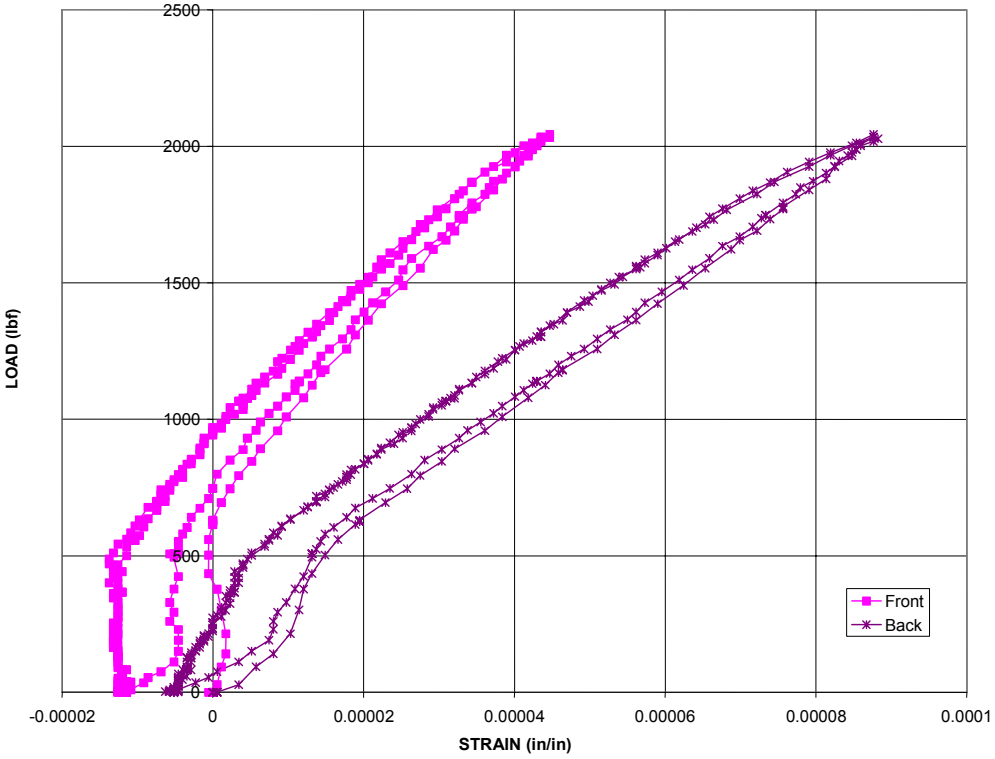

FIGURE F-86. STRAIN GAGE DATA, SCG-8, 1,025,000 CYCLES

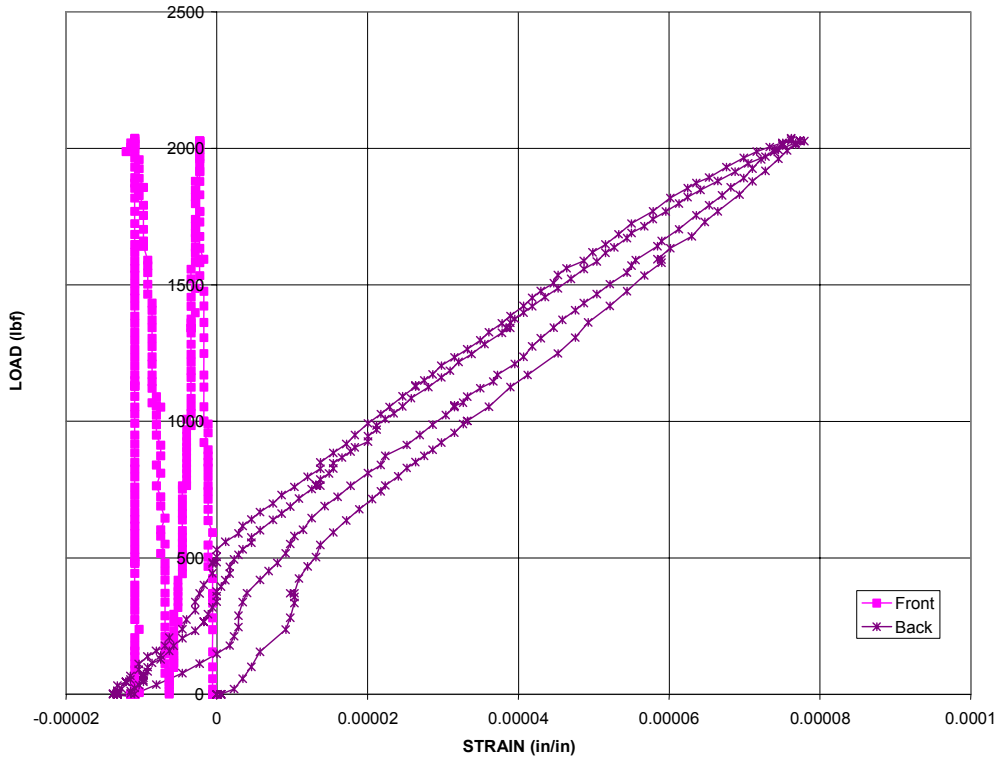

FIGURE F-87. STRAIN GAGE DATA, SCG-8, 1,125,000 CYCLES

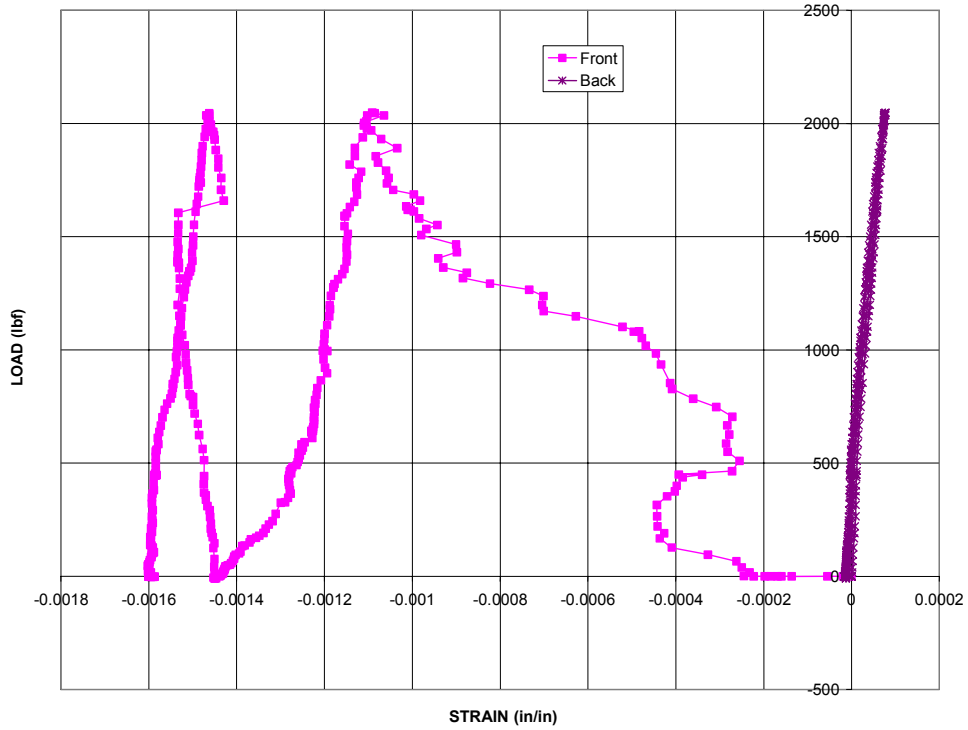

FIGURE F-88. STRAIN GAGE DATA, SCG-8, 1,225,000 CYCLES

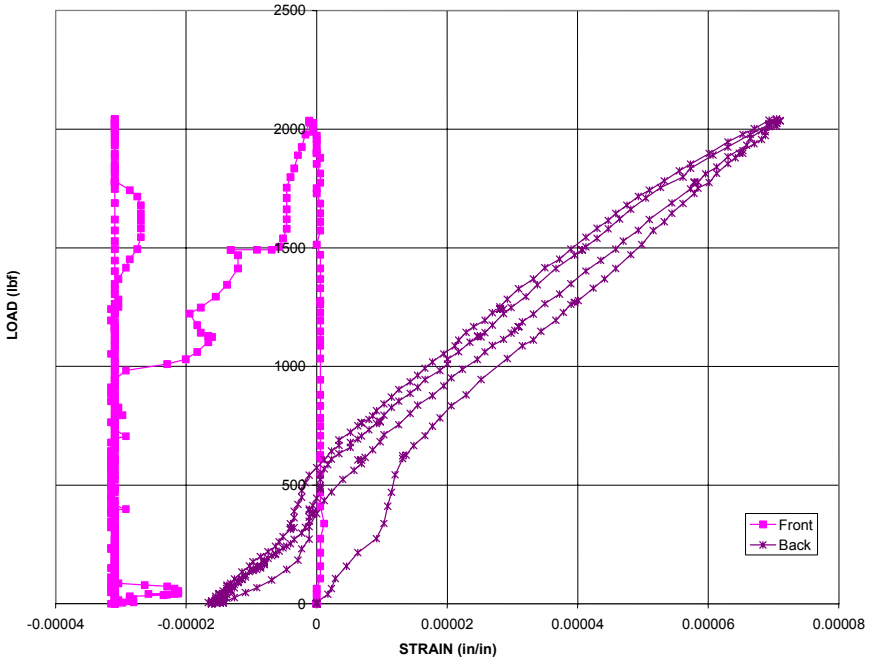

FIGURE F-89. STRAIN GAGE DATA, SCG-8, 1,325,000 CYCLES

F.8 SPECIMEN SCG-9 CALIBRATION DATA.

Specimen SCG-9 has 0.120″ steel doublers and was tested under EIFS spectrum loads with maximum stress of 13.4 ksi. Strain surveys were taken before and after the specimen was disassembled for periodic inspection.

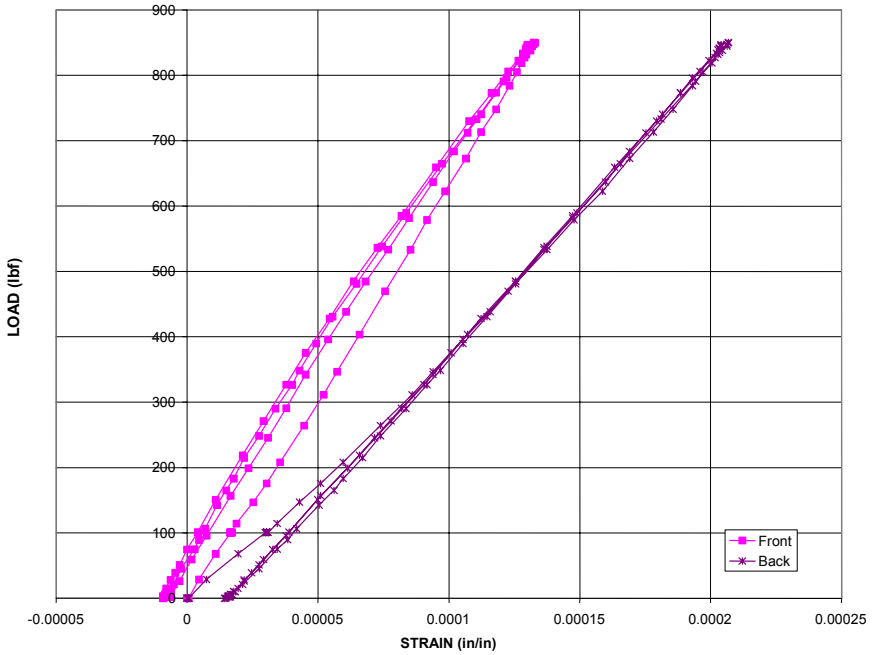

FIGURE F-90. STRAIN GAGE DATA, SCG-9, CALIBRATION #1

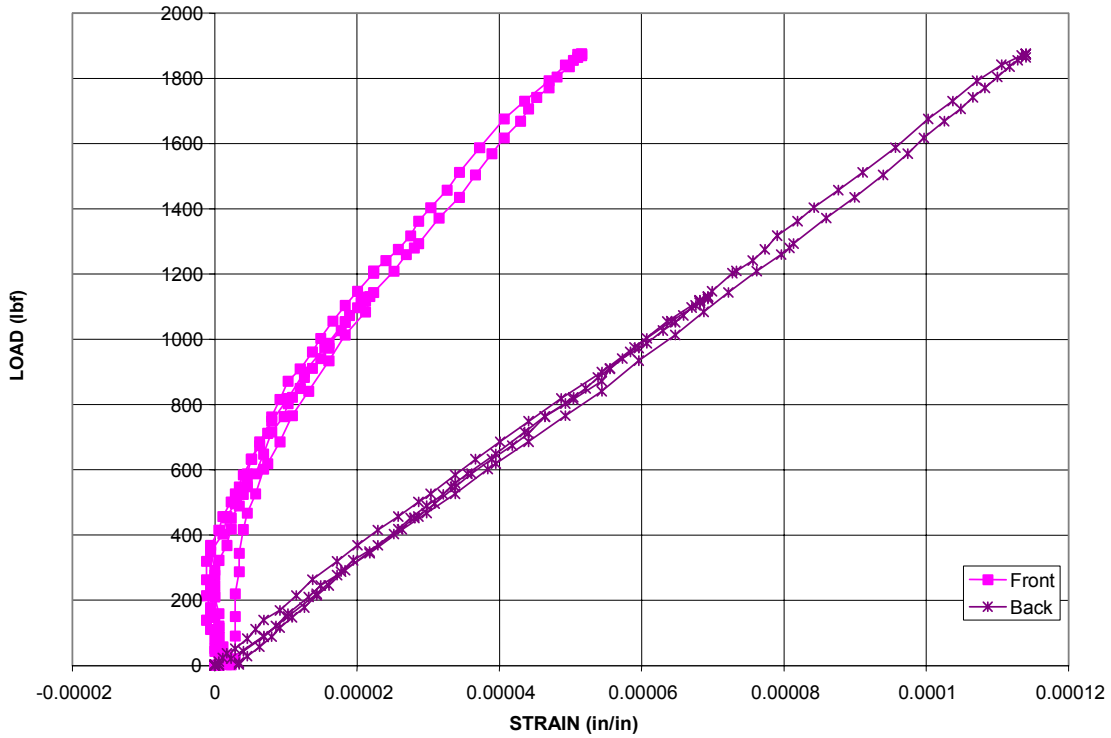

FIGURE F-91. STRAIN GAGE DATA, SCG-9, 0 CYCLES

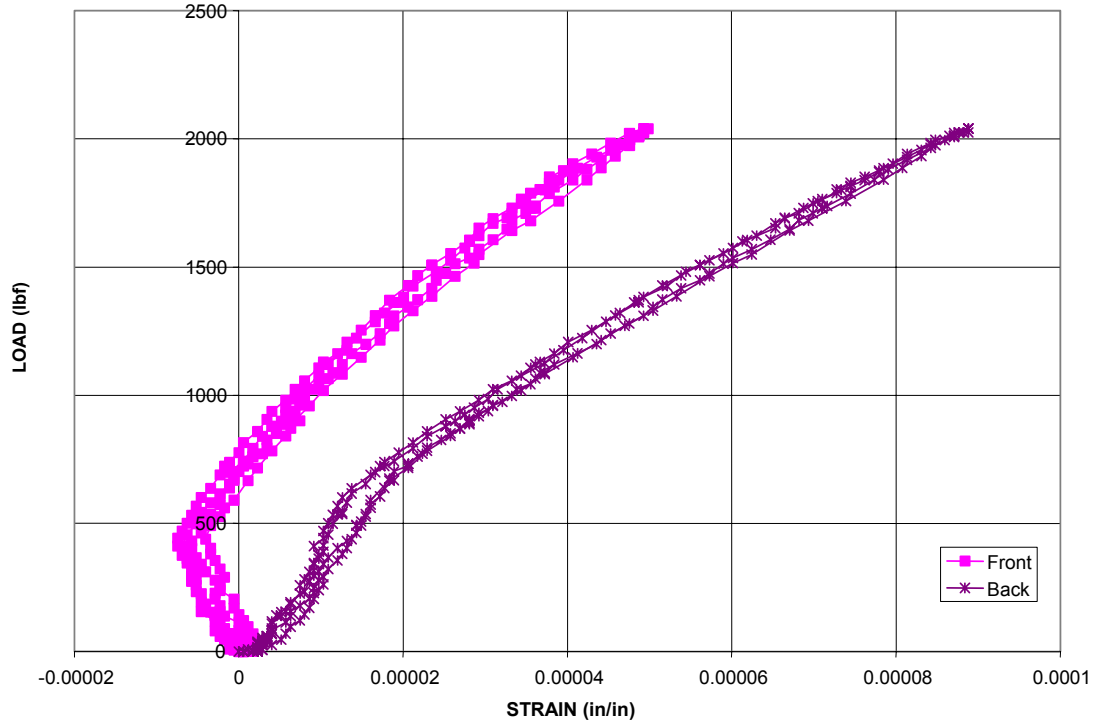

FIGURE F-92. STRAIN GAGE DATA, SCG-9, 1,100,000 CYCLES

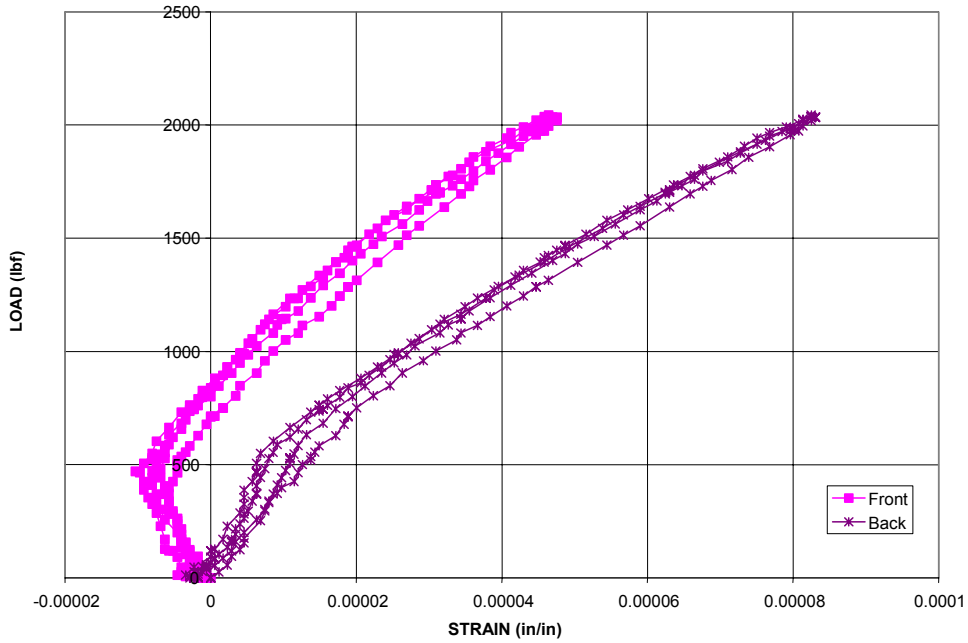

FIGURE F-93. STRAIN GAGE DATA, SCG-9, 1,200,000 CYCLES

F.9 SPECIMEN SCG-11 CALIBRATION DATA.

Specimen SCG-11 has 0.063″ steel doublers and was cycled at a constant amplitude of 10 ksi, R = 0.1. Strain surveys were taken before and after the specimen was disassembled for periodic inspection.

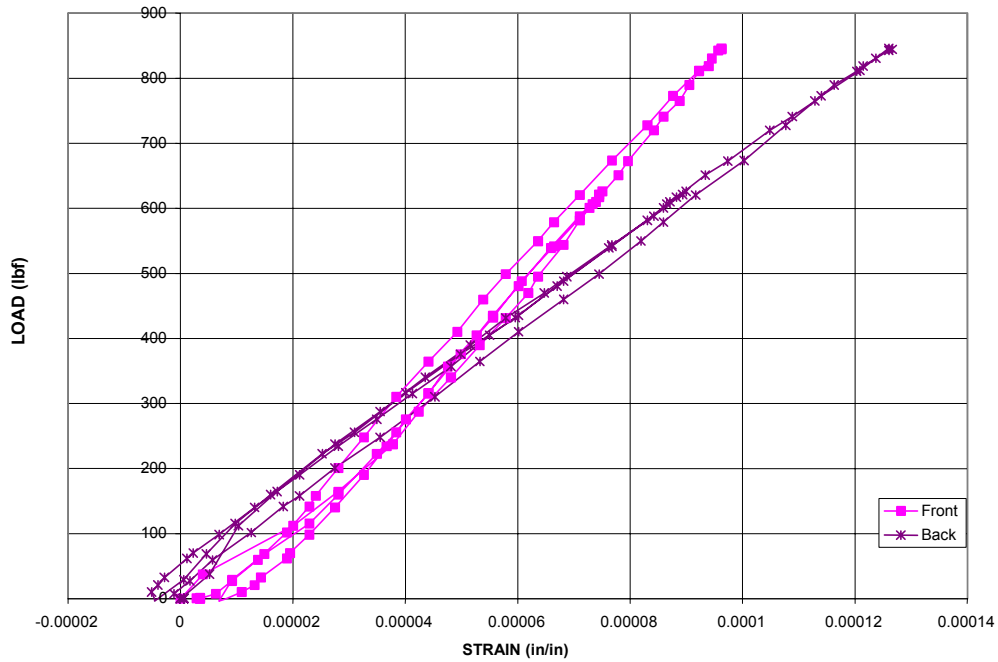

FIGURE F-94. STRAIN GAGE DATA, SCG-11, CALIBRATION #1 RUST REMOVED

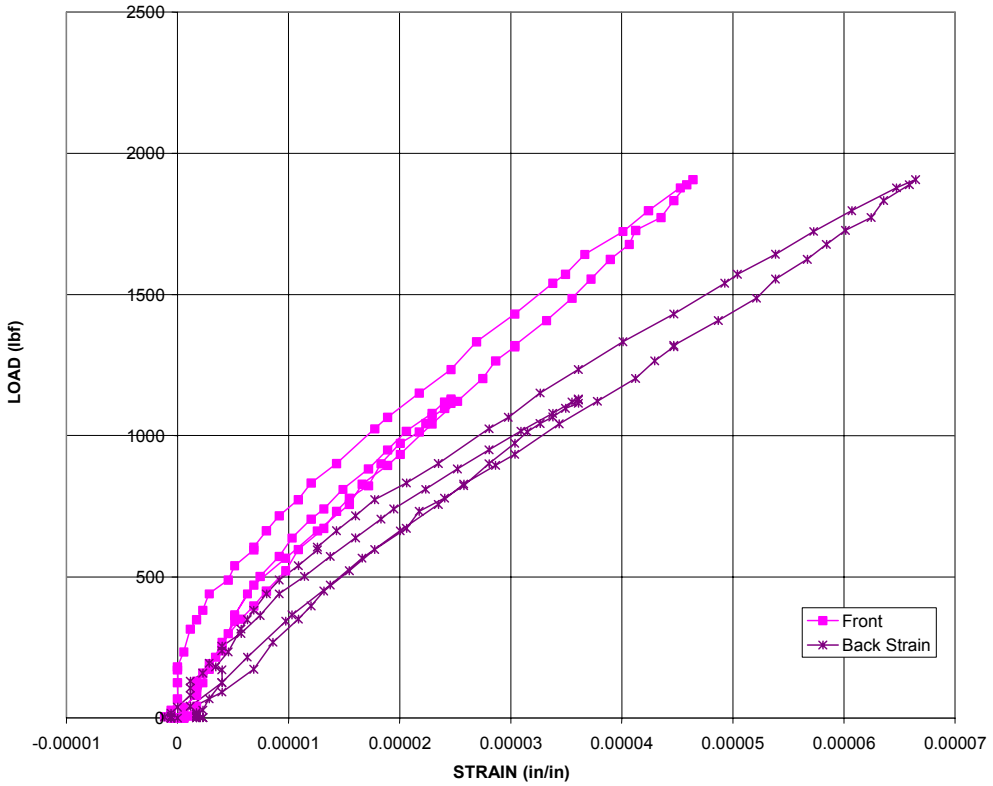

FIGURE F-95. STRAIN GAGE DATA, SCG-11, 0 CYCLES RUST REMOVED

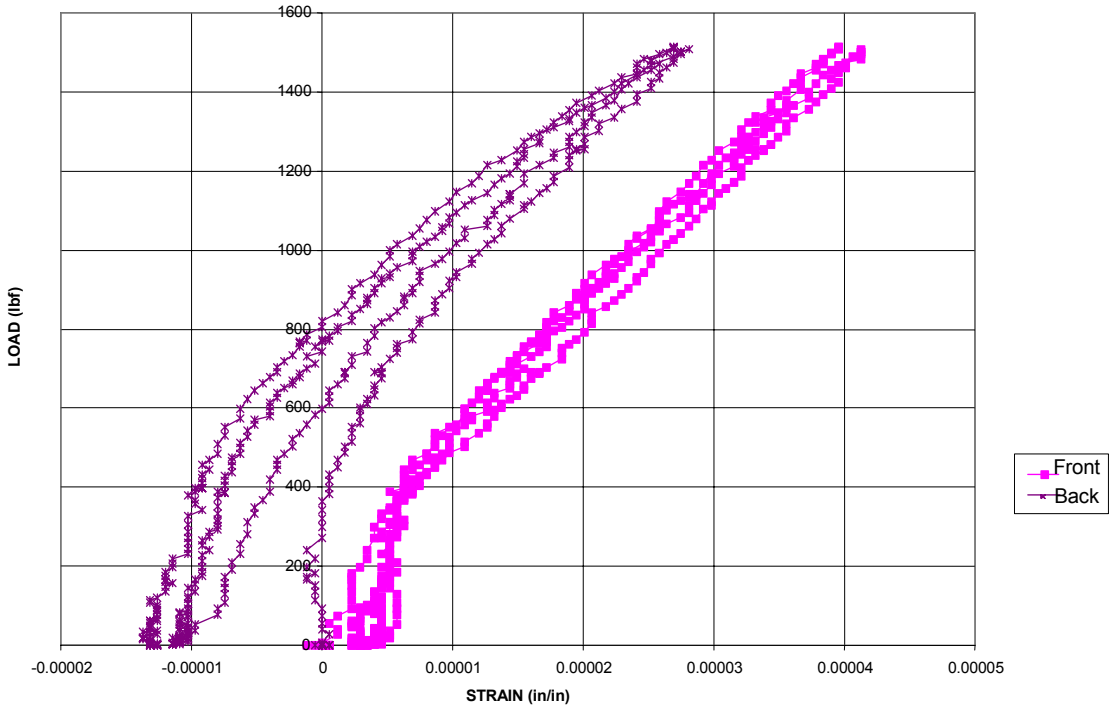

FIGURE F-96. STRAIN GAGE DATA, SCG-11, 30,000 CYCLES

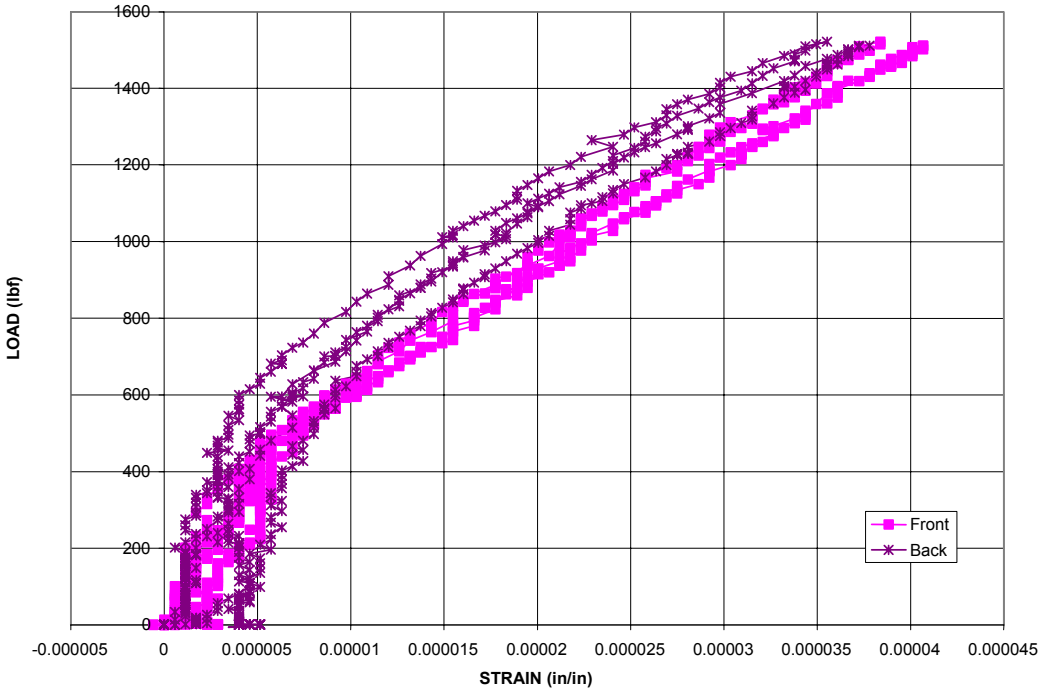

FIGURE F-97. STRAIN GAGE DATA, SCG-11, 50,000 CYCLES

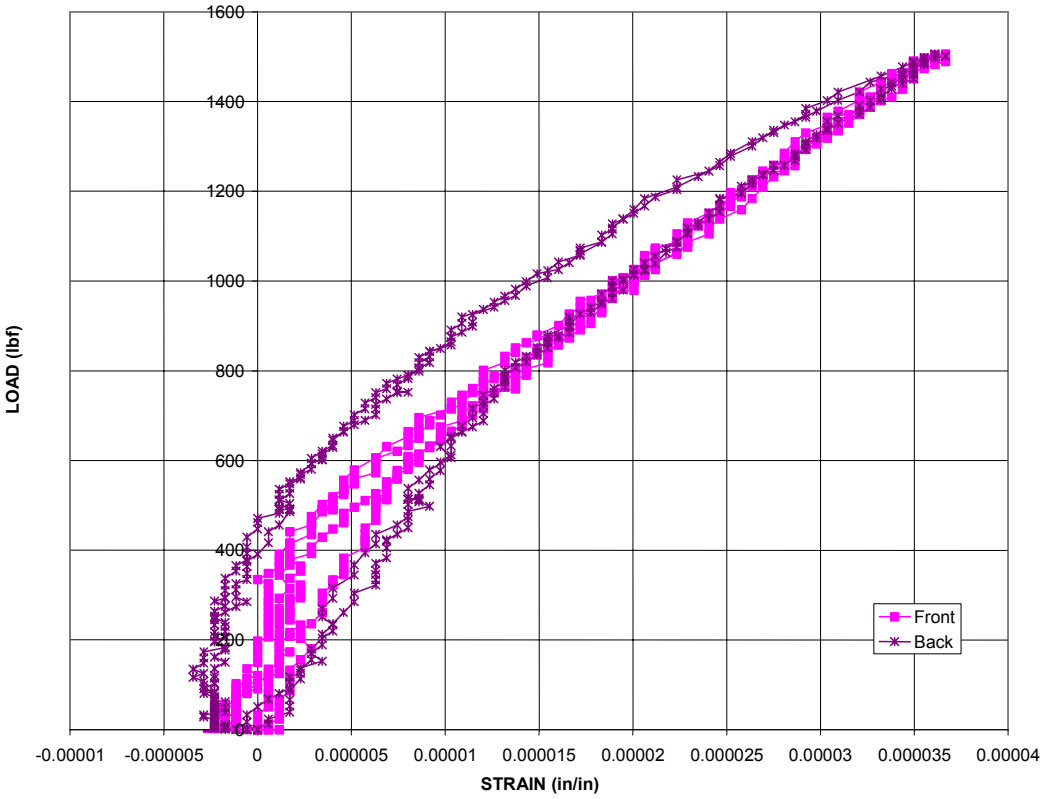

FIGURE F-98. STRAIN GAGE DATA, SCG-11, 60,000 CYCLES

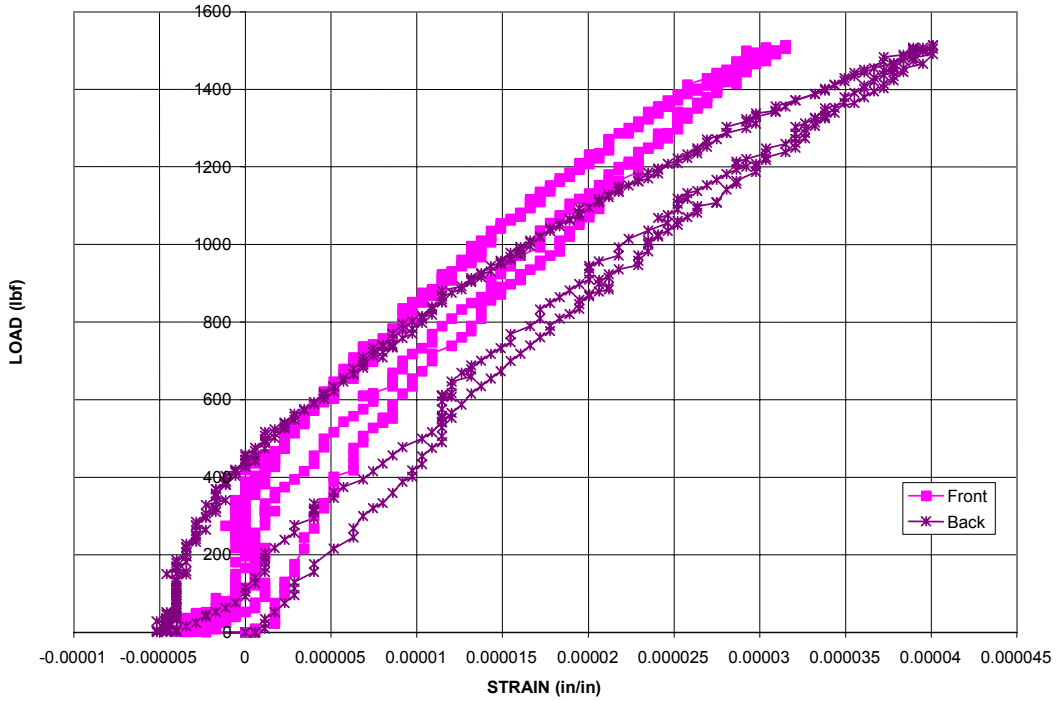

FIGURE F-99. STRAIN GAGE DATA, SCG-11, 80,000 CYCLES

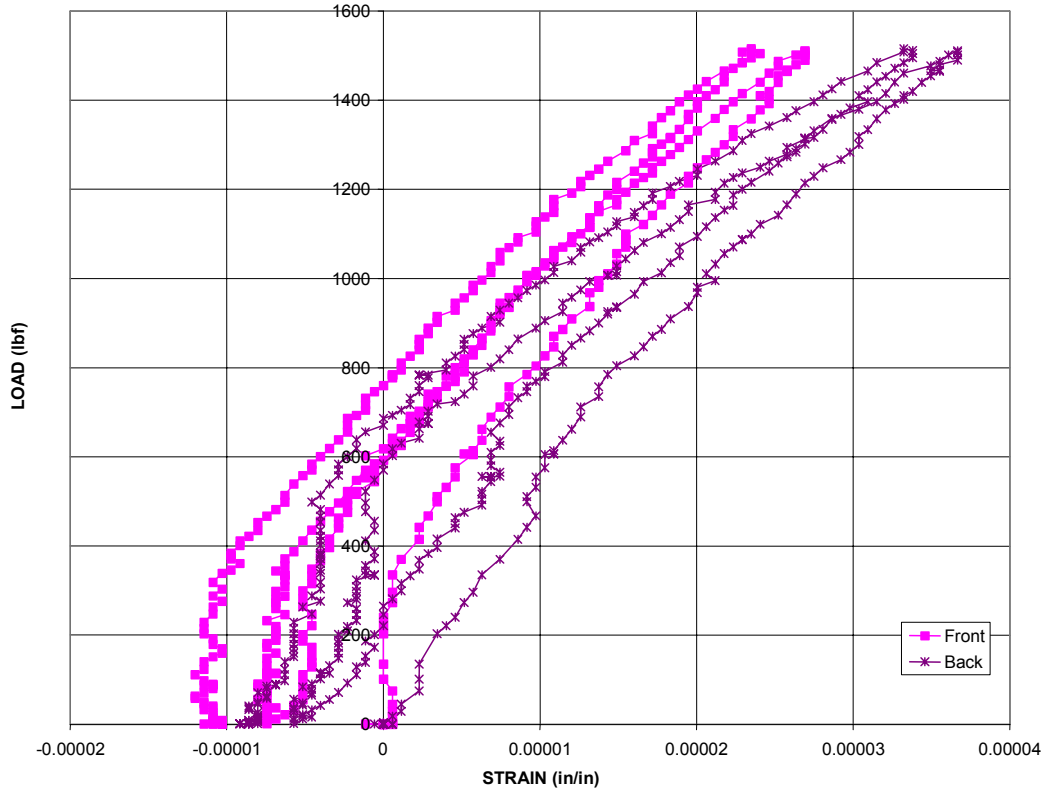

FIGURE F-100. STRAIN GAGE DATA, SCG-11, 95,000 CYCLES

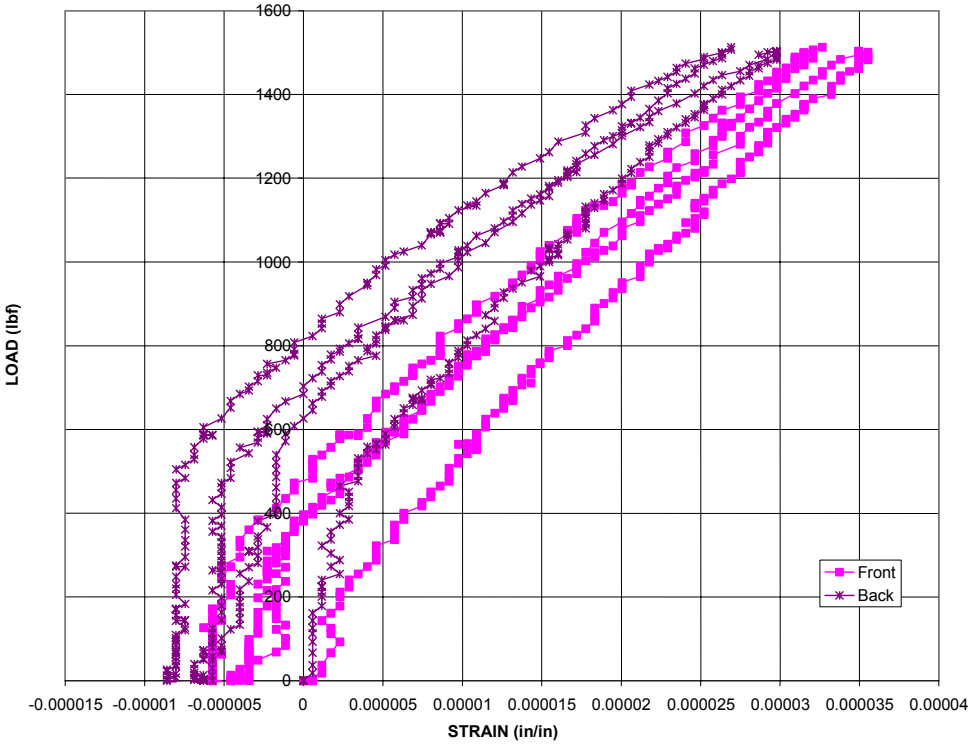

FIGURE F-101. STRAIN GAGE DATA, SCG-11, 110,000 CYCLES

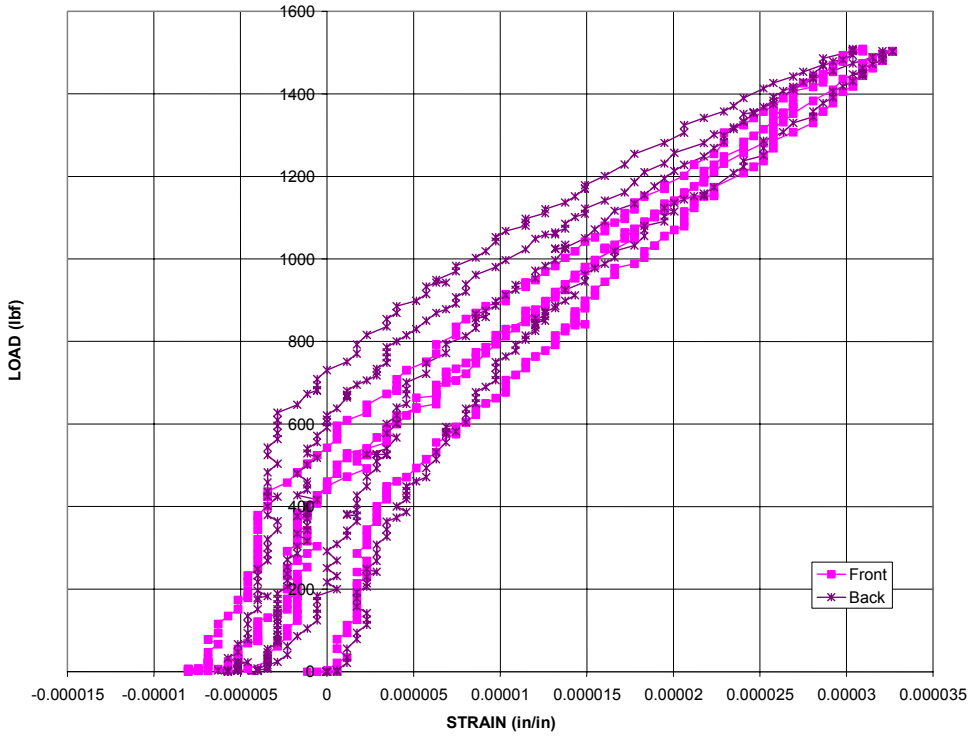

FIGURE F-102. STRAIN GAGE DATA, SCG-11, 130,000 CYCLES

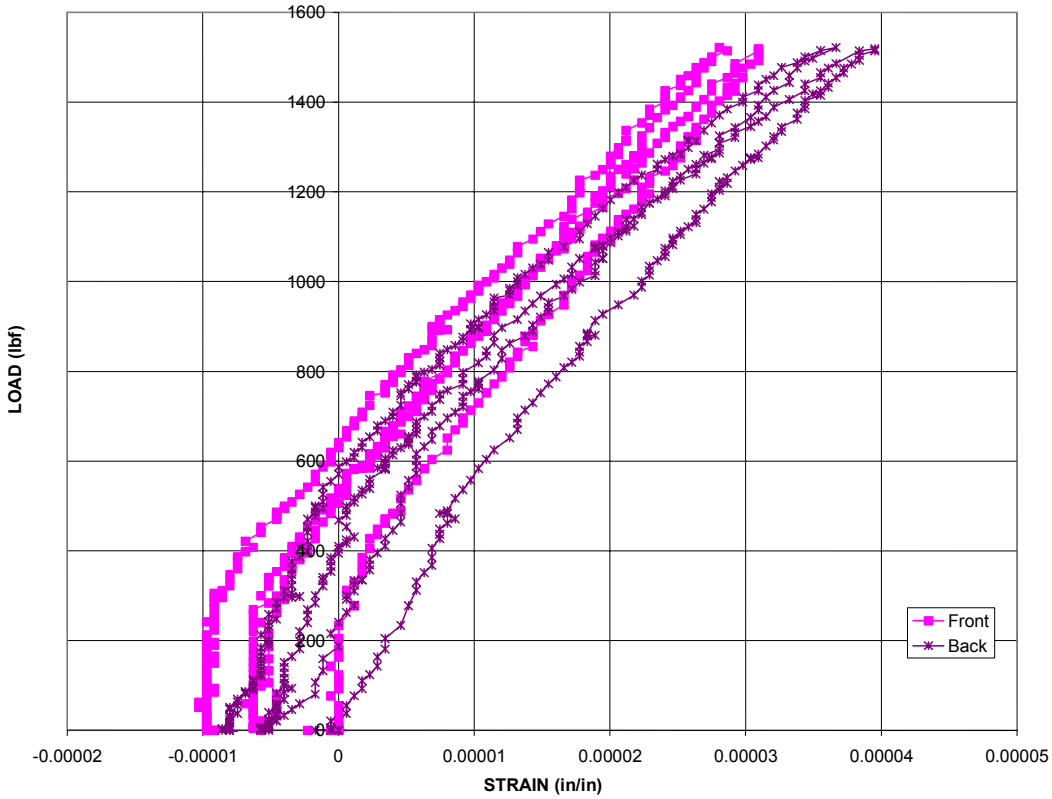

FIGURE F-103. STRAIN GAGE DATA, SCG-11, 145,000 CYCLES

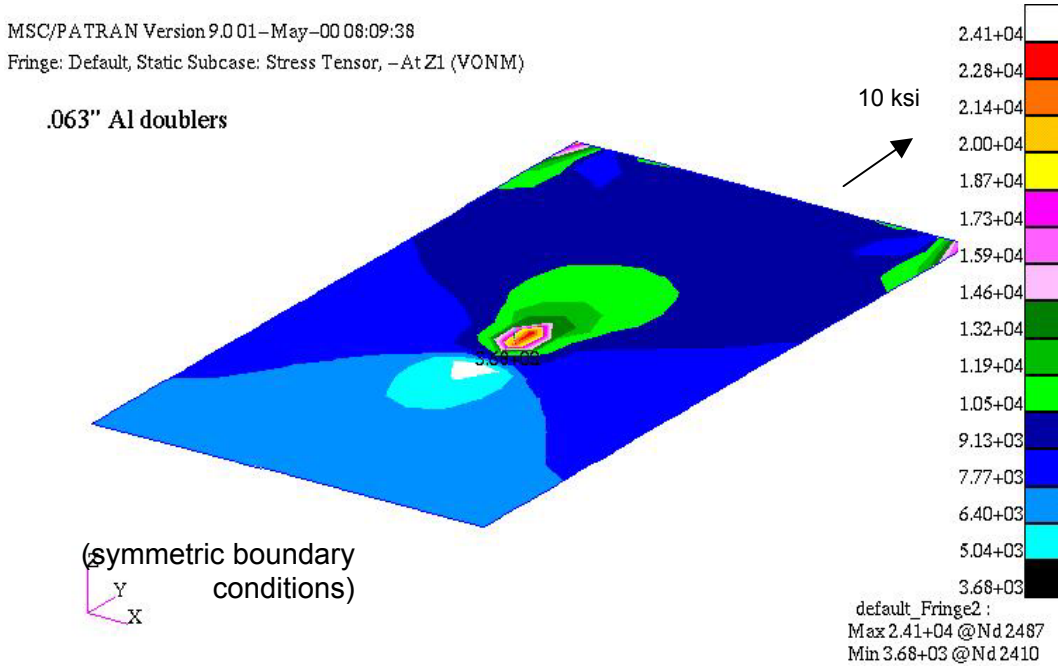

FIGURE F-104. STRESS DISTRIBUTION FOR HALF-MODEL WITH 0.063″ Al DOUBLERS

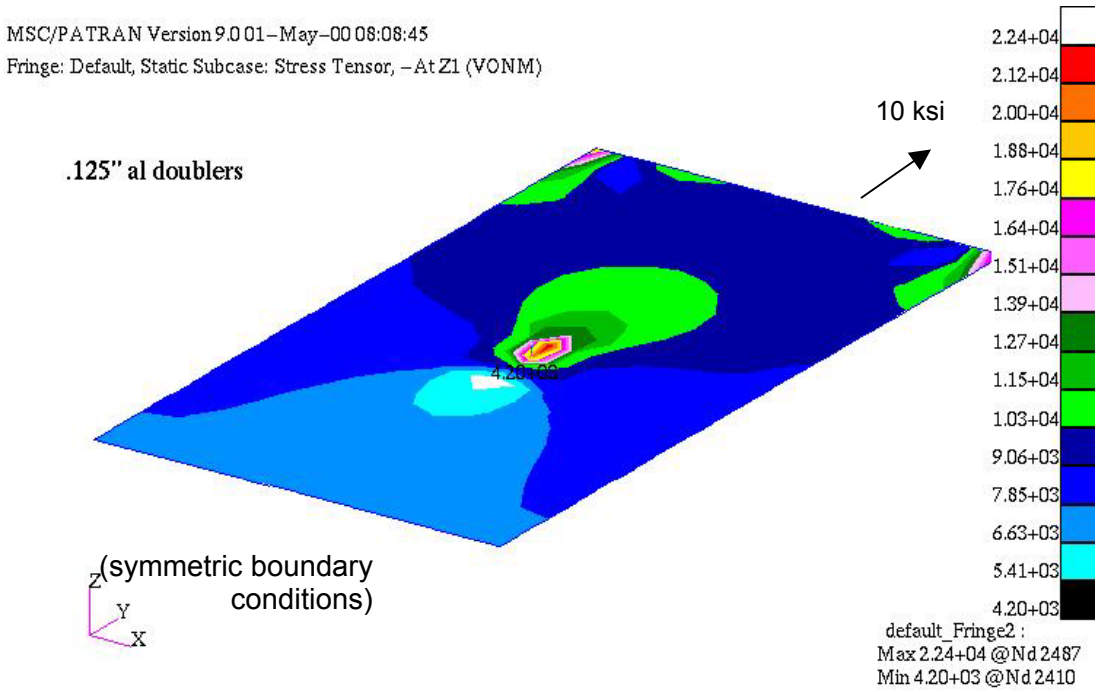

FIGURE F-105. STRESS DISTRIBUTION FOR HALF-MODEL WITH 0.125″ Al DOUBLERS

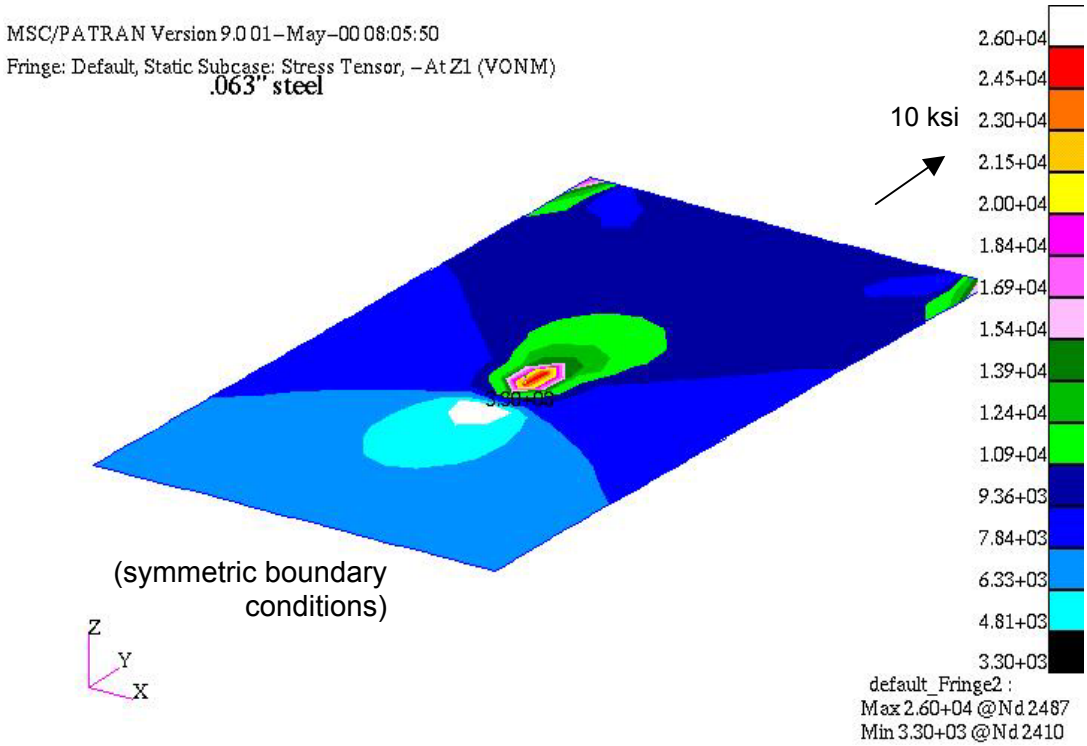

FIGURE F-106. STRESS DISTRIBUTION FOR HALF-MODEL WITH 0.063″ STEEL DOUBLERS

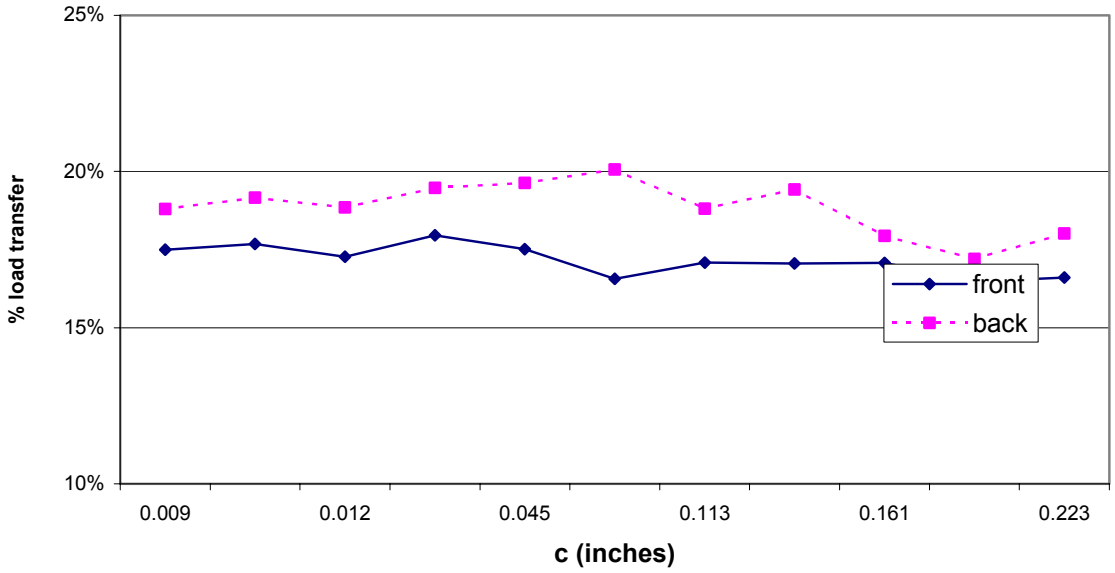

FIGURE F-107. CHANGE IN LOAD TRANSFER WITH CRACK EXTENSION, SCG-1s

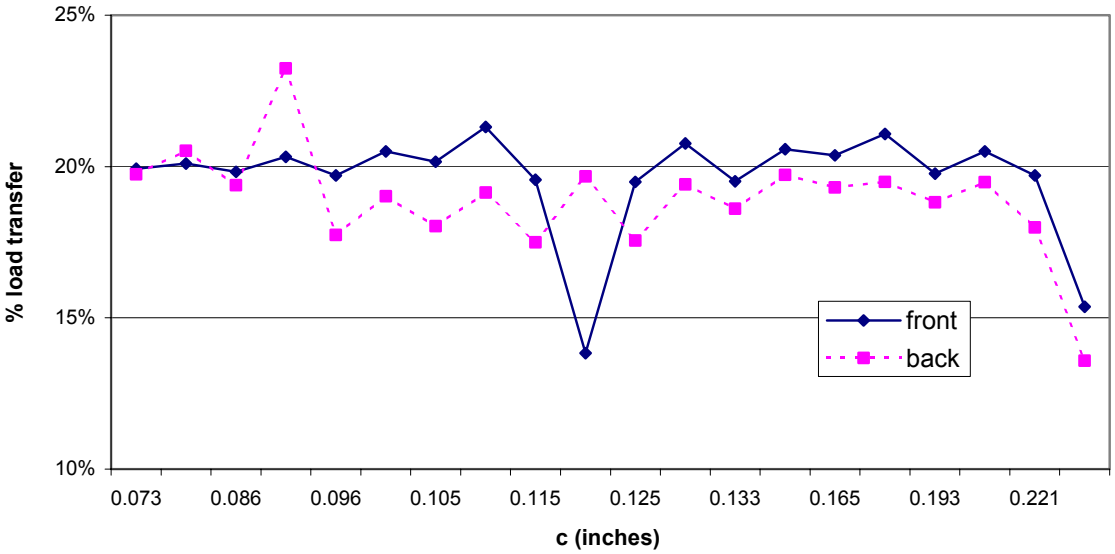

FIGURE F-108. CHANGE IN LOAD TRANSFER WITH CRACK EXTENSION, SCG-2

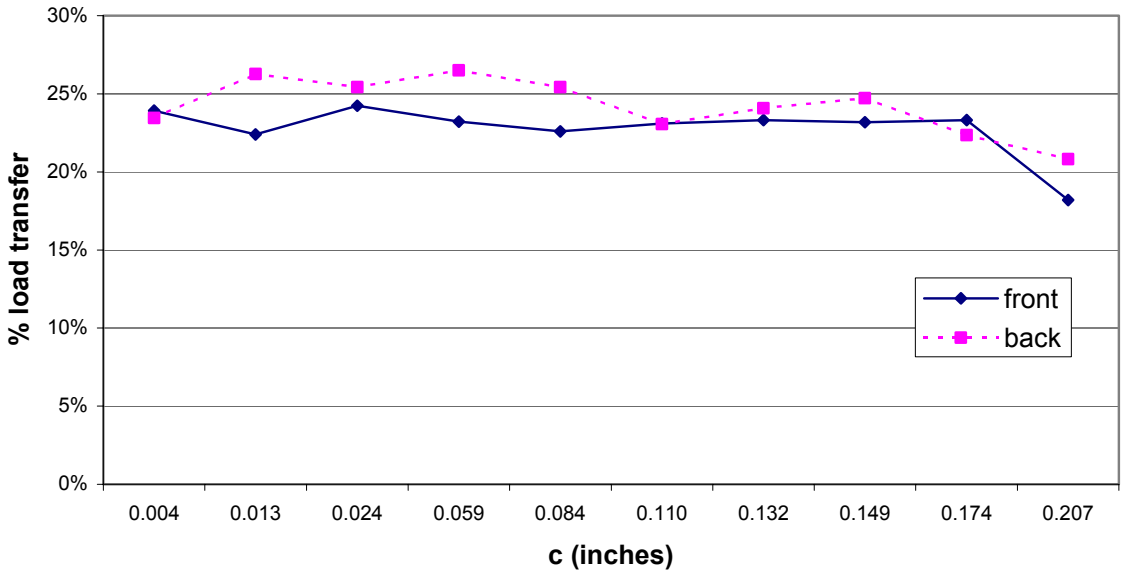

FIGURE F-109. CHANGE IN LOAD TRANSFER WITH CRACK EXTENSION, SCG-6

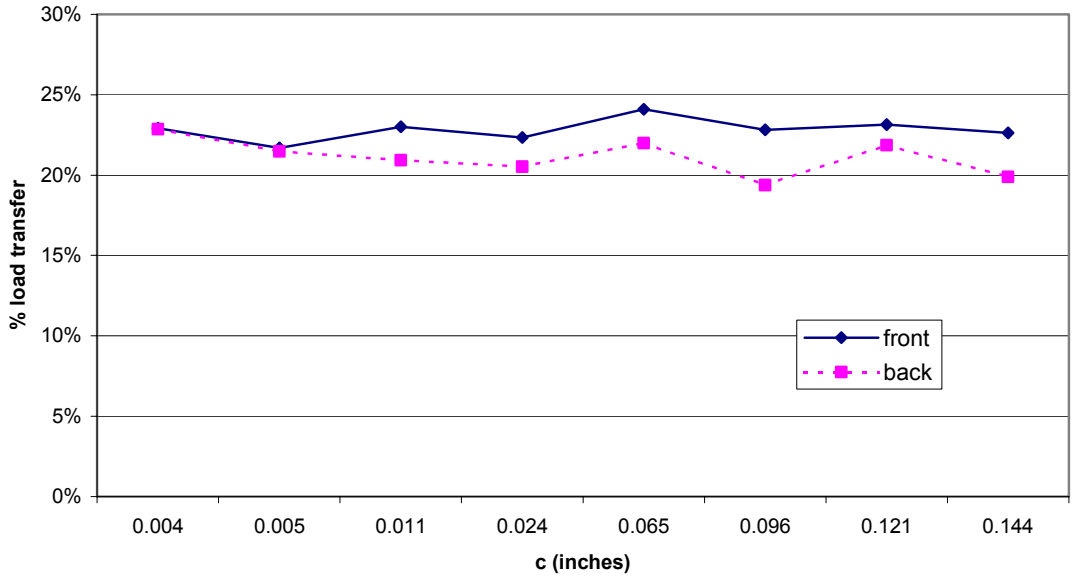

FIGURE F-110. CHANGE IN LOAD TRANSFER WITH CRACK EXTENSION, SCG-7

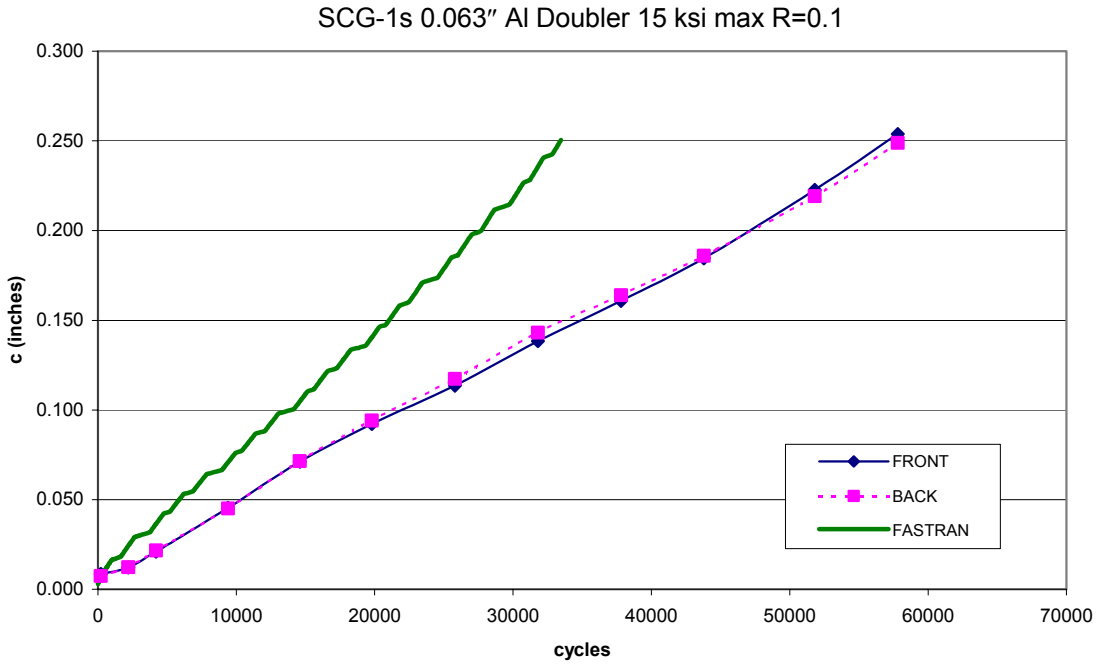

FIGURE F-111. FASTRAN/TEST COMPARISON, CRACK LENGTH VS CYCLES FOR SCG-1s

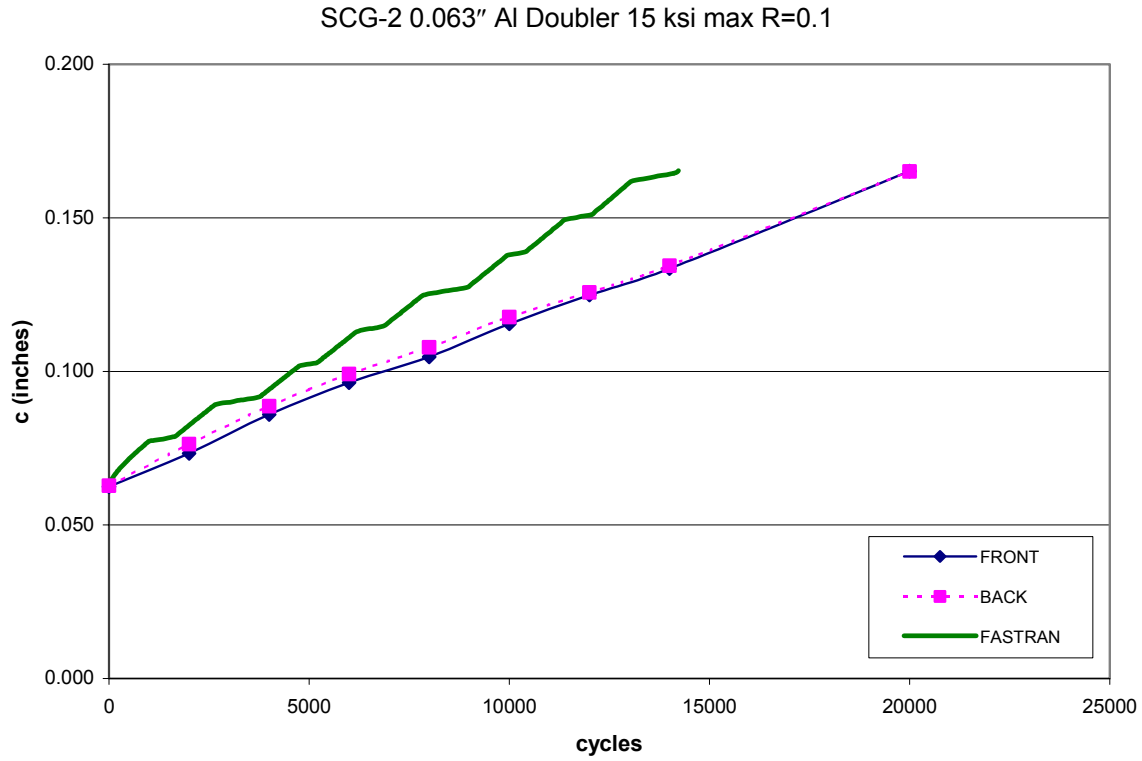

FIGURE F-112. FASTRAN/TEST COMPARISON, CRACK LENGTH VS CYCLES FOR SCG-2

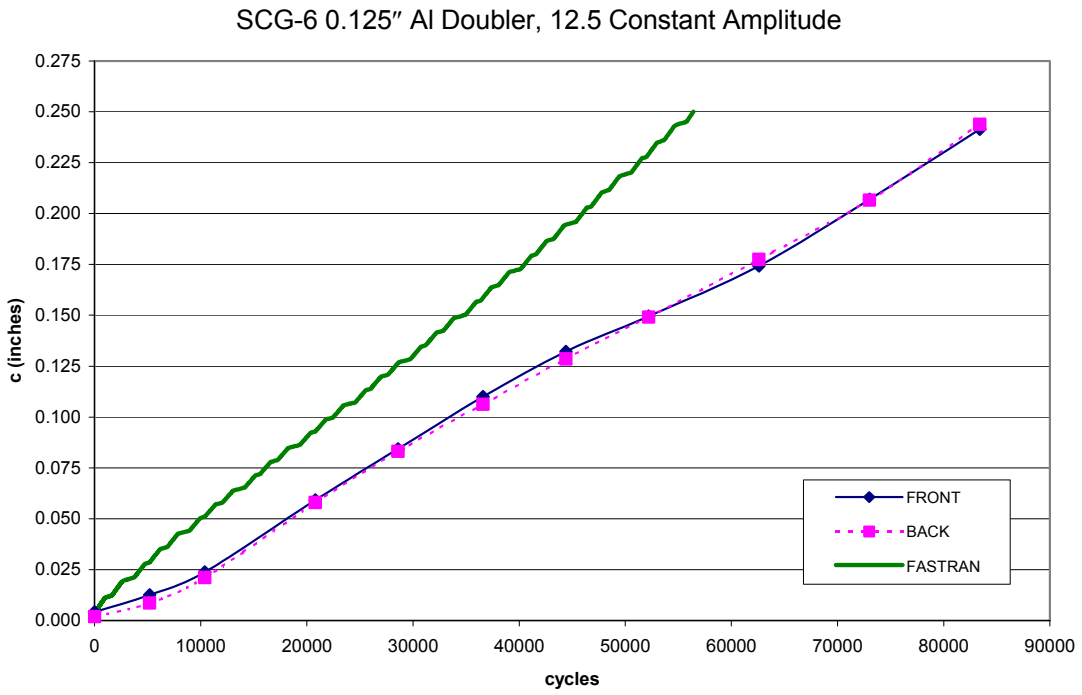

FIGURE F-113. FASTRAN/TEST COMPARISON, CRACK LENGTH VS CYCLES FOR SCG-6

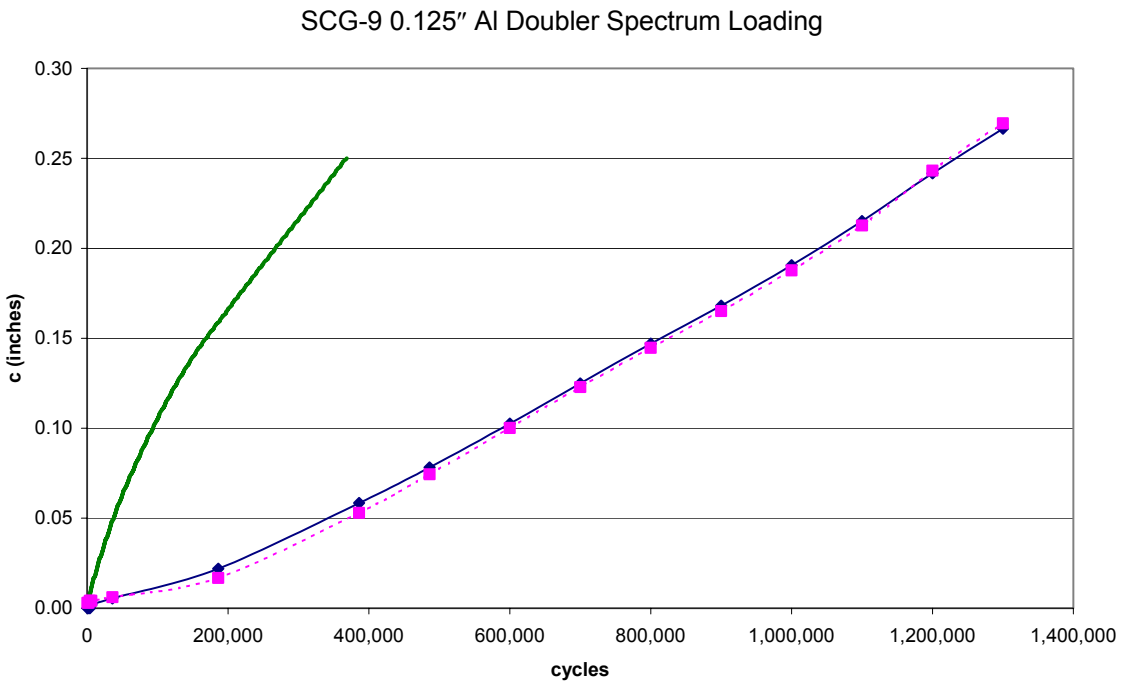

FIGURE F-114. FASTRAN/TEST COMPARISON, CRACK LENGTH VS CYCLES FOR SCG-9

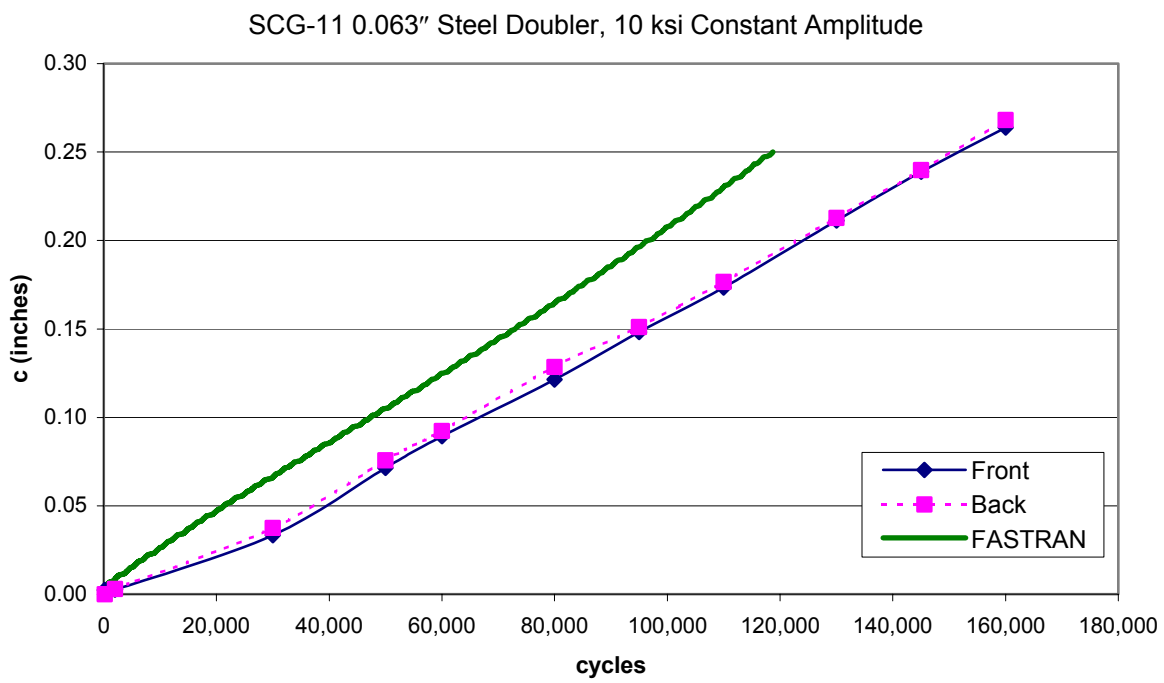

FIGURE F-115. FASTRAN/TEST COMPARISON, CRACK LENGTH VS CYCLES FOR SCG-11

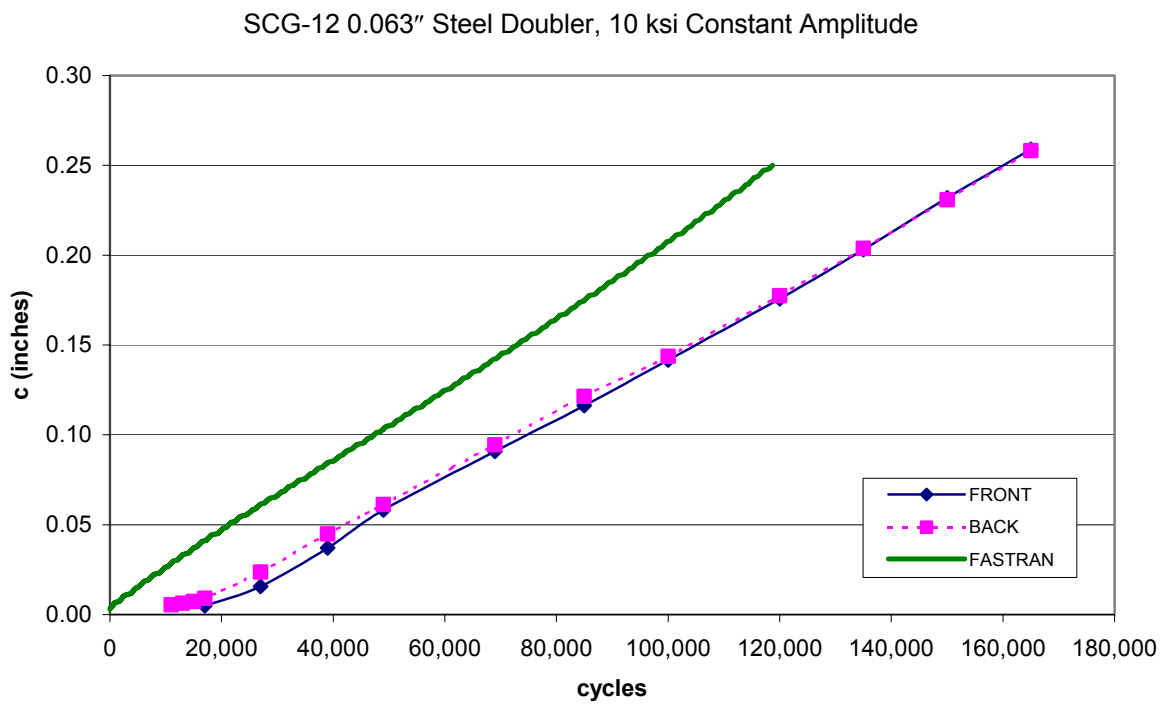

FIGURE F-116. FASTRAN/TEST COMPARISON, CRACK LENGTH VS CYCLES FOR SCG-12

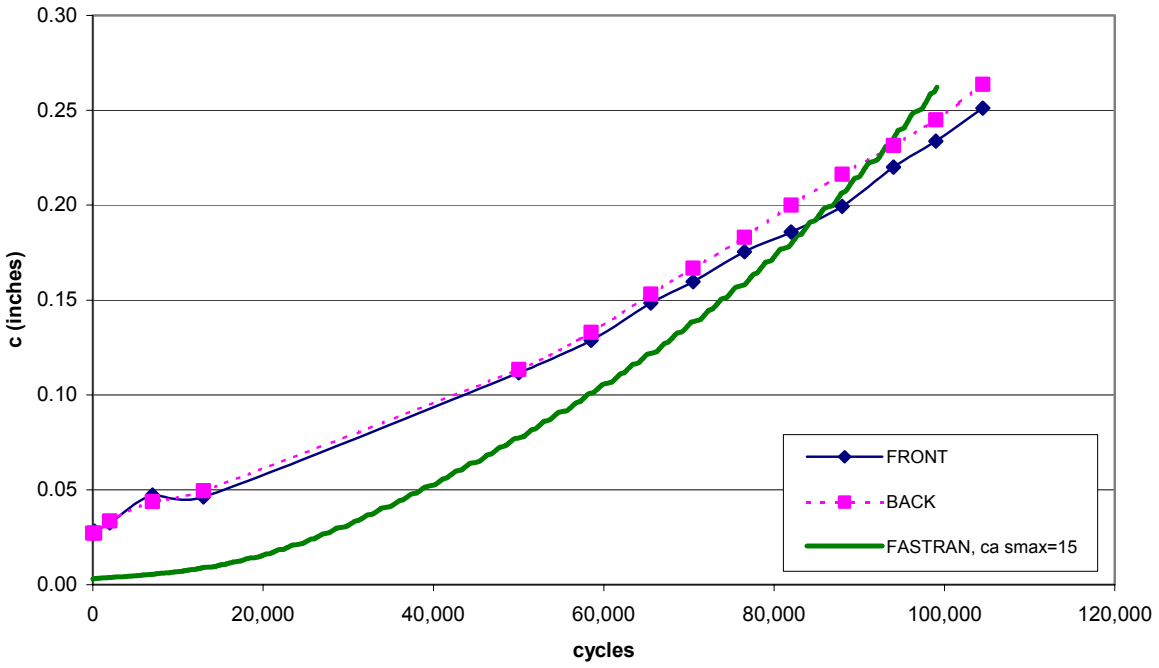

FIGURE F-117. FASTRAN/TEST COMPARISON, CRACK LENGTH VS CYCLES FOR SCG-17s NO DOUBLER

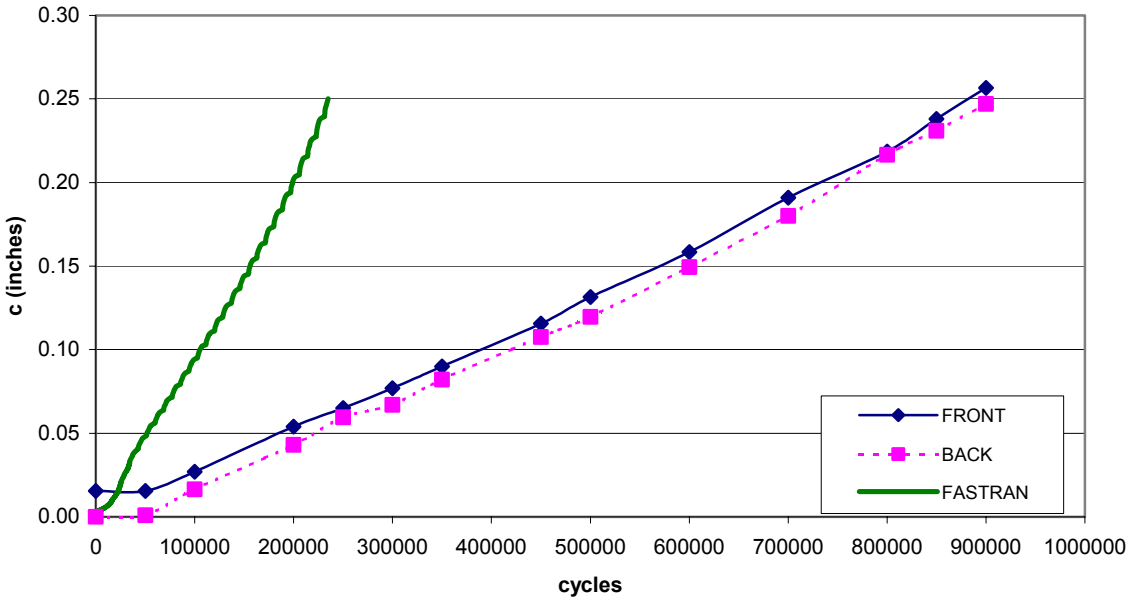

FIGURE F-118. FASTRAN/TEST COMPARISON, CRACK LENGTH VS CYCLES FOR SCG-19s