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# MECHANICAL TESTING OF LARGE THALLIUM DOPED SODIUM IODIDE SINGLE CRYSTALS

By Henry M. Lee

Structures and Propulsion Laboratory
Science and Engineering

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16. ABSTRACT

This report presents the findings of mechanical tests performed on five thallium-doped sodium iodide [NaI(Tl)] crystals. These crystals were all in the shape of circular flat plates, 20.0 in. in diameter and 0.5 in. thick. The test setup, testing procedure, and the test data are presented.

The report shows that these large crystals exhibit a high degree of material plasticity, as well as a much higher strength than previously anticipated, on the order of 500 psi. Also revealed from the testing was the fact that crystals with a large number of grain boundaries developed less plasticity, and therefore less permanent deformation, than those with fewer grain boundaries.

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# MECHANICAL TESTING OF LARGE THALLIUM DOPED SODIUM IODIDE SINGLE CRYSTALS

## SUMMARY

To determine the structural behavior of large thallium-doped single crystals of sodium iodide [NaI(Tl)], five specimens in the shape of circular flat plates 20.0 in. in diameter and 0.5 in. thick were utilized in mechanical tests at the Marshall Space Flight Center's Materials and Processes Laboratory. A test fixture in a dry box was designed to subject each crystal to a uniform pressure load across its entire surface, with a built-in "O" ring to prevent motion normal to it. Careful loading and unloading of each crystal along with precise measurements of the deformations, were used to generate the test data.

Results of the testing revealed that the large crystals possess considerable material plasticity. It also became quite evident that the ultimate tensile strength ($F_{tu}$) was much higher than previously anticipated [1]. Although each specimen was loaded in such a manner as to develop at least 500 psi in the material, only one extremely hydrated crystal failed during the testing sequence.

Another phenomenon was consistently seen in testing, and that was the fact that crystals with a large number of grain boundaries developed less plasticity, and therefore less permanent deformation, than those with fewer grain boundaries.

Another significant goal of the program was the development of a procedure to be utilized in stress screening each candidate flight crystal. The purpose for this screening was to eliminate any potentially weak crystal prior to assembly into an experiment scheduled for extended Earth orbit, and to gain assurance that material yielding could be kept to a minimum.

## INTRODUCTION

Historically, thallium-doped sodium iodide [NaI(Tl)] single-crystal mechanical tests have been accomplished only on small samples, with results ranging from 250 psi to 900 psi for ultimate tensile strength [1]. The Marshall Space Flight Center (MSFC), however, is developing an experiment known as the burst and transient source experiment (BATSE) which will employ single crystals 20.0 in. in diameter and 0.5 in. thick. Each detector will consist of a single crystal scintillator designed to monitor the unocculted sky for gamma ray bursts, transient sources, and intensity variations of known sources in the approximate range of 60 keV to 600 KeV. This experiment is to be launched into Earth orbit aboard the Space Shuttle in 1988. Each crystal must, therefore, be able to structurally survive the normal handling, transportation, and launch acceleration levels, as well as on-orbit thermal environments.

The lack of fracture mechanics data and the seemingly unpredictable strength of the crystals, coupled with the scientific desire to have as little permanent deformation (yielding) of the material as possible, led to a testing procedure that would stress screen each potential flight crystal, as well as develop the needed mechanical characteristics.

## TEST SETUP

The basic apparatus used to accomplish the desired mechanical testing of the NaI(Tl) single crystals was a test fixture held within a plexiglass glove box purged with dry air (about 3 percent relative humidity). The temperature and relative humidity in the glove box were continuously monitored. Figure 1 shows the basic test setup. The vacuum gage was actually a manometer filled with silicon oil. The test fixture itself was an aluminum structure with an "O" ring groove 0.112 in. deep by 0.190 in. wide and 19.5 in. in diameter. An "O" ring made of a silicon rubber with a Shore hardness of 30 was utilized to provide an air tight seal as well as a soft surface for the crystal to bear against. Displacement dial indicators were used to record the motion of the outer edge of the crystal just above the "O" ring and the very center of the crystal. These gages were capable of measuring displacement of each specimen to ±0.00005 in. The vacuum source was connected to a ballast tank which had a control valve plus a bleed valve to accurately regulate the magnitude of the differential pressure imposed on the test article. Because of the high density of NaI(Tl), each test crystal had an additional equivalent uniform pressure load of the crystal specimen thickness (T) times the material density ($\rho$) (= 0.0661 psi). This gravity load produced a maximum stress of ±31 psi on the surfaces of the crystal at the center.

In addition, every specimen came with an arrow (⇧) mark on the edge to indicate the frontside or backside of the crystal. The position of the arrow was carefully noted prior to each series of tests.

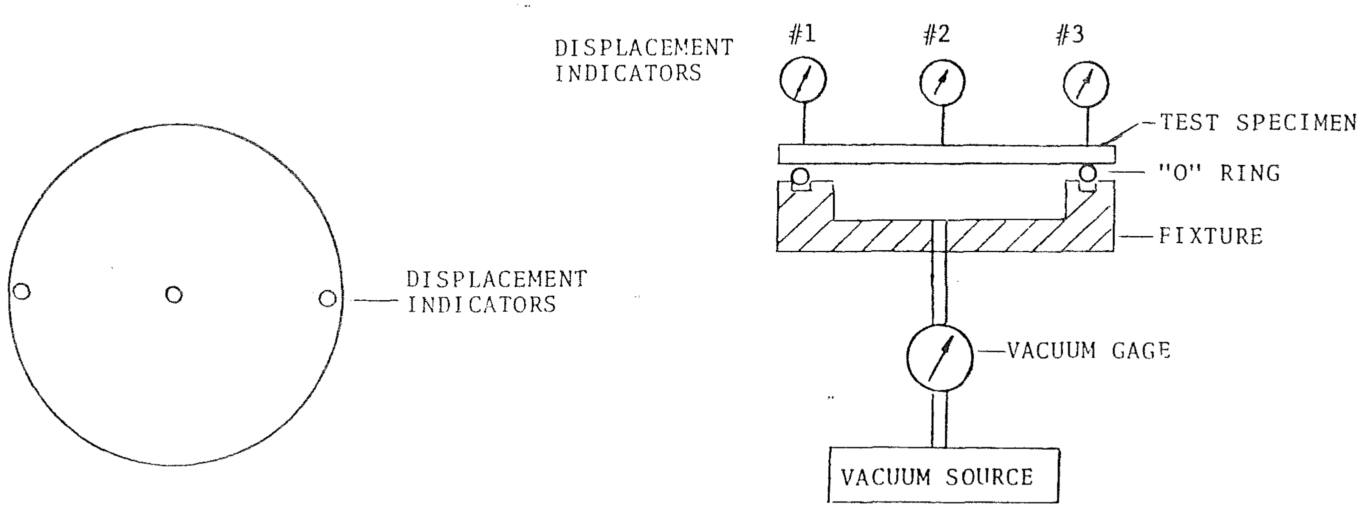


Figure 1. Test setup.

## TESTING PROCEDURE

Mechanical testing of each test crystal consisted of loading each crystal to limit load (0.23 psi) and returning to zero load, then reloading it to 1.4 times limit load (0.35 psi) and back to zero load. This process was performed on both sides of each specimen, and was utilized as a development screening sequence for all prospective flight crystals. Three crystals were then loaded to over 3 times limit load (1.00 psi). Two crystals were also cycled 20 times to 1.4 times limit and then reloaded to over 3 times limit. This last series of tests was accomplished to determine if any significant degradation in crystal strength occurred due to cyclic loading. Table 1 depicts the test history for each crystal.

The actual testing of the crystals consisted of the following typical procedure:

a) Purge the drybox to less than 10 percent relative humidity.

b) Carefully place the crystal specimen in the "O" ring and center it on the fixture; note which side is in tension.

c) Swing the dial indicators perpendicular to the crystal surface and lock in place.

d) Purge the drybox to less than 10 percent relative humidity.

e) Close control valve on vacuum ballast.

f) Start vacuum pump.

g) Take an initial reading on manometer and dials.

h) Open control valve slowly and adjust to give proper manometer reading.

i) Allow system to equilibrate, then read manometer and dials.

j) Readjust for each pressure desired and read manometer and dials after equilibrating the following pressures:

1) Limit load pressure (screening) psi 0.0, 0.05, 0.15, 0.20, 0.23, 0.15, 0.10, 0.05, 0.0.

2) 1.4 x limit load pressure (screening) psi 0.0, 0.05, 0.10, 0.15, 0.20, 0.25, 0.30, 0.35, 0.25, 0.15, 0.05, 0.0.

k) Swing dial indicators away from specimen, remove crystal and turn it over.

l) Repeat steps (b) through (j).

All other testing was accomplished utilizing a similar routine.

# TABLE 1. CRYSTAL TEST HISTORY

| CRYSTAL # | LIMIT TEST BOTH SIDES | 1.4 X LIMIT BOTH SIDES | >3 X LIMIT | | 20 CYCLES AT 1.4 X LIMIT THEN >3 X LIMIT | | COMMENTS |
|---|---|---|---|---|---|---|---|
| | | | ⇩ | ⇧ | ⇩ | ⇧ | |
| 1 | | | | | | | Failed in shipment |
| 2 | | | | | | | Failed in shipment |
| 3 | X | X | X | | | X | Good condition |
| 4 | X | X | X | X(failed)* | | | Extremely hydrated |
| 5 | X | X | X | X | | | Good condition |
| 6 | X | X | | | | | Good condition |
| 7 | X | X | | | X | X | Good condition |

*NOTE: Crystal #4 failed at 3 X Limit pressure

## CRYSTAL GRAIN BOUNDARIES

A total of seven crystal specimens were used at MSFC for mechanical testing. All seven were 20.0 in. in diameter and 0.5 in. thick. Each was sealed in an environmental plastic bag, and included with it was a blue line drawing of every grain boundary. Test crystals numbers 1 through 4 had a large number of grain boundaries as shown in Figures 2 through 5. Only crystals numbers 3 and 4 were tested from this lot, since numbers 1 and 2 were destroyed in shipment to MSFC. Figure 6 reveals an overlay of the grain boundaries and the handling fracture lines for crystal number 1. It is evident from this figure that the grain boundaries played an insignificant role in crack propagation. In contrast, test crystals numbers 5 through 7 had a smaller number of grain boundaries as seen in Figures 7 through 9. Figure 10 graphically depicts the fracture induced by uniform pressure loading for crystal number 4. These fracture lines definitely appear to be related to the grain boundaries that are shown in Figure 5. Although crystal number 4 was probably weakened because of extreme hydration during its testing sequence, failure still occurred near 500 psi of material stress.

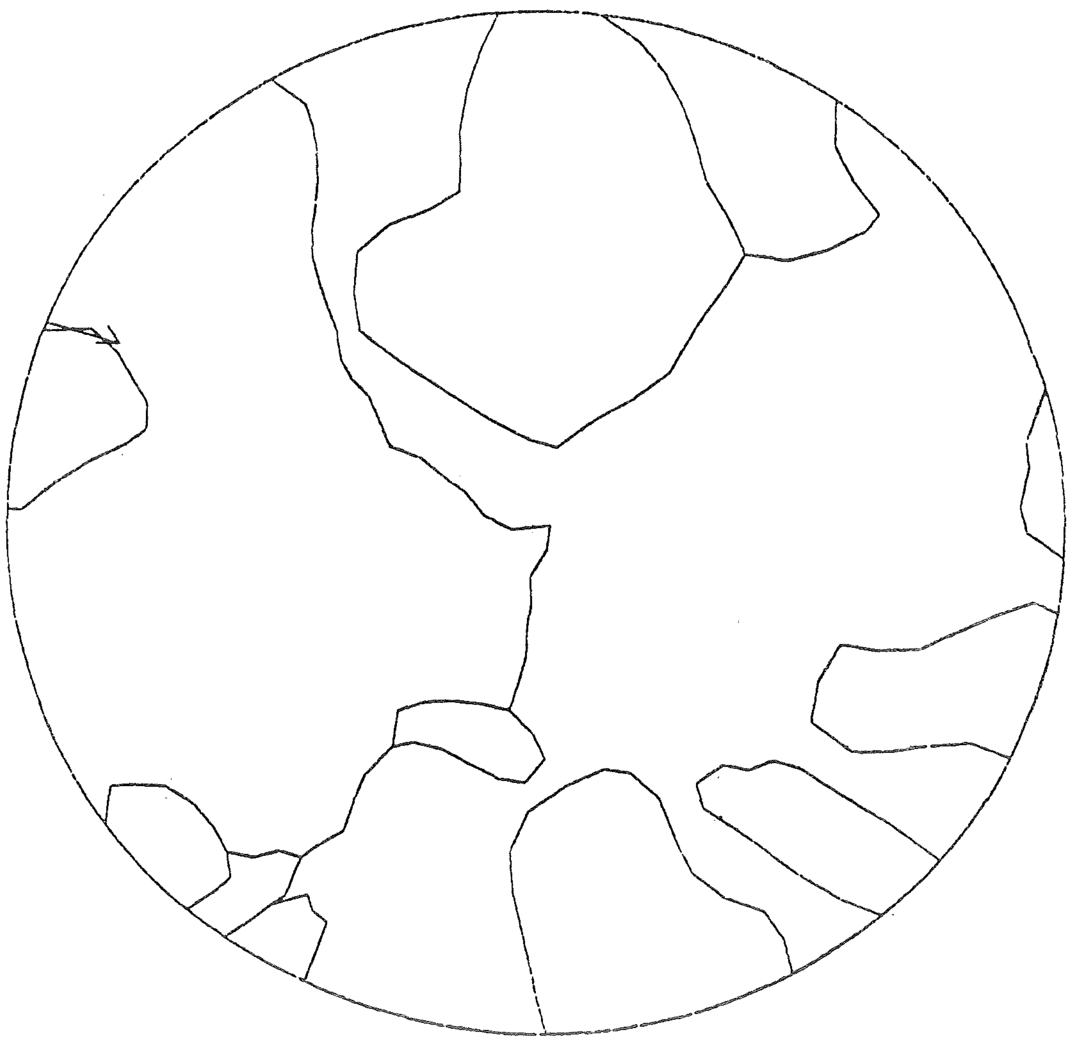

Figure 2. Test crystal No. 1 grain boundaries.

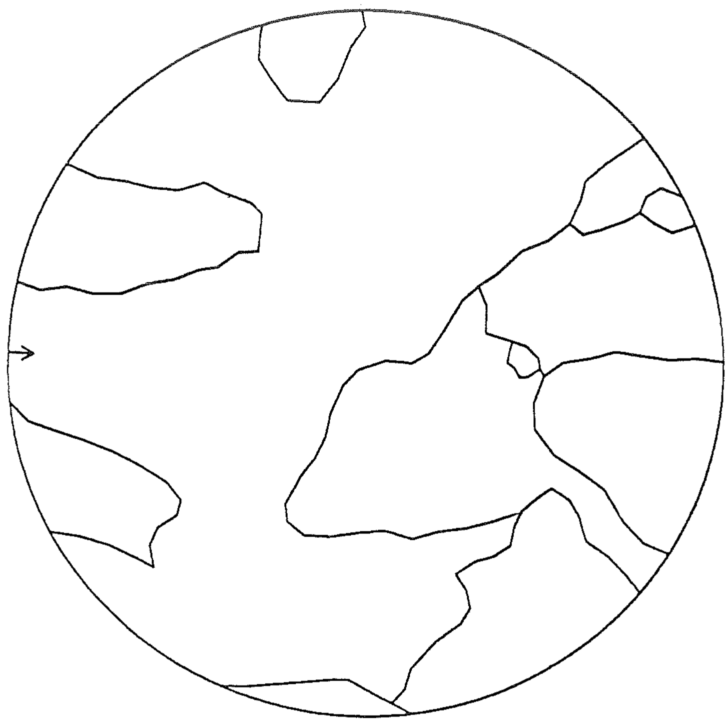

Figure 3. Test crystal No. 2 grain boundaries.

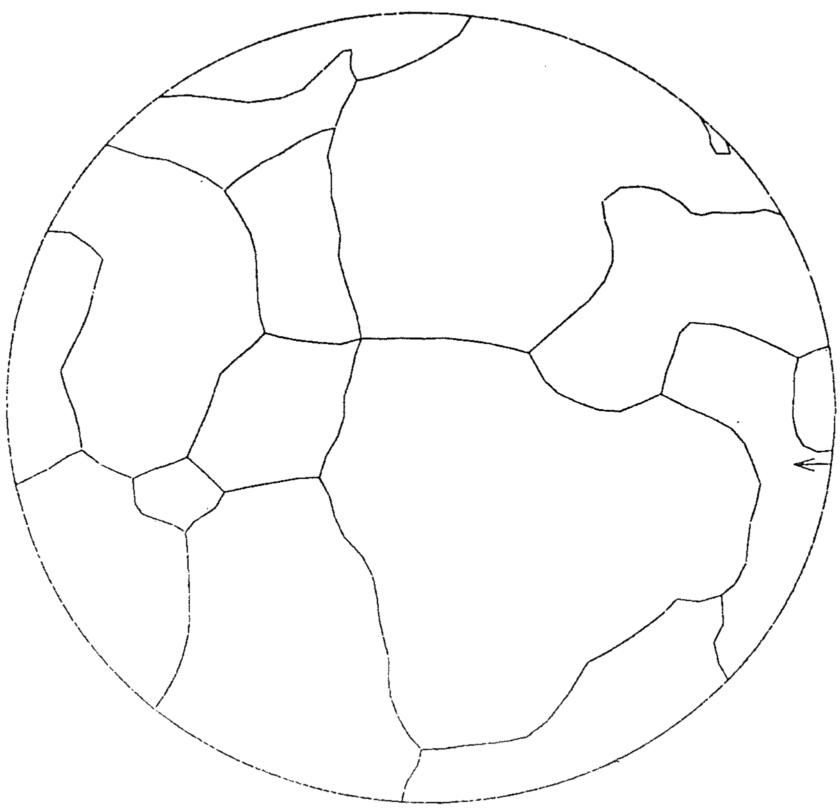

Figure 4. Test crystal No. 3 grain boundaries.

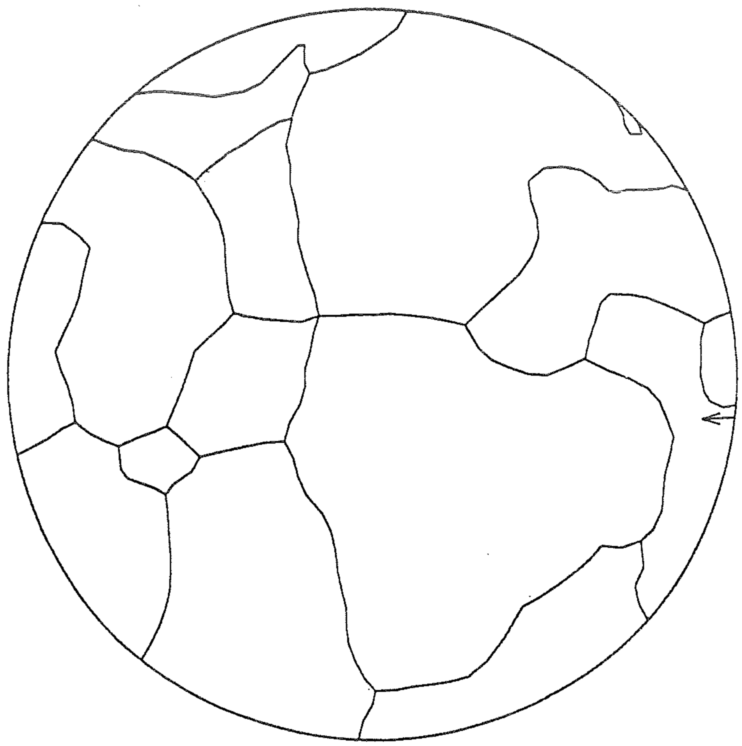

Figure 5. Test crystal No. 4 grain boundaries.

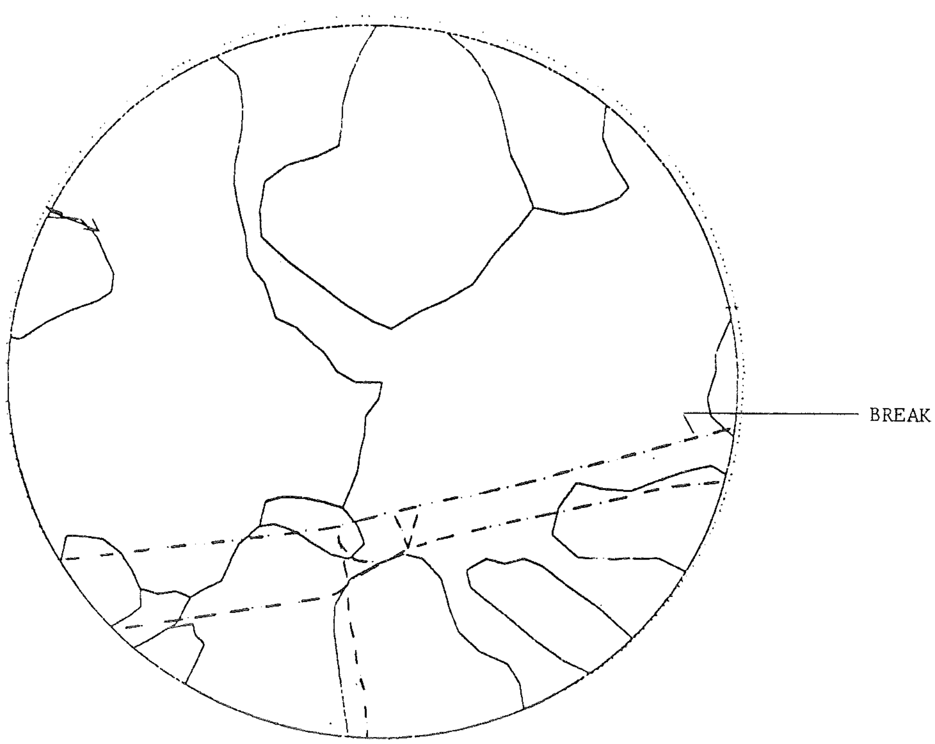


Figure 6. Test crystal No. 1 failure.

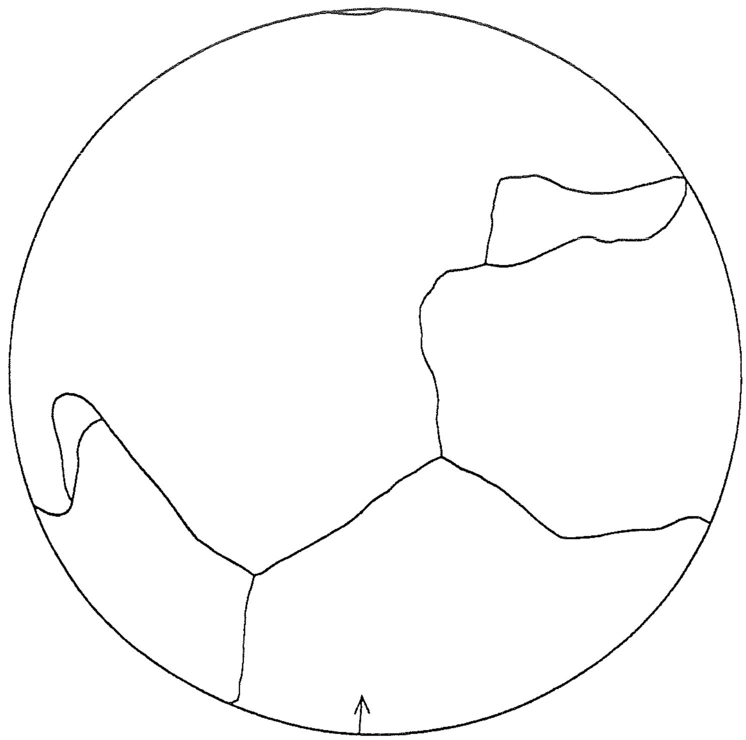

Figure 7. Test crystal No. 5 grain boundaries.

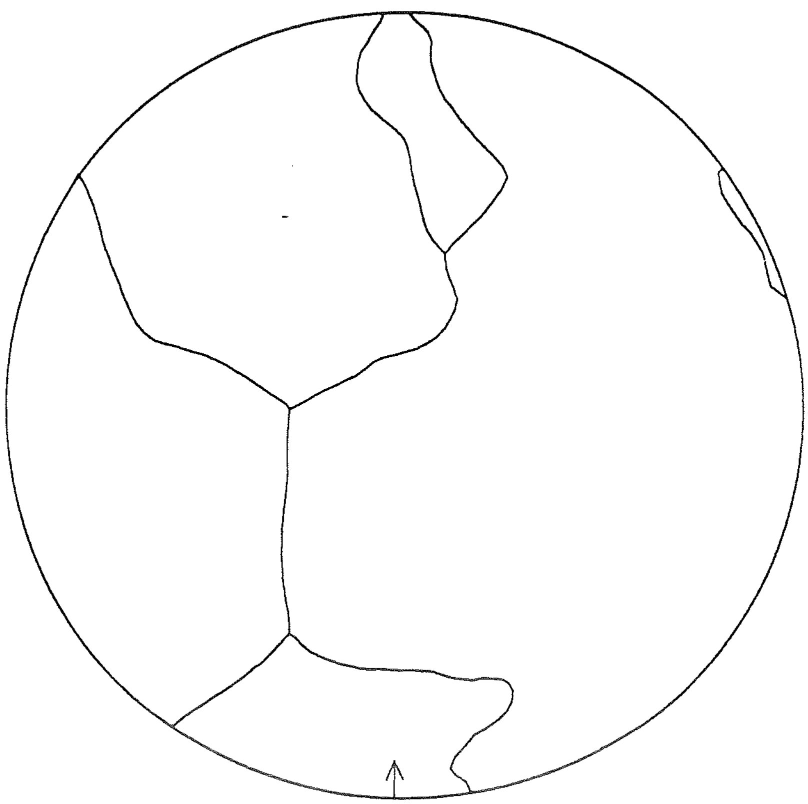

Figure 8. Test crystal No. 6 grain boundaries.

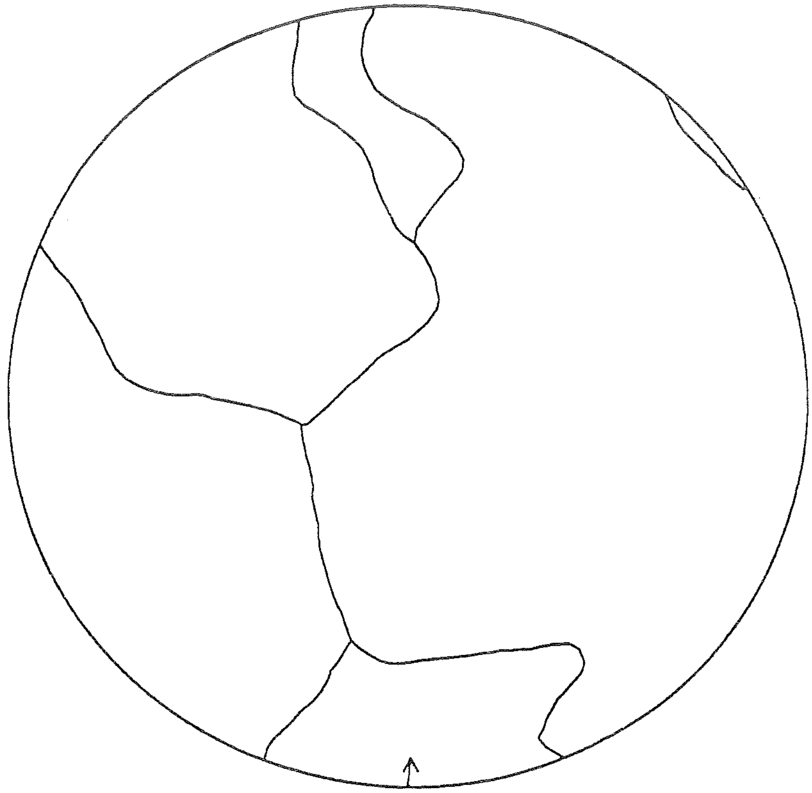

Figure 9. Test crystal No. 7 grain boundaries.

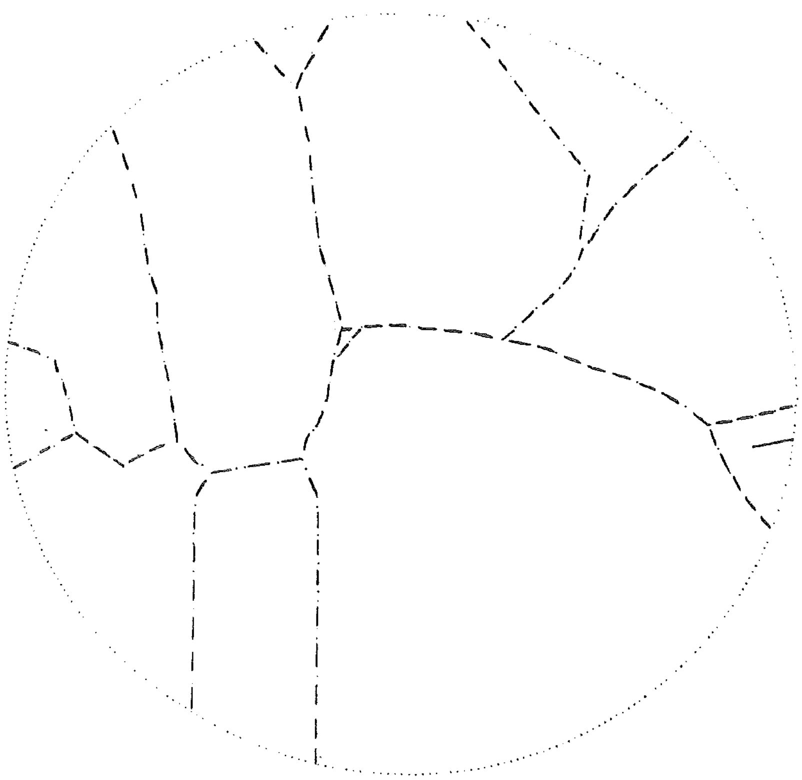

Figure 10. Test crystal No. 4 failure cracks.

## PRESENTATION OF DATA

The most informative way of revealing the mechanical testing results is to present plots of differential pressure versus center displacement for both sides of a particular test specimen. Also included on these plots is differential pressure versus stress at the center of the crystal as calculated by flat plate theory [2]. The equations for a circular flat plate under a uniform pressure load are shown in detail in Appendix A of this report. Data are presented for limit pressure, and 1.4 times limit pressure loadings on the same plot for each side of the test crystal. These plots can be seen in Figures 11 through 20 for test crystal numbers 3 through 7, respectively. Three specimens were also loaded to over 3 times limit pressure (known as maximum loading 1.0 psi). This pressure was an equipment limitation and was chosen because it was previously thought that none of the crystals could survive that high a load. Plots of the differential pressure versus center deflection for the three crystals loaded this way are shown in Figures 21 through 25. The raw data necessary to produce each of these plots are tabulated in Appendix B.

In addition to the aforementioned plots, Figures 26 and 27 depict stress-strain curves generated from the maximum loading tests for crystals numbers 3 and 5. The method utilized to create these curves is shown in Appendix C.

## CONCLUSIONS

Large thallium-doped sodium iodide crystals developed a significant amount of material plasticity (>0.1 percent elongation) and withstood near 500 psi material stress during mechanical testing at MSFC. In addition, test crystals with a large number of grain boundaries proved more elastic, and therefore showed less permanent deformation after testing than those with fewer grain boundaries. At this time, no clear correlation of ultimate strength and the number of grain boundaries can be seen in the testing of five crystals. It is desirable, however, from a science perspective to utilize those crystals which exhibit minimal permanent deformation for flight units on the BATSE. The following guidelines have been established for crystal screening of potential flight units after loading both sides to 1.4 times limit pressure:

a) Crystals developing permanent deformation less than 0.001 in. will be classified as highly desirable.

b) Crystals developing permanent deformation greater than 0.001 in. but less than 0.0025 in. will be classified as acceptable.

c) Crystals developing permanent deformation greater than 0.0025 in. will be classified as unacceptable.

No noticeable degradation of crystal strength was observed during the cyclic load tests. Twenty load cycles at 1.4 times limit were placed on two crystals for this series of tests. Twenty cycles was chosen because it represents about four times the expected number of limit load cycles on the shuttle liftoff. These two crystals were subsequently reloaded to over three times limit load with no reported failures.

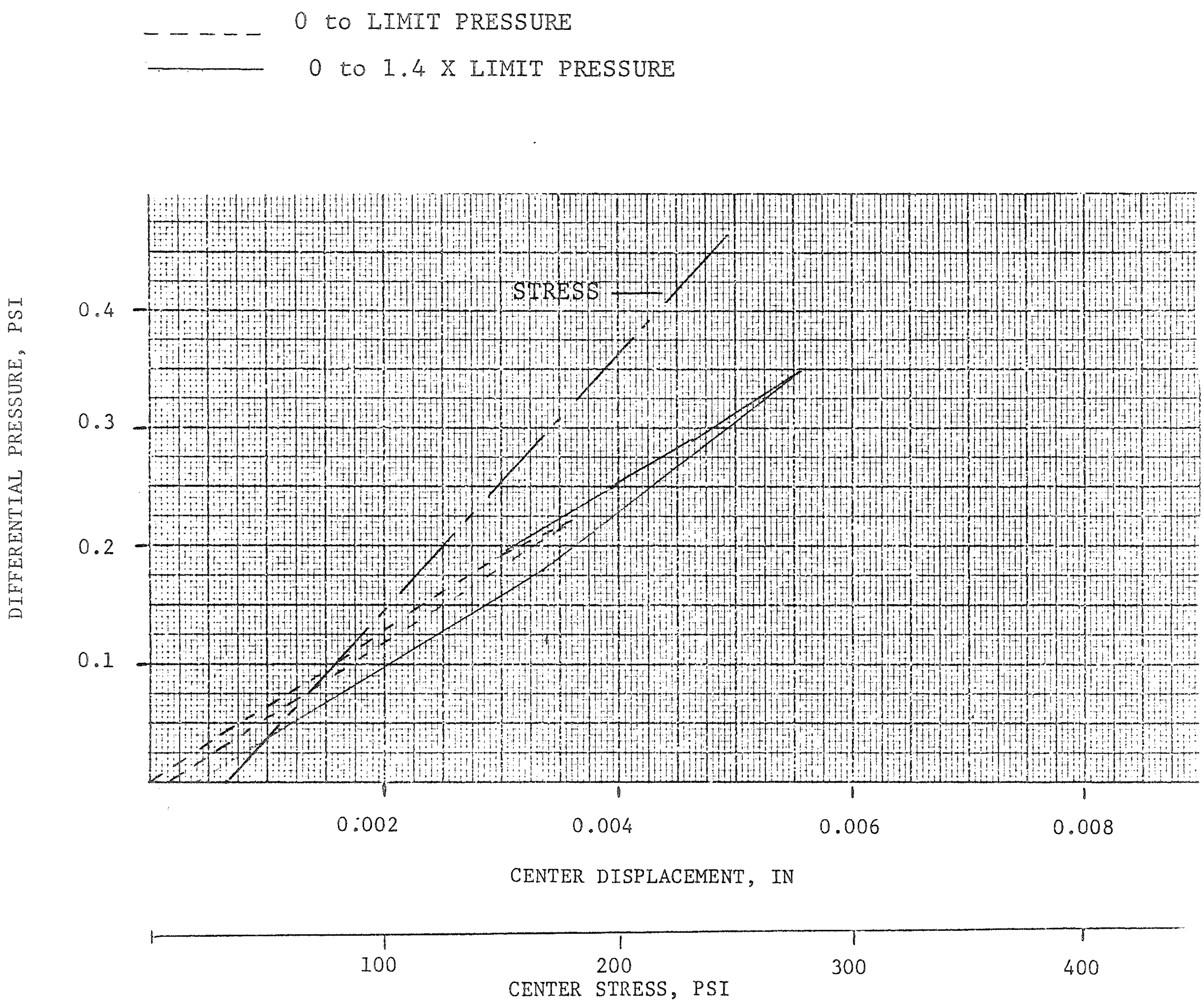


Figure 11. Crystal No. 3 frontside ⇩ center displacement screening test.

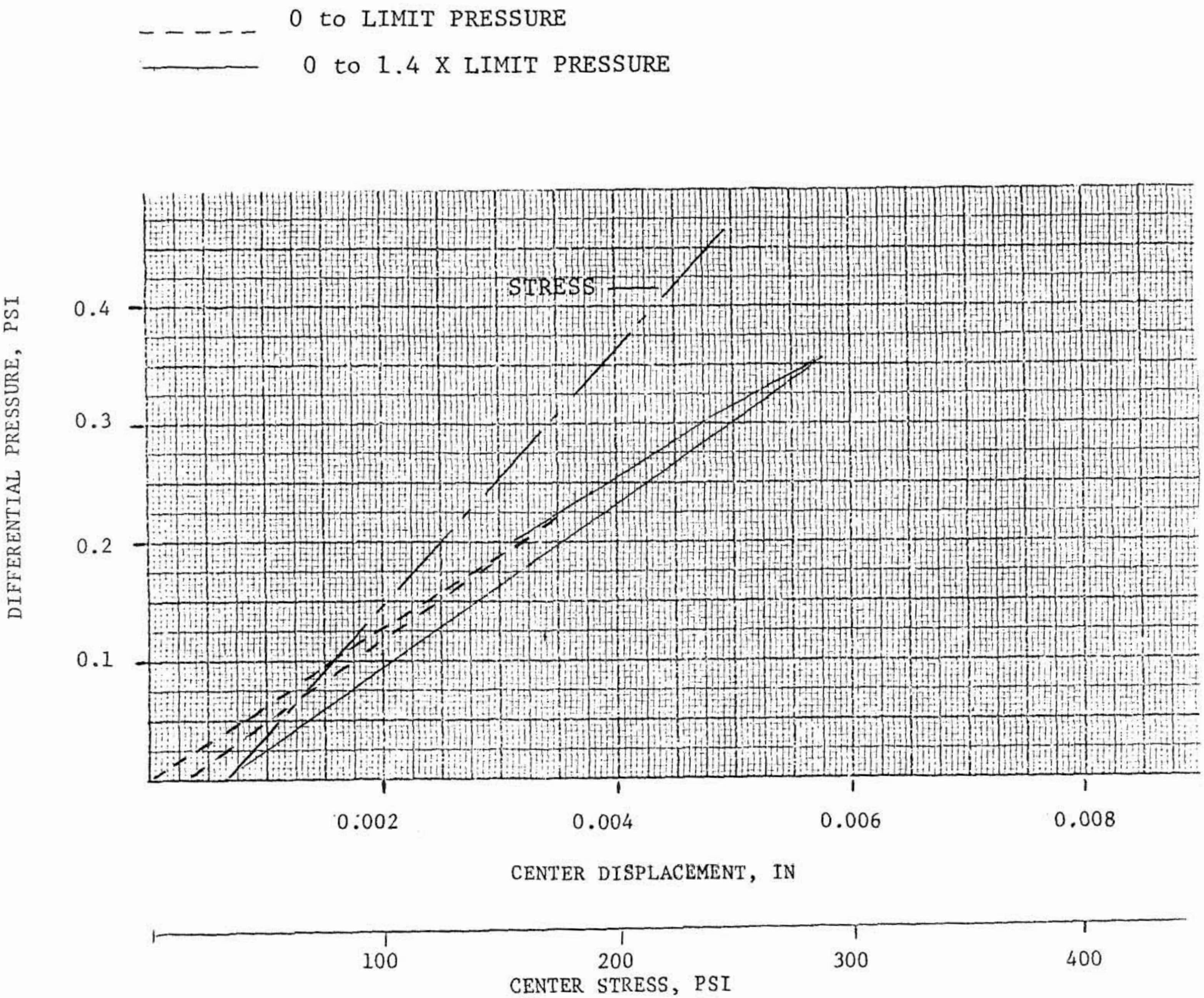


Figure 12. Crystal No. 4 backside ⇧ center displacement screening test.

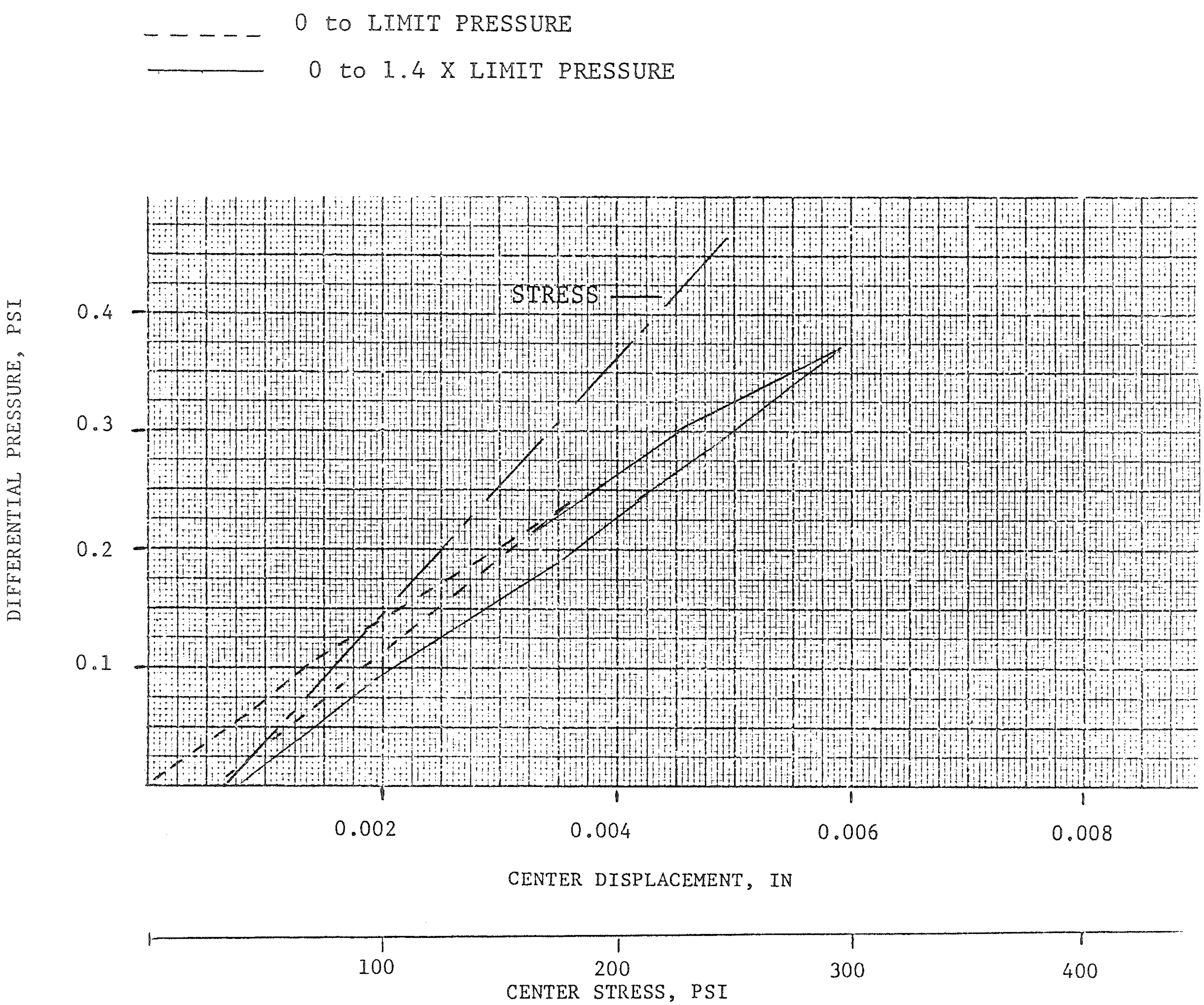


Figure 13. Crystal No. 4 frontside ⇩ center displacement screening test.

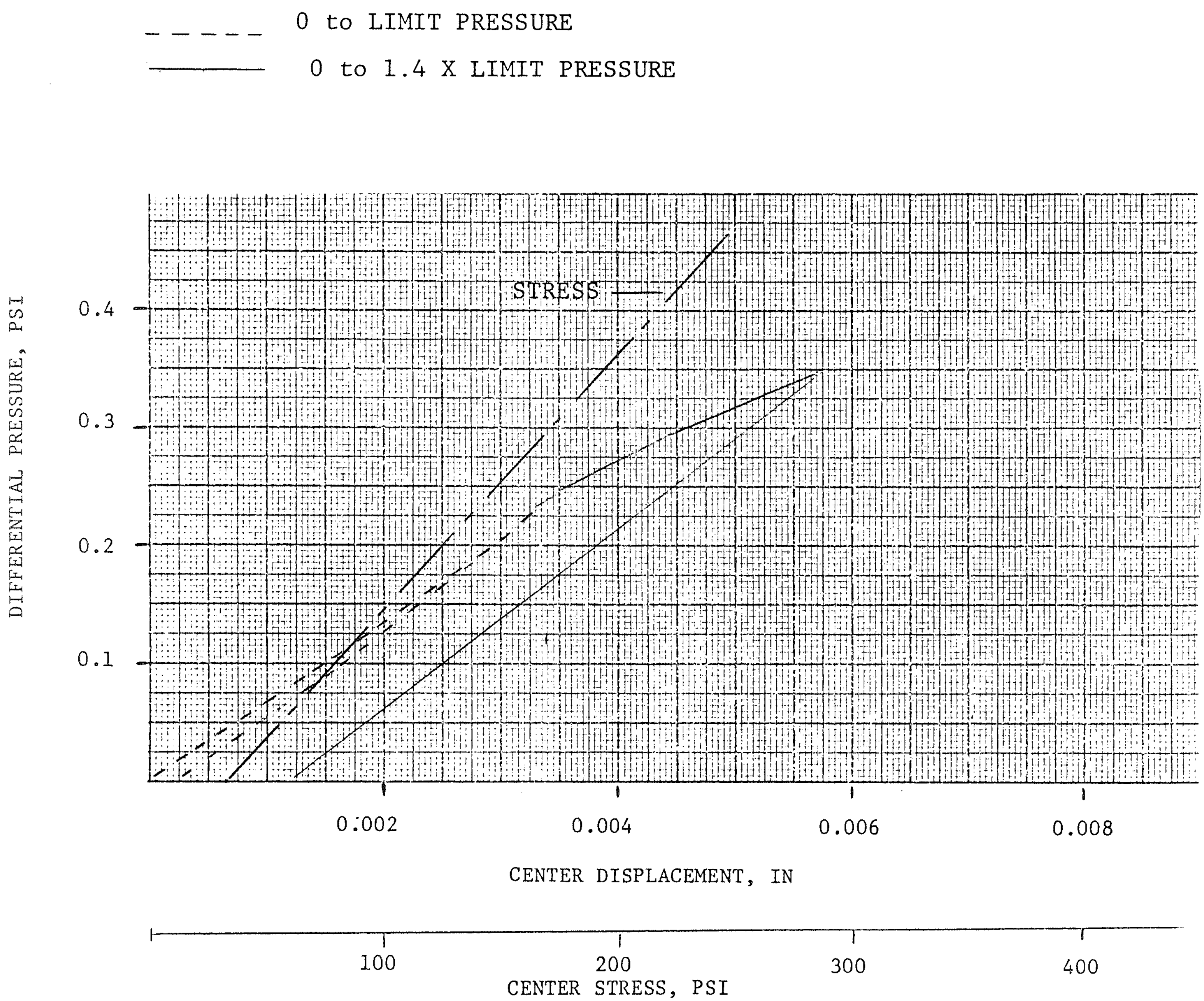


Figure 14. Crystal No. 4 backside center displacement screening test.

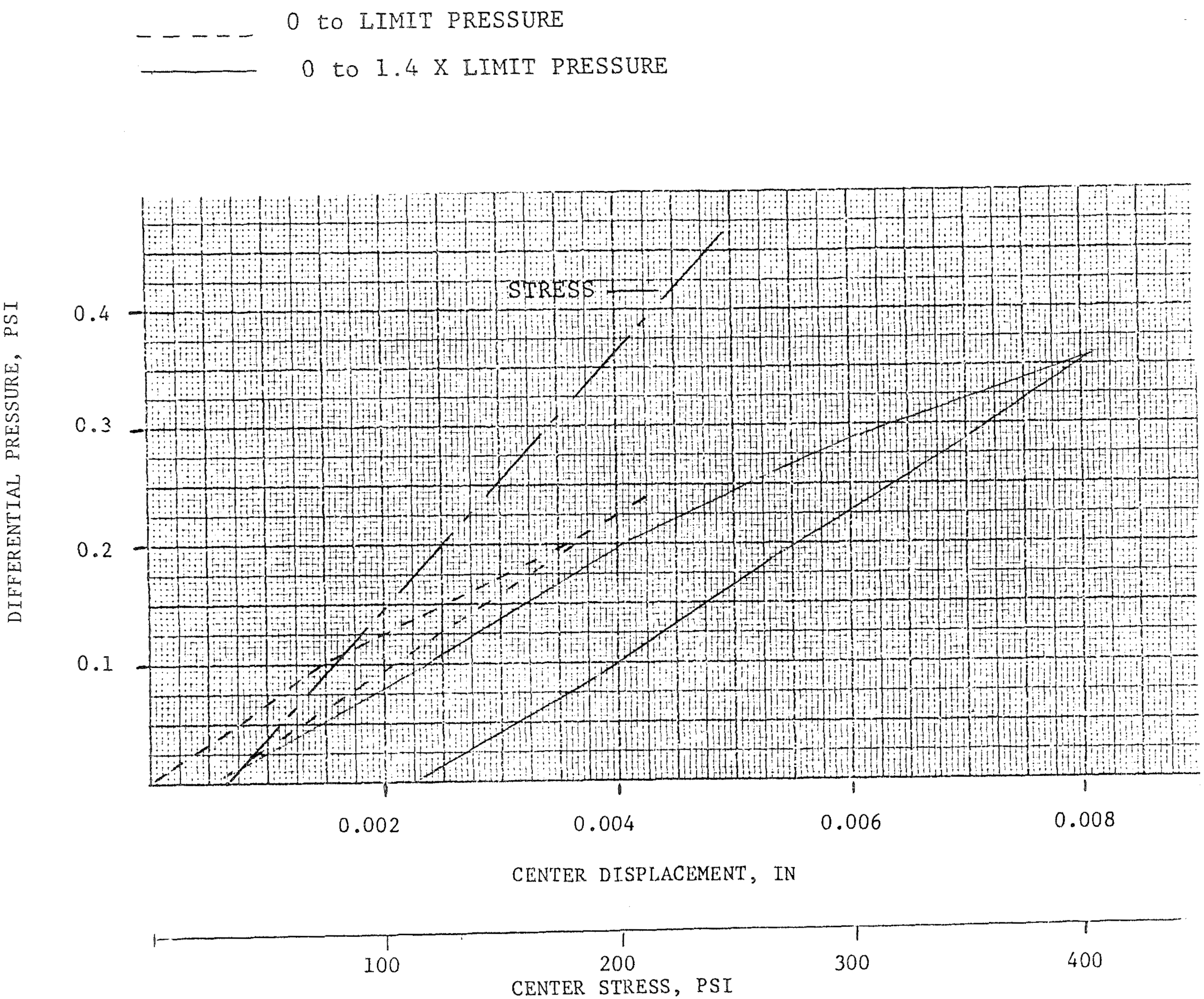


Figure 15. Crystal No. 5 frontside ⇩ center displacement screening test.

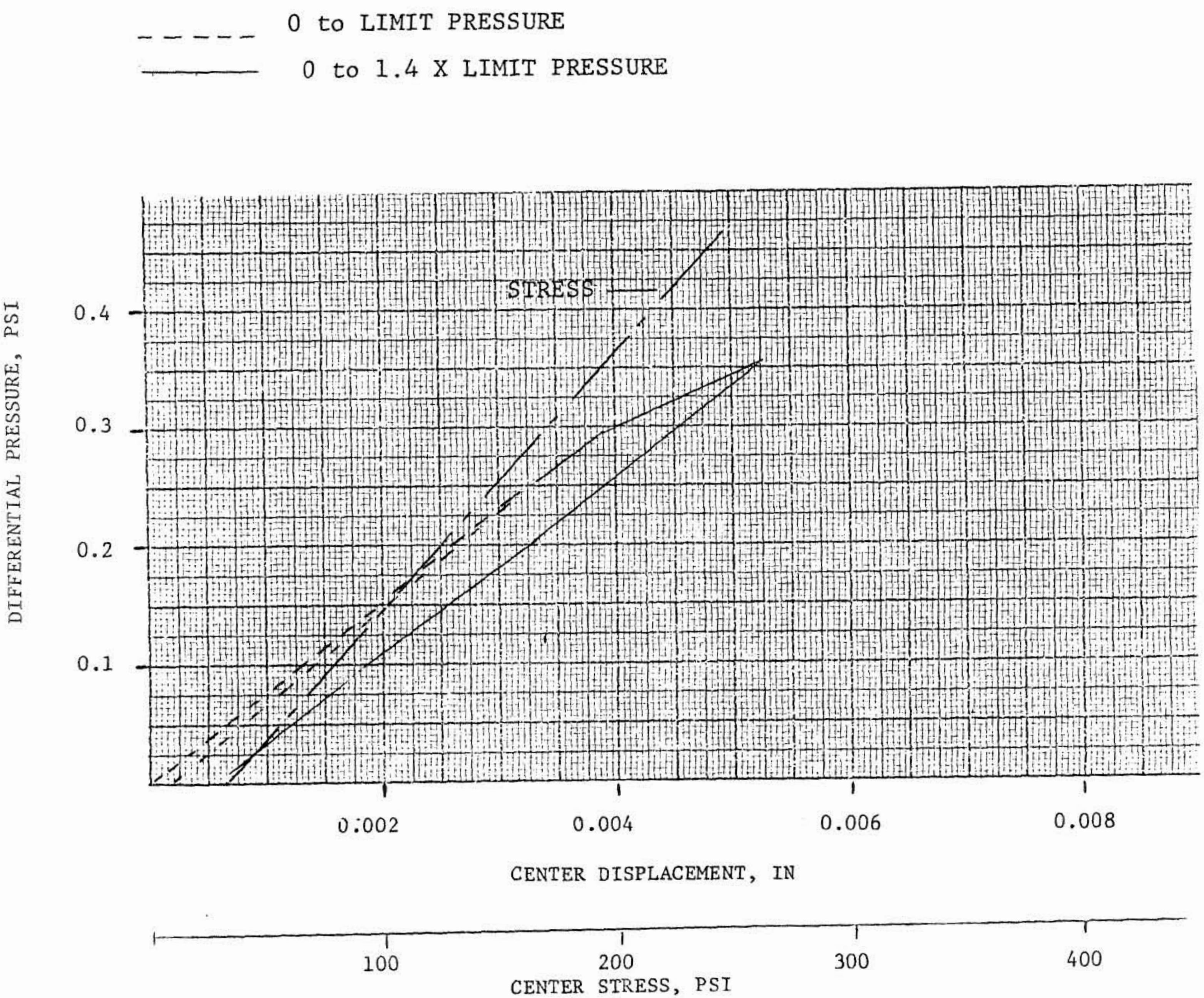


Figure 16. Crystal No. 5 backside ⇧ center displacement screening test.

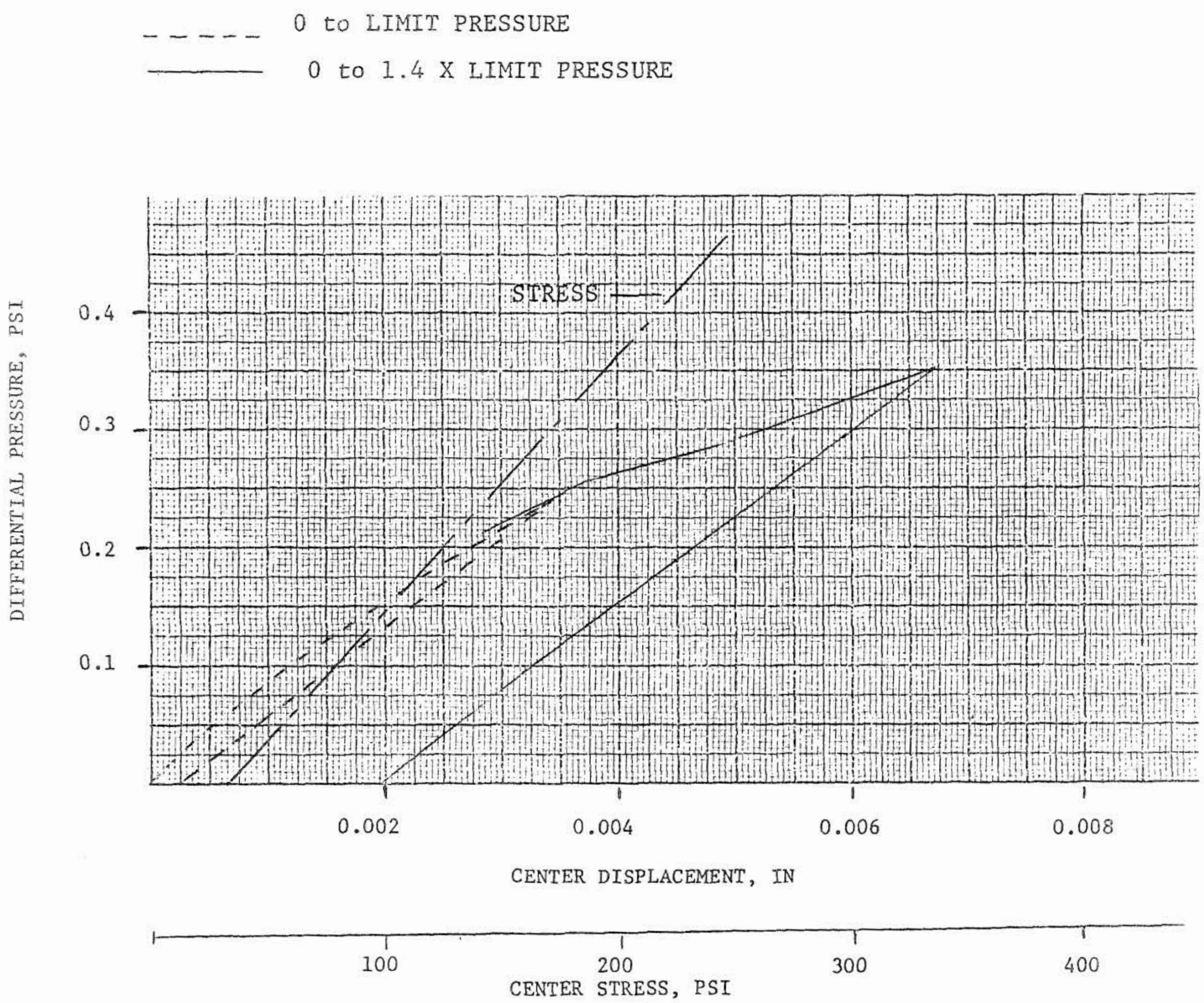


Figure 17. Crystal No. 6 frontside ⇩ center displacement screening test.

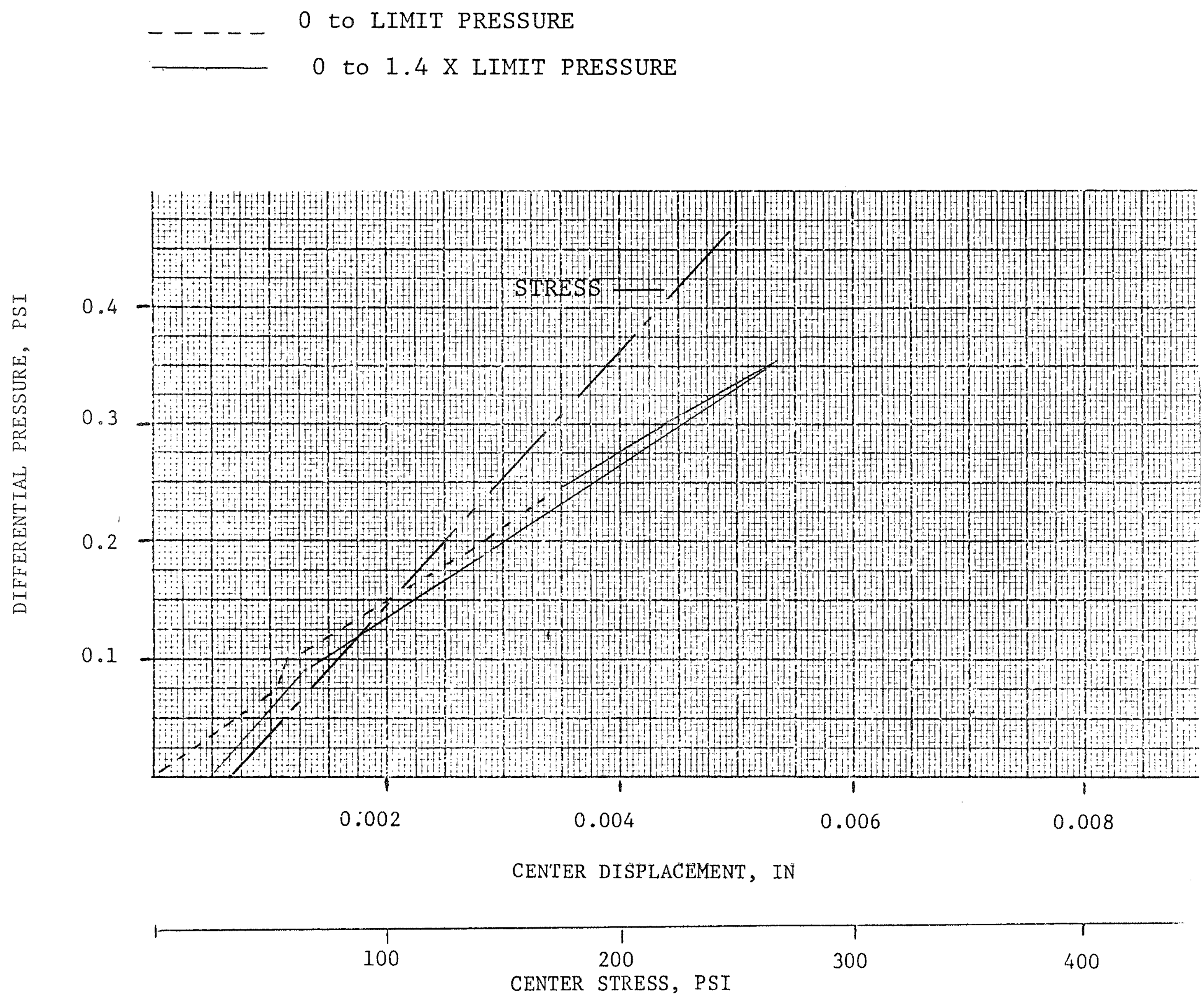


Figure 18. Crystal No. 7 backside ⇧ center displacement screening test.

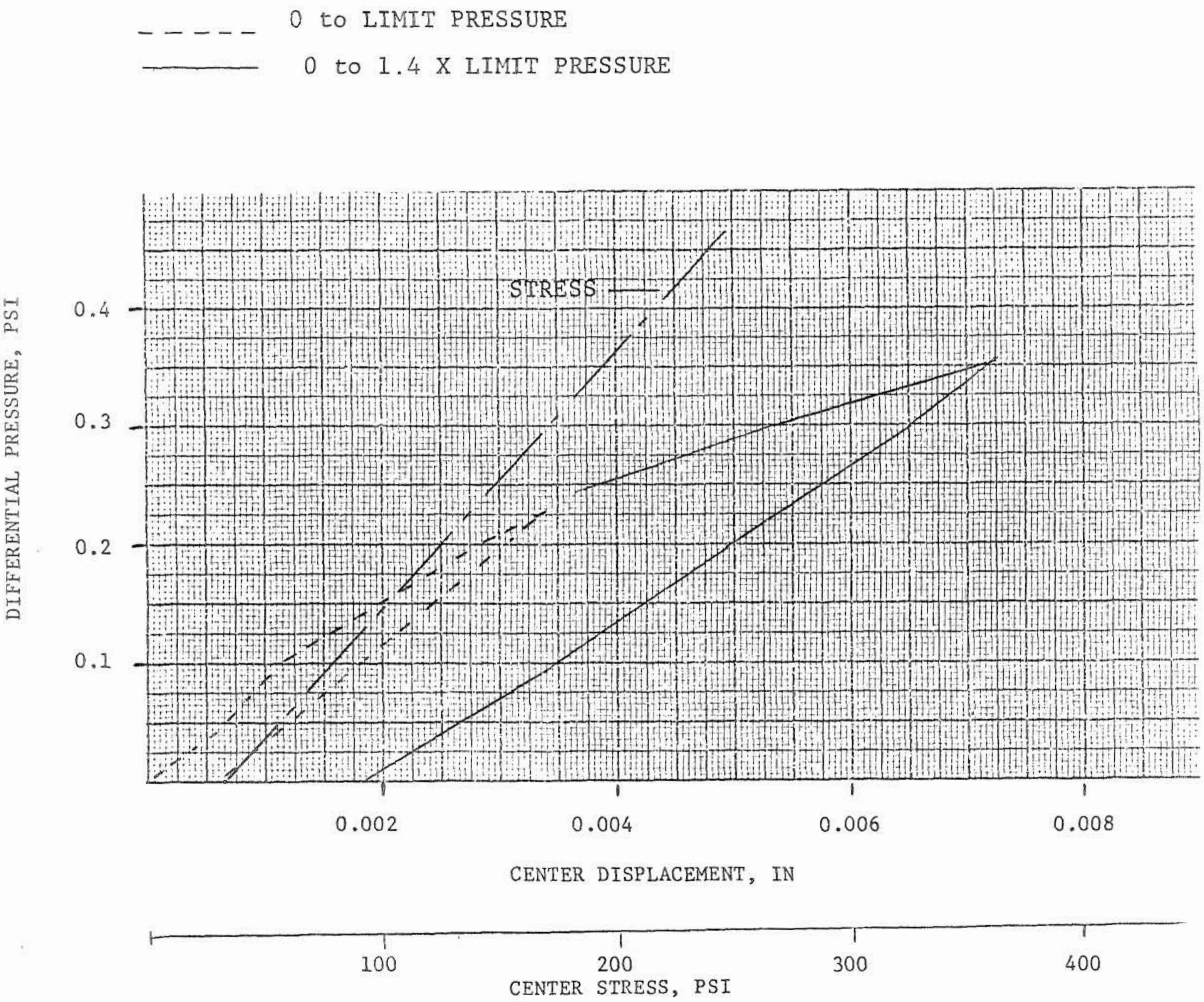


Figure 19. Crystal No. 7 frontside ⇩ center displacement screen test.

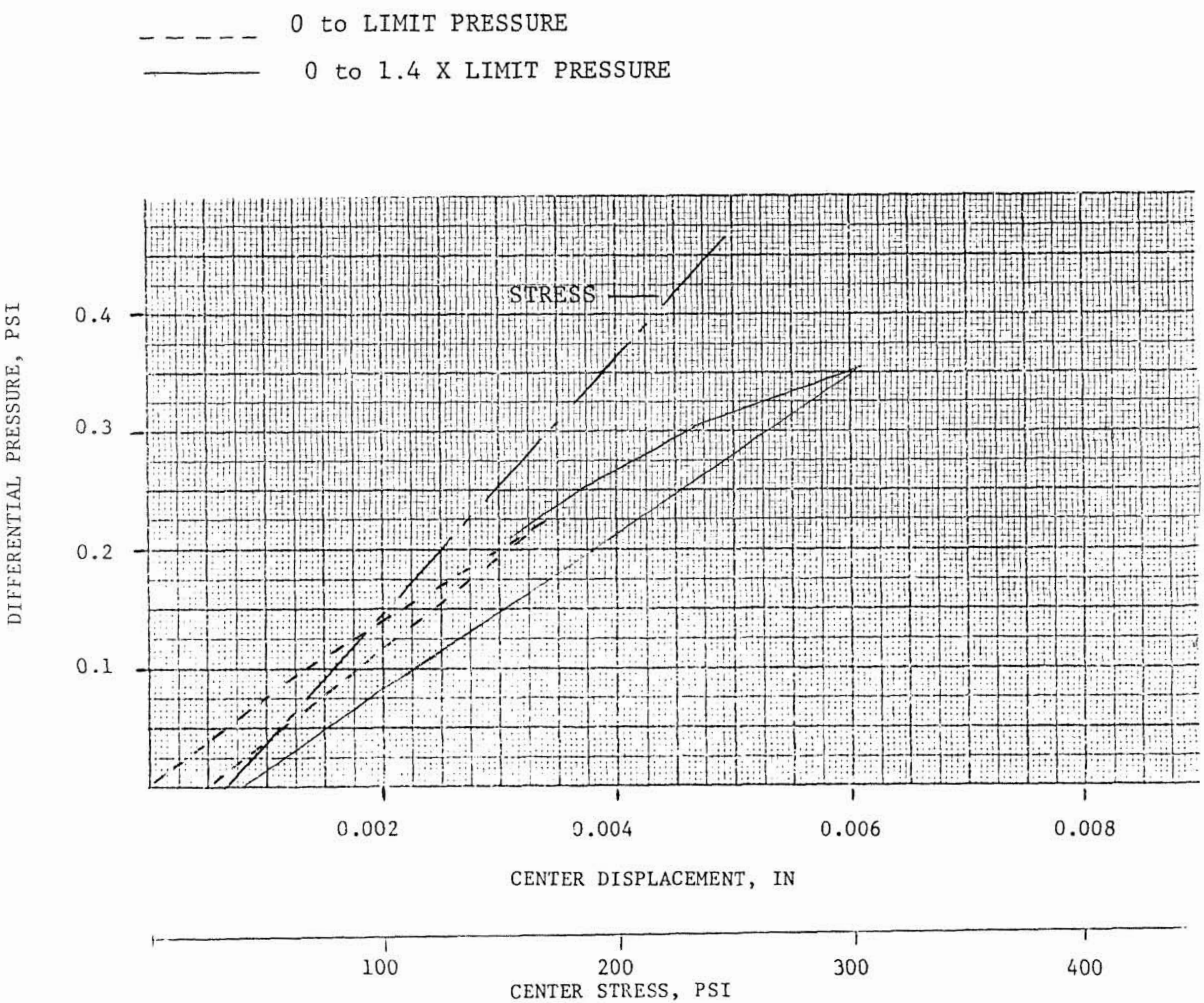


Figure 20. Crystal No. 7 backside ⇧ center displacement screening test.

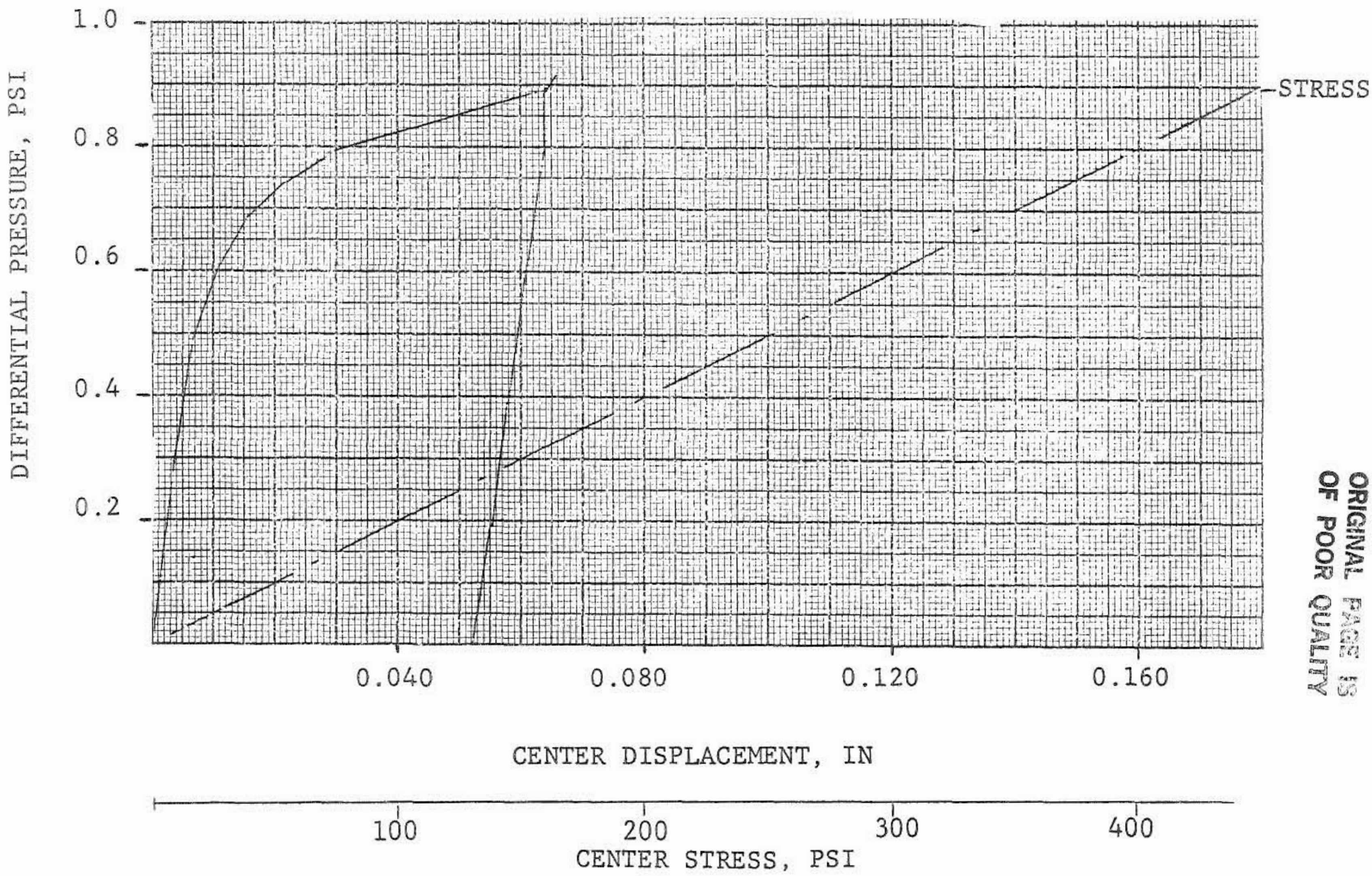




Figure 21. Crystal No. 3 frontside ⇩ center displacement maximum load test.

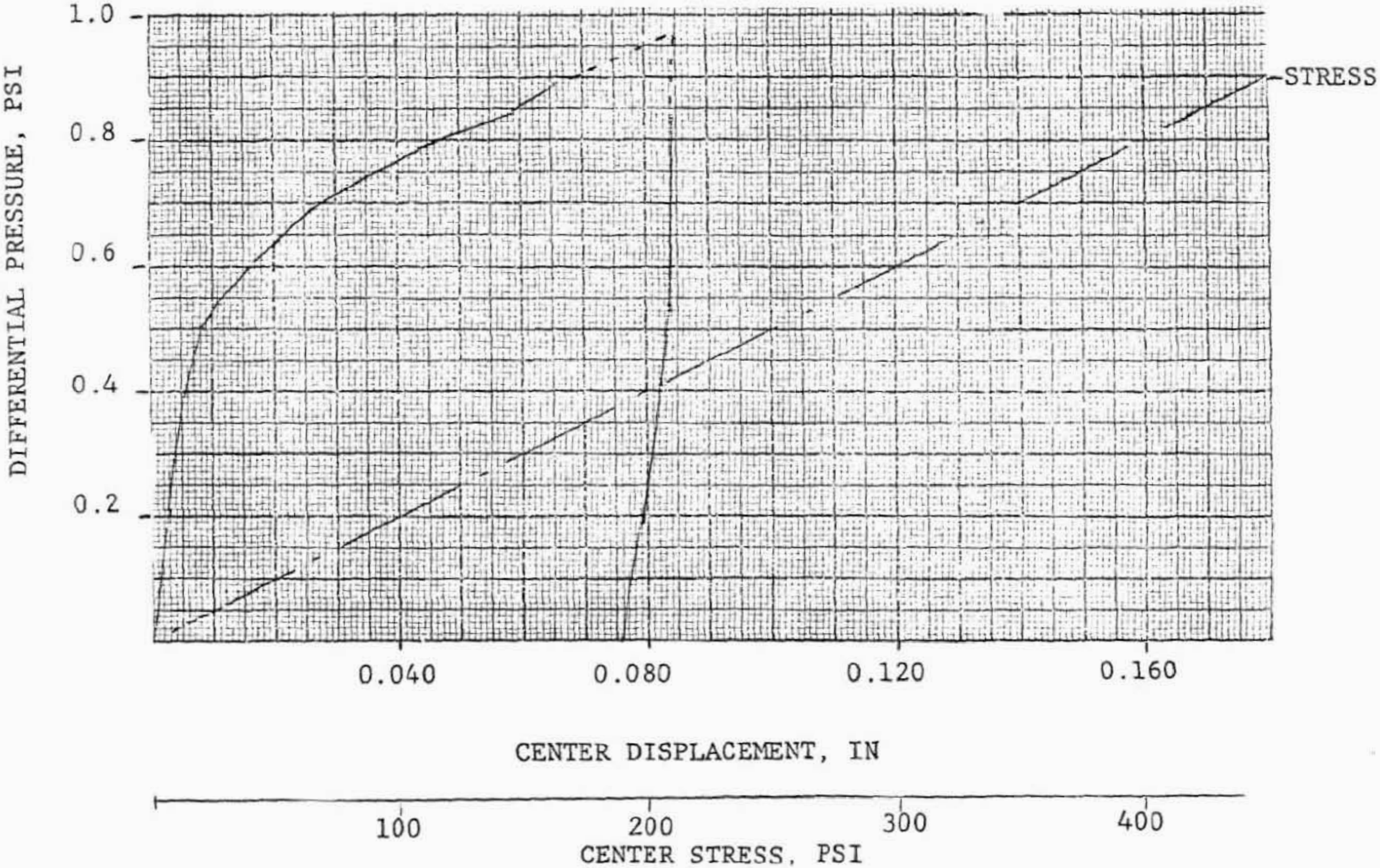


Figure 22. Crystal No. 4 frontside ⇩ center displacement maximum load test.

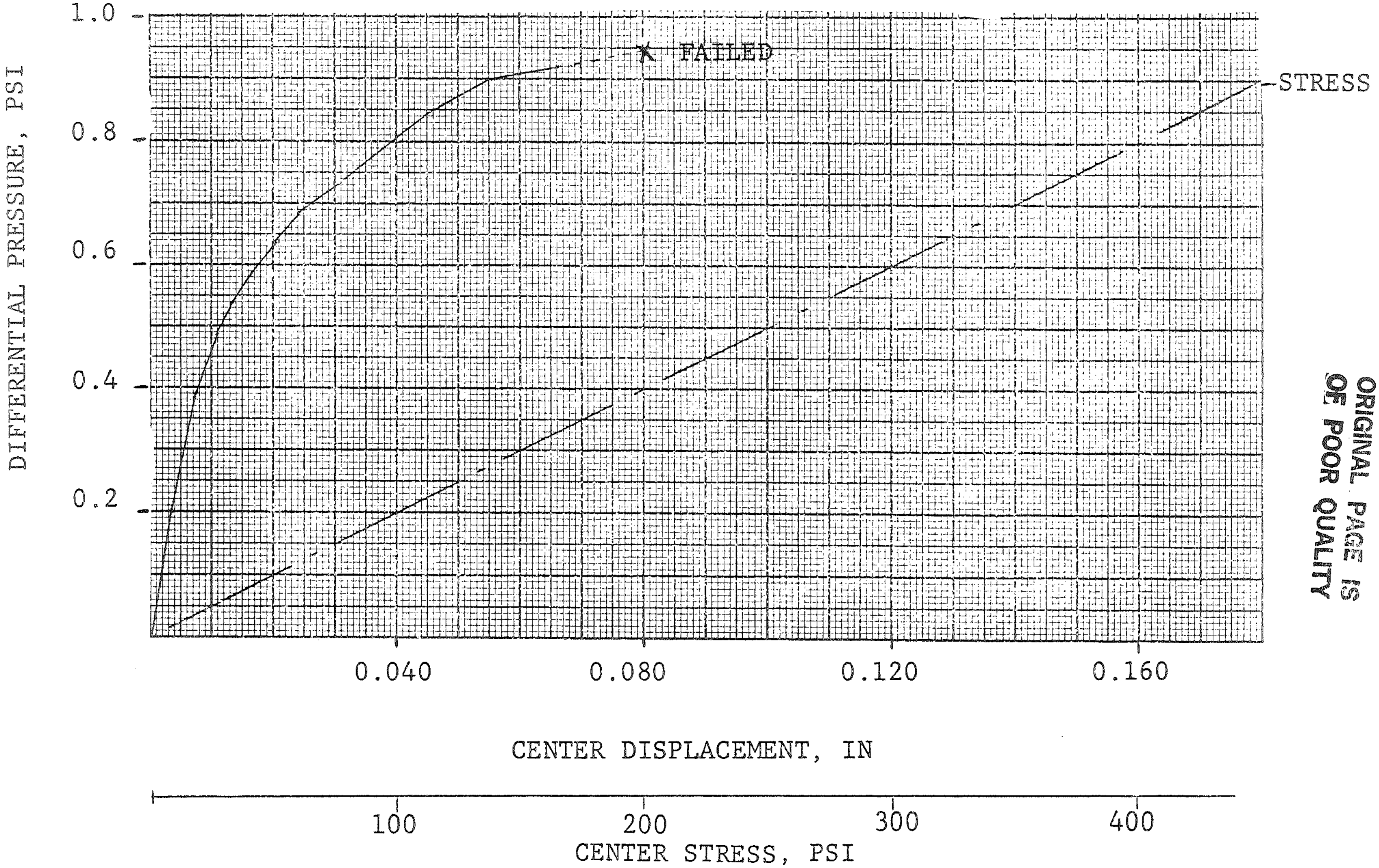


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Figure 23. Crystal No. 4 backside ⇧ center displacement maximum load test.

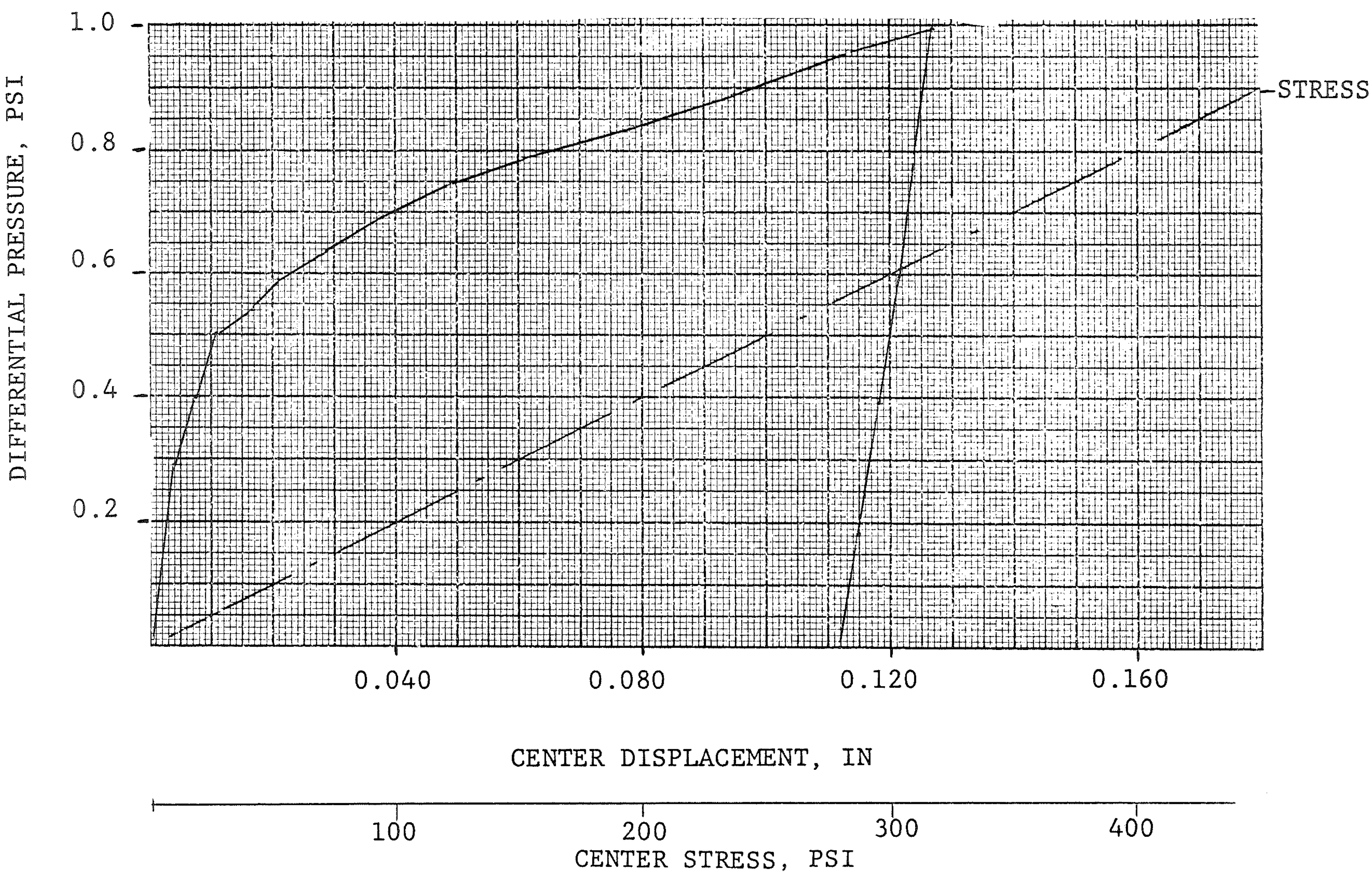



Figure 24. Crystal No. 5 frontside ⇩ center displacement maximum load test.

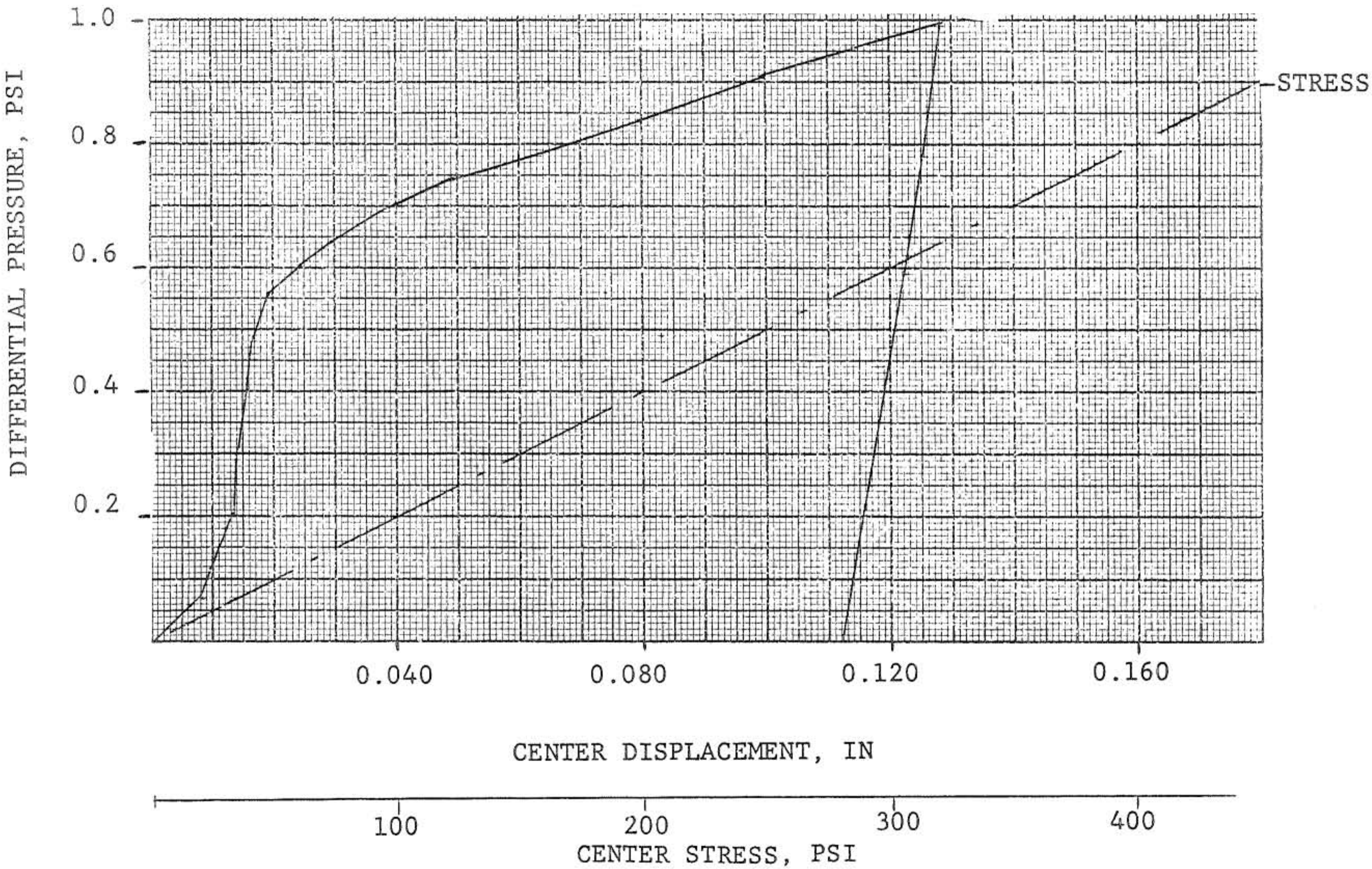



Figure 25. Crystal No. 5 backside center displacement maximum load test.

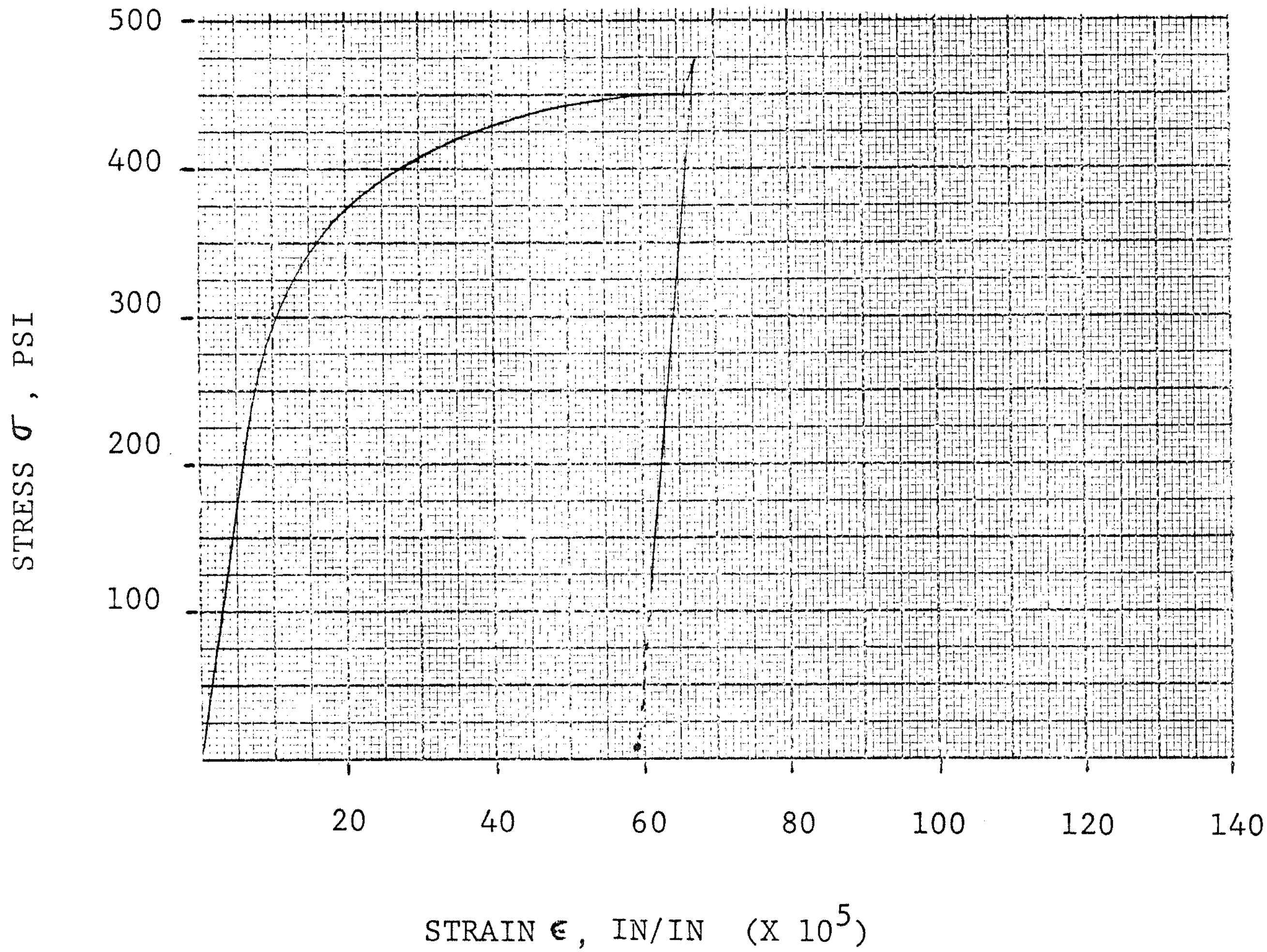



Figure 26. Crystal No. 3 frontside ⇩ stress-strain curve.

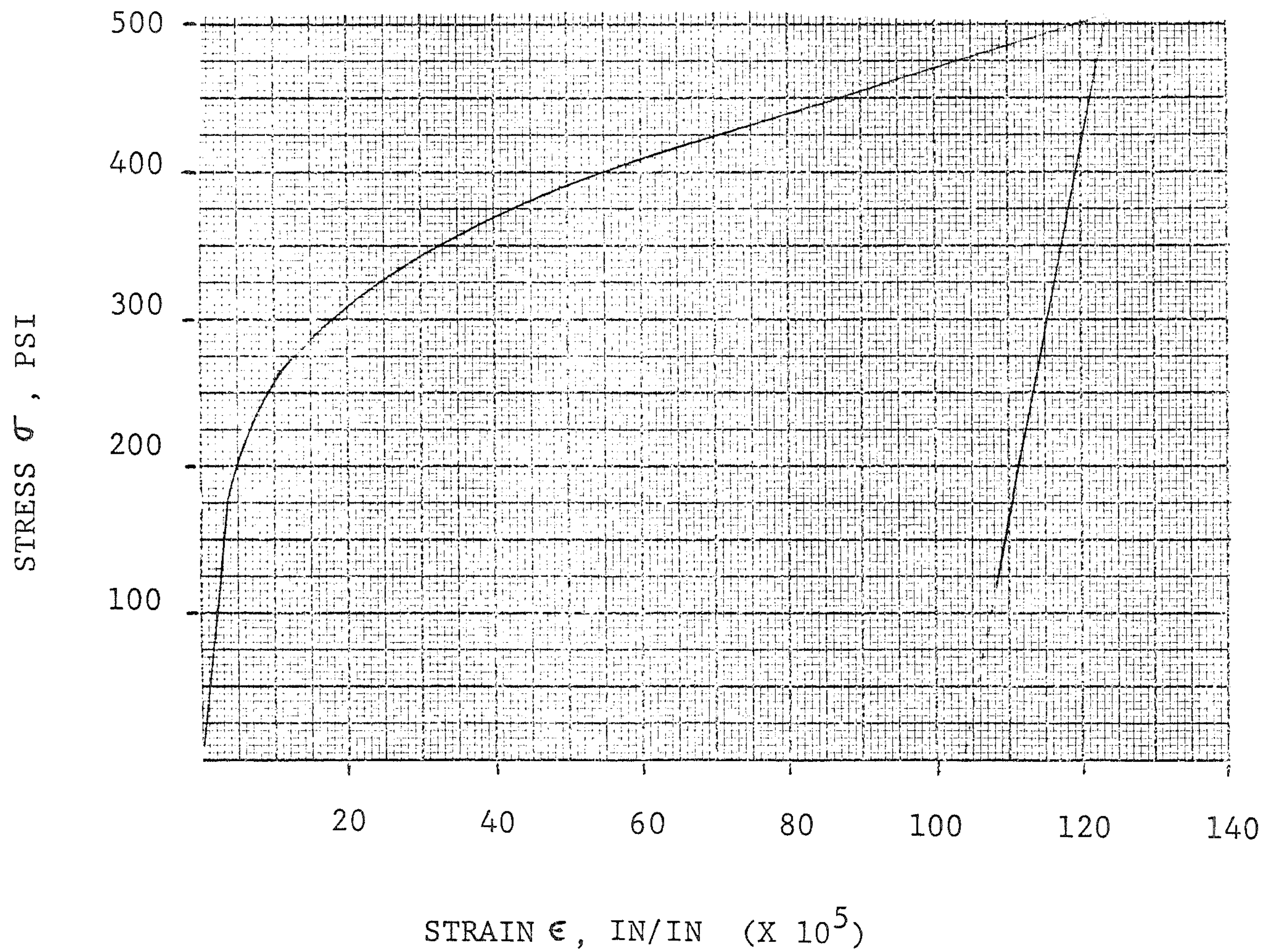



Figure 27. Crystal No. 5 frontside ⇩ stress-strain curve.

## REFERENCES


1. GSFC Letter, September 24, 1980, C. Haehner and T. Heslin to E. Angelo, MOR Bend Test Results for NaI(Tl) and Additional Elastic Moduli Measurements.

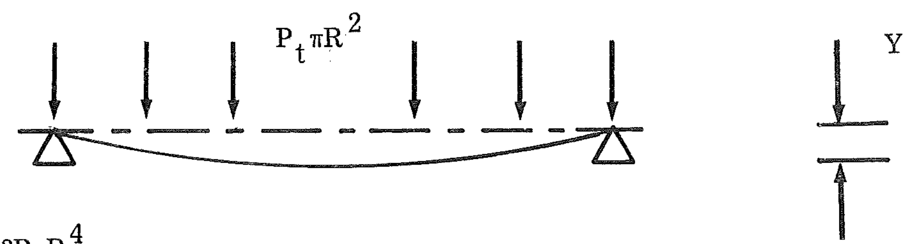
2. Roark, R. J.: Formulas for Stress and Strain. McGraw-Hill Book Company, New York 4th Edition, 1965.

## APPENDIX A

## CIRCULAR FLAT PLATE EQUATIONS

The maximum deflection as well as the maximum stress in a circular flat plate depend upon the mechanical properties of the material, geometry of the plate, type of loading, and boundary conditions.

The analytical expressions [2] below, depict the maximum deflection and maximum stress for an isotropic material loaded with a uniform pressure across the entire surface, and with the edges constrained normal to the plate.




$$Y_{max} = \frac{3P_t R^4}{16Em^2T^3} [(m-1)(5m + 1)] \qquad \text{(deflection)}$$

and

$$S_{max} = \frac{3P_t R^2}{8mT^2} (3m + 1) \qquad \text{(stress)}$$

where

$Y_{max}$ = maximum center deflection

$S_{max}$ = maximum center stress

E = modulus of elasticity

m = reciprocal of Poisson's ratio

$\nu$ = Poisson's ratio

$\rho$ = weight density

R = radius of plate

T = thickness of plate

$P_t = \Delta P + T\rho$

$\Delta P = P + T$

P = differential pressure from vacuum source

NaI (T1) Properties

$E = 3.8 \times 10^6$ psi

$\nu = 0.31$

$\rho = 0.1323$ lb/in.$^3$

$R = 9.75$ in.

$T = 0.50$ in.

# APPENDIX B

## TABULATED TEST DATA

The following tabulated data represents the measured data for each crystal test. Data from deflection gages numbers 1 through 3 were recorded versus the differential pressure calculated from the manometer. Gage numbers 1 and 3 were averaged to yield the edge displacement over the "O" ring. To calculate the net center displacement of the crystal, the average edge motion was subtracted from the gage number 2 reading.

CRYSTAL # 3

TEST DATE 4/5/85

POSITION OF ARROW: ⇩

TEST TYPE: LIMIT PRESSURE

| ΔP (PSI) | G1 GAGE #1 (IN) | G3 GAGE #3 (IN) | G2 GAGE #2 (IN) | EDGE GE = G1 + G3/2 (IN) | CENTER GC = G2 - GE (IN) |
|---|---|---|---|---|---|
| 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 0.041 | 0.00240 | 0.00260 | 0.00310 | 0.00250 | 0.00060 |
| 0.084 | 0.00460 | 0.00470 | 0.00600 | 0.00465 | 0.00135 |
| 0.155 | 0.00790 | 0.00790 | 0.01030 | 0.0079 | 0.00240 |
| 0.194 | 0.00940 | 0.00930 | 0.1240 | 0.00935 | 0.00305 |
| 0.228 | 0.0108 | 0.0108 | 0.01440 | 0.0108 | 0.00360 |
| 0.0 | 0.0011 | 0.0010 | 0.00120 | 0.00105 | 0.00015 |

CRYSTAL # 3 TEST DATE 4/5/85

POSITION OF ARROW: ⇩ TEST TYPE: 1.4 X LIMIT PRESSURE

| ΔP (PSI) | G1 GAGE #1 (IN) | G3 GAGE #3 (IN) | G2 GAGE #2 (IN) | EDGE GE = G1 + G3/2 (IN) | CENTER GC = G2 - GE (IN) |
|---|---|---|---|---|---|
| 0.0 | 0.0011 | 0.0010 | 0.00120 | 0.00105 | 0.00015 |
| 0.045 | 0.0031 | 0.00305 | 0.0038 | 0.003075 | 0.000725 |
| 0.104 | 0.0059 | 0.0058 | 0.0075 | 0.00585 | 0.00165 |
| 0.196 | 0.0097 | 0.0096 | 0.0127 | 0.00965 | 0.00305 |
| 0.251 | 0.0118 | 0.0117 | 0.0157 | 0.01175 | 0.00395 |
| 0.291 | 0.0131 | 0.0132 | 0.0178 | 0.01315 | 0.00465 |
| 0.349 | 0.0150 | 0.0149 | 0.0205 | 0.01495 | 0.00555 |
| 0.181 | 0.0102 | 0.0101 | 0.0135 | 0.01015 | 0.00335 |
| 0.0 | 0.0016 | 0.0013 | 0.0018 | 0.00145 | 0.00035 |

CRYSTAL # 3

TEST DATE 4/5/85

POSITION OF ARROW: 

TEST TYPE: LIMIT PRESSURE

| ΔP (PSI) | G1 GAGE #1 (IN) | G3 GAGE #3 (IN) | G2 GAGE #2 (IN) | EDGE GE = G1 + G3/2 (IN) | CENTER GC = G2 - GE (IN) |
|---|---|---|---|---|---|
| 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 0.052 | 0.0033 | 0.0034 | 0.0042 | 0.00335 | 0.00085 |
| 0.104 | 0.0059 | 0.0059 | 0.0067 | 0.0059 | 0.0016 |
| 0.189 | 0.0095 | 0.0095 | 0.0125 | 0.0095 | 0.0030 |
| 0.221 | 0.0107 | 0.0107 | 0.0142 | 0.0107 | 0.0035 |
| 0.0 | 0.0009 | 0.0009 | 0.0012 | 0.0009 | 0.0003 |

CRYSTAL # 3

TEST DATE 4/5/85

POSITION OF ARROW: ⇧

TEST TYPE: 1.4 X LIMIT PRESSURE

| ΔP (PSI) | G1 GAGE #1 (IN) | G3 GAGE #3 (IN) | G2 GAGE #2 (IN) | EDGE GE = G1 + G3/2 (IN) | CENTER GC = G2 - GE (IN) |
|---|---|---|---|---|---|
| 0.0 | 0.0009 | 0.0009 | 0.0012 | 0.0009 | 0.0003 |
| 0.092 | 0.0054 | 0.0054 | 0.0069 | 0.0054 | 0.0015 |
| 0.202 | 0.0100 | 0.0099 | 0.0131 | 0.00995 | 0.00315 |
| 0.242 | 0.0115 | 0.0115 | 0.0153 | 0.0115 | 0.00380 |
| 0.305 | 0.0135 | 0.0135 | 0.0183 | 0.0135 | 0.00480 |
| 0.355 | 0.0150 | 0.0151 | 0.0208 | 0.01505 | 0.00575 |
| 0.179 | 0.0101 | 0.0100 | 0.0133 | 0.01005 | 0.00325 |
| 0.0 | 0.0014 | 0.0013 | 0.0020 | 0.00135 | 0.00065 |

CRYSTAL # 3

TEST DATE 5/6/85

POSITION OF ARROW: ⇩

TEST TYPE: >3 X LIMIT PRESSURE

| ΔP (PSI) | G1 GAGE #1 (IN) | G3 GAGE #3 (IN) | G2 GAGE #2 (IN) | EDGE GE = G1 + G3/2 (IN) | CENTER GC = G2 - GE (IN) |
|---|---|---|---|---|---|
| 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 0.076 | 0.0060 | 0.0049 | 0.0063 | 0.0054 | 0.0009 |
| 0.191 | 0.0133 | 0.0111 | 0.0146 | 0.0122 | 0.0024 |
| 0.293 | 0.0181 | 0.0149 | 0.0206 | 0.0165 | 0.0041 |
| 0.385 | 0.0214 | 0.0182 | 0.0253 | 0.0198 | 0.0055 |
| 0.499 | 0.0245 | 0.0213 | 0.0310 | 0.0229 | 0.0081 |
| 0.539 | 0.0256 | 0.0224 | 0.0330 | 0.0240 | 0.0090 |
| 0.600 | 0.0270 | 0.0240 | 0.0366 | 0.0255 | 0.01110 |
| 0.646 | 0.0281 | 0.0252 | 0.0399 | 0.02665 | 0.01325 |
| 0.693 | 0.0291 | 0.0266 | 0.0444 | 0.02785 | 0.01655 |
| 0.744 | 0.0303 | 0.0283 | 0.0508 | 0.0293 | 0.0215 |
| 0.791 | 0.0315 | 0.0303 | 0.0598 | 0.0309 | 0.0289 |
| 0.891 | 0.0348 | 0.0364 | 0.1002 | 0.03585 | 0.06435 |
| 0.934 | 0.0355 | 0.0371 | 0.1020 | 0.0363 | 0.0657 |
| 0.787 | 0.0337 | 0.0355 | 0.0984 | 0.0346 | 0.0638 |
| 0.585 | 0.0302 | 0.0321 | 0.0923 | 0.03115 | 0.06115 |
| 0.391 | 0.0254 | 0.0277 | 0.0849 | 0.02655 | 0.05835 |
| 0.197 | 0.0179 | 0.0211 | 0.0753 | 0.0195 | 0.0558 |
| 0.0 | 0.0042 | 0.0091 | 0.0592 | 0.00665 | 0.05255 |

CRYSTAL # 4 TEST DATE 4/11/85

POSITION OF ARROW: ⇧ TEST TYPE: LIMIT PRESSURE

| ΔP (PSI) | G1 GAGE #1 (IN) | G3 GAGE #3 (IN) | G2 GAGE #2 (IN) | EDGE GE = G1 + G3/2 (IN) | CENTER GC = G2 - GE (IN) |
|---|---|---|---|---|---|
| 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 0.0481 | 0.0041 | 0.0039 | 0.0047 | 0.0040 | 0.0007 |
| 0.098 | 0.0082 | 0.0076 | 0.0094 | 0.0079 | 0.0015 |
| 0.205 | 0.0151 | 0.0137 | 0.0174 | 0.0144 | 0.0030 |
| 0.228 | 0.0165 | 0.0150 | 0.0190 | 0.01575 | 0.00325 |
| 0.205 | 0.0156 | 0.0142 | 0.0179 | 0.0149 | 0.0030 |
| 0.0949 | 0.0095 | 0.0090 | 0.0108 | 0.00925 | 0.00155 |
| 0.0 | 0.0013 | 0.0017 | 0.0017 | 0.0015 | 0.0002 |

CRYSTAL # 4

TEST DATE 4/11/85

POSITION OF ARROW: ⇧

TEST TYPE: 1.4 X LIMIT PRESSURE

| ΔP (PSI) | G1 GAGE #1 (IN) | G3 GAGE #3 (IN) | G2 GAGE #2 (IN) | EDGE GE = G1 + G3/2 (IN) | CENTER GC = G2 - GE (IN) |
|---|---|---|---|---|---|
| 0.0 | 0.0013 | 0.0017 | 0.0017 | 0.0015 | 0.0002 |
| 0.102 | 0.0091 | 0.0086 | 0.0104 | 0.00885 | 0.00155 |
| 0.201 | 0.0151 | 0.0138 | 0.0174 | 0.01445 | 0.00295 |
| 0.248 | 0.0177 | 0.0161 | 0.0204 | 0.0169 | 0.0035 |
| 0.294 | 0.0200 | 0.0183 | 0.0236 | 0.01915 | 0.00445 |
| 0.349 | 0.0221 | 0.0204 | 0.0270 | 0.02125 | 0.00575 |
| 0.0 | 0.0014 | 0.0020 | 0.0029 | 0.0017 | 0.0012 |

CRYSTAL # 4      TEST DATE 4/11/85

POSITION OF ARROW: ⇩      TEST TYPE: LIMIT PRESSURE

| ΔP (PSI) | G1 GAGE #1 (IN) | G3 GAGE #3 (IN) | G2 GAGE #2 (IN) | EDGE GE = G1 + G3/2 (IN) | CENTER GC = G2 - GE (IN) |
|---|---|---|---|---|---|
| 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 0.062 | 0.005 | 0.0051 | 0.0059 | 0.00505 | 0.00085 |
| 0.100 | 0.0077 | 0.0075 | 0.0089 | 0.0076 | 0.0013 |
| 0.212 | 0.0144 | 0.0135 | 0.0171 | 0.01395 | 0.00315 |
| 0.241 | 0.01616 | 0.0149 | 0.0191 | 0.0155 | 0.00360 |
| 0.0 | 0.0006 | 0.0015 | 0.0016 | 0.00105 | 0.00055 |

CRYSTAL # 4

TEST DATE 4/11/85

POSITION OF ARROW: ⇩

TEST TYPE: 1.4 X LIMIT PRESSURE

| ΔP (PSI) | G1 GAGE #1 (IN) | G3 GAGE #3 (IN) | G2 GAGE #2 (IN) | EDGE GE = G1 + G3/2 (IN) | CENTER GC = G2 - GE (IN) |
|---|---|---|---|---|---|
| 0.0 | 0.006 | 0.0015 | 0.0016 | 0.00105 | 0.00055 |
| 0.100 | 0.0082 | 0.008 | 0.0096 | 0.0081 | 0.0015 |
| 0.206 | 0.0142 | 0.0137 | 0.0173 | 0.01415 | 0.00315 |
| 0.246 | 0.0168 | 0.0155 | 0.0199 | 0.01615 | 0.00375 |
| 0.301 | 0.0194 | 0.0176 | 0.0230 | 0.0185 | 0.0045 |
| 0.371 | 0.0225 | 0.0199 | 0.0271 | 0.0212 | 0.0059 |
| 0.296 | 0.0198 | 0.0178 | 0.0237 | 0.0188 | 0.0049 |
| 0.242 | 0.0176 | 0.0161 | 0.0210 | 0.01685 | 0.00415 |
| 0.195 | 0.0153 | 0.0142 | 0.0183 | 0.01475 | 0.00355 |
| 0.091 | 0.0093 | 0.009 | 0.0111 | 0.00915 | 0.00195 |
| 0.0 | 0.0015 | 0.0022 | 0.0026 | 0.00185 | 0.00075 |

CRYSTAL # 4

TEST DATE 5/7/85

POSITION OF ARROW: ⇩

TEST TYPE: >3 X LIMIT PRESSURE

| ΔP (PSI) | G1 GAGE #1 (IN) | G3 GAGE #3 (IN) | G2 GAGE #2 (IN) | EDGE GE = G1 + G3/2 (IN) | CENTER GC = G2 - GE (IN) |
|---|---|---|---|---|---|
| 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 0.087 | 0.0054 | 0.0055 | 0.0065 | 0.00545 | 0.00105 |
| 0.184 | 0.0110 | 0.0106 | 0.0131 | 0.0108 | 0.0023 |
| 0.285 | 0.0154 | 0.0146 | 0.0187 | 0.0150 | 0.0037 |
| 0.398 | 0.0192 | 0.0182 | 0.0244 | 0.0187 | 0.0057 |
| 0.503 | 0.0224 | 0.0213 | 0.0302 | 0.02185 | 0.00835 |
| 0.542 | 0.0234 | 0.0226 | 0.0339 | 0.0230 | 0.0109 |
| 0.597 | 0.0249 | 0.0246 | 0.0402 | 0.02475 | 0.01545 |
| 0.637 | 0.0259 | 0.0262 | 0.0463 | 0.02605 | 0.02025 |
| 0.688 | 0.0271 | 0.0281 | 0.0536 | 0.0276 | 0.0260 |
| 0.739 | 0.0283 | 0.0305 | 0.0644 | 0.0294 | 0.0350 |
| 0.784 | 0.0294 | 0.0325 | 0.0746 | 0.03095 | 0.04365 |
| 0.842 | 0.0307 | 0.0350 | 0.0882 | 0.03285 | 0.05535 |
| 0.890 | 0.0318 | 0.0370 | 0.0997 | 0.0344 | 0.0653 |
| 0.946 | 0.0332 | 0.0398 | Gage bot-tomed | 0.0365 | - |
| 0.534 | 0.0268 | 0.0353 | 0.1154 | 0.03105 | 0.08435 |
| 0.406 | 0.0233 | 0.0322 | 0.1103 | 0.02775 | 0.08255 |
| 0.193 | 0.0157 | 0.0253 | 0.1000 | 0.0205 | 0.0795 |
| 0.0 | 0.0043 | 0.0126 | 0.0847 | 0.00845 | 0.07625 |

CRYSTAL # 4

TEST DATE 5/8/85

POSITION OF ARROW: ⇧

TEST TYPE: >3 X LIMIT PRESSURE

| ΔP (PSI) | G1 GAGE #1 (IN) | G3 GAGE #3 (IN) | G2 GAGE #2 (IN) | EDGE GE = G1 + G3/2 (IN) | CENTER GC = G2 - GE (IN) |
|---|---|---|---|---|---|
| 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 0.059 | 0.0032 | 0.0029 | 0.0038 | 0.00305 | 0.00075 |
| 0.201 | 0.0094 | 0.0095 | 0.0131 | 0.00945 | 0.00365 |
| 0.290 | 0.0138 | 0.0128 | 0.0177 | 0.0133 | 0.0044 |
| 0.391 | 0.0171 | 0.0164 | 0.0245 | 0.01675 | 0.00775 |
| 0.488 | 0.0199 | 0.0197 | 0.0308 | 0.0198 | 0.0110 |
| 0.546 | 0.0214 | 0.0218 | 0.0352 | 0.0216 | 0.0136 |
| 0.586 | 0.0224 | 0.0234 | 0.0392 | 0.0229 | 0.0163 |
| 0.642 | 0.0236 | 0.0257 | 0.0453 | 0.02465 | 0.02065 |
| 0.685 | 0.0245 | 0.0274 | 0.0499 | 0.02595 | 0.02395 |
| 0.740 | 0.0257 | 0.0306 | 0.0598 | 0.02815 | 0.03165 |
| 0.777 | 0.0264 | 0.0324 | 0.0656 | 0.0294 | 0.0362 |
| 0.845 | 0.0276 | 0.0352 | 0.0765 | 0.0314 | 0.0451 |
| 0.900 | 0.0285 | 0.0381 | 0.0883 | 0.0333 | 0.0550 |
| 0:939 | 0.0296 | 0.0408 | 0.1019 | 0.0352 | 0.0667 |
| Near 1.00 psi. | Failed | - | - | - | - |

CRYSTAL # 5

TEST DATE 4/26/85

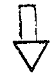
POSITION OF ARROW: ⇩

TEST TYPE: LIMIT PRESSURE

| ΔP (PSI) | G1 GAGE #1 (IN) | G3 GAGE #3 (IN) | G2 GAGE #2 (IN) | EDGE GE = G1 + G3/2 (IN) | CENTER GC = G2 - GE (IN) |
|---|---|---|---|---|---|
| 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 0.044 | 0.0036 | 0.0036 | 0.0043 | 0.0036 | 0.0007 |
| 0.100 | 0.0078 | 0.0076 | 0.0092 | 0.0077 | 0.0015 |
| 0.212 | 0.0145 | 0.0133 | 0.0176 | 0.0139 | 0.0037 |
| 0.241 | 0.0162 | 0.0147 | 0.0197 | 0.01545 | 0.00425 |
| 0.0 | 0.0010 | 0.0016 | 0.0019 | 0.0013 | 0.0006 |

CRYSTAL # 5

TEST DATE 4/26/85

POSITION OF ARROW: 

TEST TYPE: 1.4 X LIMIT PRESSURE

| ΔP (PSI) | G1 GAGE #1 (IN) | G3 GAGE #3 (IN) | G2 GAGE #2 (IN) | EDGE GE = G1 + G3/2 (IN) | CENTER GC = G2 - GE (IN) |
|---|---|---|---|---|---|
| 0.0 | 0.0010 | 0.0016 | 0.0019 | 0.0013 | 0.0006 |
| 0.099 | 0.0077 | 0.0078 | 0.0101 | 0.00775 | 0.00235 |
| 0.206 | 0.0143 | 0.0131 | 0.0178 | 0.0137 | 0.0041 |
| 0.254 | 0.0169 | 0.0152 | 0.0213 | 0.01605 | 0.00525 |
| 0.292 | 0.0187 | 0.0167 | 0.0238 | 0.01605 | 0.00525 |
| 0.360 | 0.0214 | 0.0188 | 0.0282 | 0.0201 | 0.0081 |
| 0.294 | 0.0193 | 0.0171 | 0.0252 | 0.0182 | 0.0071 |
| 0.193 | 0.0147 | 0.0135 | 0.0195 | 0.0141 | 0.0054 |
| 0.089 | 0.0085 | 0.0084 | 0.0123 | 0.00845 | 0.00385 |
| 0.0 | 0.0015 | 0.002 | 0.004 | 0.00175 | 0.00225 |

CRYSTAL # 5

TEST DATE 4/26/85

POSITION OF ARROW: ⇧

TEST TYPE: LIMIT PRESSURE

| ΔP (PSI) | G1 GAGE #1 (IN) | G3 GAGE #3 (IN) | G2 GAGE #2 (IN) | EDGE GE = G1 + G3/2 (IN) | CENTER GC = G2 - GE (IN) |
|---|---|---|---|---|---|
| 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 0.047 | 0.0037 | 0.0044 | 0.0046 | 0.00405 | 0.00055 |
| 0.094 | 0.0074 | 0.0083 | 0.0091 | 0.00785 | 0.00125 |
| 0.202 | 0.0141 | 0.0145 | 0.0169 | 0.0143 | 0.0026 |
| 0.245 | 0.0167 | 0.0167 | 0.0199 | 0.0167 | 0.0032 |
| 0.0 | 0.0014 | 0.0021 | 0.0019 | 0.00125 | 0.00015 |

CRYSTAL # 5

TEST DATE 4/26/85

POSITION OF ARROW: ⇧

TEST TYPE: 1.4 X LIMIT PRESSURE

| ΔP (PSI) | G1 GAGE #1 (IN) | G3 GAGE #3 (IN) | G2 GAGE #2 (IN) | EDGE GE = G1 + G3/2 (IN) | CENTER GC = G2 - GE (IN) |
|---|---|---|---|---|---|
| 0.0 | 0.0014 | 0.0021 | 0.0019 | 0.00175 | 0.00015 |
| 0.092 | 0.008 | 0.0089 | 0.0096 | 0.00845 | 0.00115 |
| 0.204 | 0.0145 | 0.0149 | 0.0174 | 0.0147 | 0.0027 |
| 0.249 | 0.017 | 0.0170 | 0.0203 | 0.0170 | 0.0033 |
| 0.296 | 0.0192 | 0.0190 | 0.0230 | 0.0191 | 0.0039 |
| 0.358 | 0.0218 | 0.0211 | 0.0267 | 0.02145 | 0.00525 |
| 0.202 | 0.0155 | 0.0157 | 0.0189 | 0.0156 | 0.0033 |
| 0.099 | 0.0097 | 0.0104 | 0.0119 | 0.01005 | 0.00185 |
| 0.0 | 0.0015 | 0.0023 | 0.0025 | 0.0019 | 0.0006 |

CRYSTAL # 5

TEST DATE 5/8/85

POSITION OF ARROW: ⇩

TEST TYPE: >3 X LIMIT PRESSURE

| ΔP (PSI) | G1 GAGE #1 (IN) | G3 GAGE #3 (IN) | G2 GAGE #2 (IN) | EDGE GE = G1 + G3/2 (IN) | CENTER GC = G2 - GE (IN) |
|---|---|---|---|---|---|
| 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 0.092 | 0.0051 | 0.0065 | 0.007 | 0.0058 | 0.0012 |
| 0.209 | 0.0104 | 0.0132 | 0.0145 | 0.0118 | 0.0027 |
| 0.296 | 0.0136 | 0.0168 | 0.0192 | 0.0152 | 0.0040 |
| 0.399 | 0.0165 | 0.0201 | 0.0259 | 0.0183 | 0.0076 |
| 0.501 | 0.0191 | 0.0229 | 0.0321 | 0.0210 | 0.0111 |
| 0.539 | 0.0206 | 0.0244 | 0.0393 | 0.0225 | 0.0168 |
| 0.591 | 0.0220 | 0.0259 | 0.0442 | 0.02395 | 0.02025 |
| 0.638 | 0.0239 | 0.0280 | 0.0544 | 0.02595 | 0.02845 |
| 0.695 | 0.0259 | 0.0301 | 0.0653 | 0.0280 | 0.0373 |
| 0.751 | 0.0283 | 0.0327 | 0.0797 | 0.0305 | 0.0492 |
| 0.792 | 0.0304 | 0.0349 | 0.0936 | 0.03265 | 0.06095 |
| 0.838 | 0.0330 | 0.0375 | 0.1110 | 0.03525 | 0.07875 |
| 0.889 | 0.0361 | 0.0406 | 0.1333 | 0.03835 | 0.09495 |
| 0.959 | 0.0392 | 0.0436 | 0.1547 | 0.0414 | 0.1133 |
| 0.996 | 0.0412 | 0.0456 | 0.1705 | 0.0434 | 0.1271 |

(CONTINUED)

CRYSTAL # 5

TEST DATE 5/8/85

POSITION OF ARROW: ⇩

TEST TYPE: >3 X LIMIT PRESSURE (CONT'D)

| ΔP (PSI) | G1 GAGE #1 (IN) | G3 GAGE #3 (IN) | G2 GAGE #2 (IN) | EDGE GE = G1 + G3/2 (IN) | CENTER GC = G2 - GE (IN) |
|---|---|---|---|---|---|
| 0.781 | 0.0394 | 0.0437 | 0.1657 | 0.04155 | 0.12415 |
| 0.597 | 0.0370 | 0.0409 | 0.1606 | 0.03895 | 0.12165 |
| 0.391 | 0.0331 | 0.0365 | 0.1534 | 0.0348 | 0.1186 |
| 0.187 | 0.0269 | 0.0296 | 0.1436 | 0.02825 | 0.11535 |
| 0.0 | 0.0159 | 0.0176 | 0.1288 | 0.01675 | 0.11205 |

CRYSTAL # 5

TEST DATE 5/9/85

POSITION OF ARROW: ⇧

TEST TYPE: >3 X LIMIT PRESSURE

| ΔP (PSI) | G1 GAGE #1 (IN) | G3 GAGE #3 (IN) | G2 GAGE #2 (IN) | EDGE GE = G1 + G3/2 (IN) | CENTER GC = G2 - GE (IN) |
|---|---|---|---|---|---|
| 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 0.068 | 0.0033 | 0.0035 | 0.0121 | 0.0034 | 0.0087 |
| 0.201 | 0.0132 | 0.0157 | 0.0277 | 0.01445 | 0.01325 |
| 0.290 | 0.0159 | 0.0193 | 0.0320 | 0.0176 | 0.0144 |
| 0.413 | 0.0192 | 0.0234 | 0.0372 | 0.0213 | 0.0159 |
| 0.486 | 0.0210 | 0.0256 | 0.0403 | 0.0233 | 0.0170 |
| 0.554 | 0.0229 | 0.0279 | 0.0452 | 0.0254 | 0.0198 |
| 0.605 | 0.0248 | 0.0305 | 0.0522 | 0.02765 | 0.02455 |
| 0.640 | 0.0268 | 0.0330 | 0.0596 | 0.0299 | 0.0297 |
| 0.695 | 0.0297 | 0.0367 | 0.0714 | 0.0332 | 0.0382 |
| 0.746 | 0.0330 | 0.0412 | 0.0861 | 0.0371 | 0.049 |
| 0.785 | 0.0371 | 0.0459 | 0.1048 | 0.0415 | 0.0633 |
| 0.836 | 0.0412 | 0.0510 | 0.1259 | 0.0461 | 0.0798 |
| 0.908 | 0.0457 | 0.0563 | 0.1503 | 0.0510 | 0.0993 |
| 0.956 | 0.0489 | 0.0600 | 0.1687 | 0.05445 | 0.11425 |
| 0.996 | 0.0517 | 0.0631 | 0.1859 | 0.0574 | 0.1285 |



(CONTINUED)

CRYSTAL # 5

TEST DATE 5/9/85

POSITION OF ARROW: ⇧

TEST TYPE: >3 X LIMIT PRESSURE (CONTINUED)

| ΔP (PSI) | G1 GAGE #1 (IN) | G3 GAGE #3 (IN) | G2 GAGE #2 (IN) | EDGE GE = G1 + G3/2 (IN) | CENTER GC = G2 - GE (IN) |
|---|---|---|---|---|---|
| 0.780 | 0.0494 | 0.0611 | 0.1806 | 0.05525 | 0.12535 |
| 0.596 | 0.0467 | 0.0581 | 0.1750 | 0.0524 | 0.1226 |
| 0.407 | 0.0430 | 0.0542 | 0.1681 | 0.0486 | 0.1195 |
| 0.217 | 0.0381 | 0.0483 | 0.1594 | 0.0432 | 0.1162 |
| 0.0 | 0.0273 | 0.0339 | 0.1430 | 0.0306 | 0.1124 |

CRYSTAL # 6

TEST DATE 5/1/85

POSITION OF ARROW: 

TEST TYPE: LIMIT PRESSURE

| ΔP (PSI) | G1 GAGE #1 (IN) | G3 GAGE #3 (IN) | G2 GAGE #2 (IN) | EDGE GE = G1 + G3/2 (IN) | CENTER GC = G2 - GE (IN) |
|---|---|---|---|---|---|
| 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 0.076 | 0.0058 | 0.0061 | 0.007 | 0.00595 | 0.00105 |
| 0.103 | 0.0078 | 0.0079 | 0.009 | 0.00785 | 0.00115 |
| 0.186 | 0.0130 | 0.0129 | 0.0155 | 0.01295 | 0.00255 |
| 0.239 | 0.0156 | 0.0153 | 0.0188 | 0.01545 | 0.00335 |
| 0.0 | 0.0009 | 0.0011 | 0.0009 | 0.001 | |

CRYSTAL # 6

TEST DATE 5/1/85

POSITION OF ARROW: ⇧

TEST TYPE: 1,4 X LIMIT PRESSURE

| ΔP (PSI) | G1 GAGE #1 (IN) | G3 GAGE #3 (IN) | G2 GAGE #2 (IN) | EDGE GE = G1 + G3/2 (IN) | CENTER GC = G2 - GE (IN) |
|---|---|---|---|---|---|
| 0.0 | 0.0009 | 0.0011 | 0.0009 | 0.001 | - |
| 0.092 | 0.0074 | 0.0076 | 0.0088 | 0.0075 | 0.0013 |
| 0.197 | 0.0136 | 0.0136 | 0.0163 | 0.0136 | 0.0027 |
| 0.243 | 0.0159 | 0.0157 | 0.0193 | 0.0158 | 0.0035 |
| 0.298 | 0.0182 | 0.0179 | 0.0224 | 0.01805 | 0.00435 |
| 0.356 | 0.0205 | 0.0200 | 0.0256 | 0.02025 | 0.00535 |
| 0.194 | 0.0146 | 0.0144 | 0.0174 | 0.0145 | 0.0029 |
| 0.092 | 0.0088 | 0.0089 | 0.0101 | 0.00885 | 0.00125 |
| 0.0 | 0.0012 | 0.0015 | 0.0014 | 0.00135 | 0.0005 |

CRYSTAL # 6 TEST DATE 5/1/85

POSITION OF ARROW: ⇩ TEST TYPE: LIMIT PRESSURE

| ΔP (PSI) | G1 GAGE #1 (IN) | G3 GAGE #3 (IN) | G2 GAGE #2 (IN) | EDGE GE = G1 + G3/2 (IN) | CENTER GC = G2 - GE (IN) |
|---|---|---|---|---|---|
| 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 0.043 | 0.0031 | 0.0036 | 0.0038 | 0.00335 | 0.00045 |
| 0.106 | 0.0078 | 0.0081 | 0.0091 | 0.00795 | 0.00125 |
| 0.186 | 0.0129 | 0.0127 | 0.0153 | 0.0128 | 0.0025 |
| 0.239 | 0.0153 | 0.0147 | 0.0184 | 0.0150 | 0.0034 |
| 0.0 | 0.0004 | 0.0013 | 0.0011 | 0.00085 | 0.00025 |

CRYSTAL # 6

TEST DATE 5/1/85

POSITION OF ARROW: 

TEST TYPE: 1.4 X LIMIT PRESSURE

| ΔP (PSI) | G1 GAGE #1 (IN) | G3 GAGE #3 (IN) | G2 GAGE #2 (IN) | EDGE GE = G1 + G3/2 (IN) | CENTER GC = G2 - GE (IN) |
|---|---|---|---|---|---|
| 0.0 | 0.004 | 0.0013 | 0.0011 | 0.00085 | 0.00025 |
| 0.087 | 0.0064 | 0.007 | 0.008 | 0.0067 | 0.0013 |
| 0.212 | 0.0137 | 0.0140 | 0.0166 | 0.01385 | 0.0028 |
| 0.257 | 0.0160 | 0.0154 | 0.0194 | 0.0157 | 0.0037 |
| 0.293 | 0.0177 | 0.0170 | 0.0224 | 0.01735 | 0.00505 |
| 0.352 | 0.0200 | 0.0190 | 0.0262 | 0.0195 | 0.0067 |
| 0.296 | 0.0181 | 0.0174 | 0.0237 | 0.01775 | 0.00595 |
| 0.189 | 0.0139 | 0.0137 | 0.0183 | 0.0138 | 0.0045 |
| 0.095 | 0.0086 | 0.009 | 0.0120 | 0.0088 | 0.0032 |
| 0.0 | 0.0006 | 0.0017 | 0.0031 | 0.0015 | 0.00195 |

CRYSTAL # 7

TEST DATE 5/2/85

POSITION OF ARROW: 

TEST TYPE: LIMIT PRESSURE

| ΔP (PSI) | G1 GAGE #1 (IN) | G3 GAGE #3 (IN) | G2 GAGE #2 (IN) | EDGE GE = G1 + G3/2 (IN) | CENTER GC = G2 - GE (IN) |
|---|---|---|---|---|---|
| 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 0.048 | 0.0043 | 0.0032 | 0.0043 | 0.00375 | 0.00055 |
| 0.095 | 0.0079 | 0.0058 | 0.0081 | 0.00685 | 0.00125 |
| 0.201 | 0.0148 | 0.0104 | 0.0156 | 0.0126 | 0.0030 |
| 0.226 | 0.0165 | 0.0115 | 0.0174 | 0.0140 | 0.0034 |
| 0.0 | 0.001 | 0.0009 | 0.001 | 0.00095 | 0.0005 |

CRYSTAL # 7

TEST DATE 5/2/85

POSITION OF ARROW: ⇧

TEST TYPE: 1.4 X LIMIT PRESSURE

| ΔP (PSI) | G1 GAGE #1 (IN) | G3 GAGE #3 (IN) | G2 GAGE #2 (IN) | EDGE GE = G1 + G3/2 (IN) | CENTER GC = G2 - GE (IN) |
|---|---|---|---|---|---|
| 0.0 | 0.001 | 0.0009 | 0.001 | 0.00095 | 0.0005 |
| 0.100 | 0.0085 | 0.0061 | 0.0086 | 0.0073 | 0.0013 |
| 0.209 | 0.0152 | 0.0104 | 0.0159 | 0.0128 | 0.0031 |
| 0.249 | 0.0124 | 0.0118 | 0.0183 | 0.0146 | 0.0037 |
| 0.304 | 0.0198 | 0.0135 | 0.0213 | 0.01665 | 0.00465 |
| 0.356 | 0.0220 | 0.0150 | 0.0246 | 0.0185 | 0.0061 |
| 0.199 | 0.0162 | 0.0110 | 0.0174 | 0.0136 | 0.0038 |
| 0.083 | 0.0094 | 0.0064 | 0.0099 | 0.0079 | 0.002 |
| 0.0 | 0.0016 | 0.0014 | 0.0023 | 0.0015 | 0.0008 |

CRYSTAL # 7

TEST DATE 5/2/85

POSITION OF ARROW: ⇩

TEST TYPE: LIMIT PRESSURE

| ΔP (PSI) | G1 GAGE #1 (IN) | G3 GAGE #3 (IN) | G2 GAGE #2 (IN) | EDGE $GE = G1 + G3/2$ (IN) | CENTER $GC = G2 - GE$ (IN) |
|---|---|---|---|---|---|
| 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 0.045 | 0.0032 | 0.0036 | 0.004 | 0.0034 | 0.0006 |
| 0.099 | 0.0065 | 0.007 | 0.0078 | 0.00675 | 0.0011 |
| 0.201 | 0.0119 | 0.0123 | 0.0149 | 0.0121 | 0.0028 |
| 0.228 | 0.0135 | 0.0139 | 0.0171 | 0.0137 | 0.0034 |
| 0.0 | 0.0012 | 0.0016 | 0.002 | 0.0014 | 0.0006 |

CRYSTAL # 7

TEST DATE 5/2/85

POSITION OF ARROW: 

TEST TYPE: 1.4 X LIMIT PRESSURE

| ΔP (PSI) | G1 GAGE #1 (IN) | G3 GAGE #3 (IN) | G2 GAGE #2 (IN) | EDGE GE = G1 + G3/2 (IN) | CENTER GC = G2 - GE (IN) |
|---|---|---|---|---|---|
| 0.0 | 0.0012 | 0.0016 | 0.002 | 0.0014 | 0.0006 |
| 0.106 | 0.0073 | 0.008 | 0.0093 | 0.00765 | 0.00165 |
| 0.190 | 0.0119 | 0.0124 | 0.0151 | 0.01215 | 0.00295 |
| 0.243 | 0.0140 | 0.0145 | 0.0179 | 0.01425 | 0.00365 |
| 0.298 | 0.0165 | 0.0168 | 0.022 | 0.01665 | 0.00535 |
| 0.355 | 0.0187 | 0.0190 | 0.0261 | 0.01885 | 0.00725 |
| 0.298 | 0.0172 | 0.0176 | 0.0239 | 0.0174 | 0.0065 |
| 0.198 | 0.0135 | 0.0142 | 0.0188 | 0.01385 | 0.00495 |
| 0.092 | 0.0084 | 0.0092 | 0.0122 | 0.0088 | 0.0034 |
| 0.0 | 0.003 | 0.0027 | 0.0047 | 0.00285 | 0.00185 |

# APPENDIX C

## STRESS-STRAIN CURVE GENERATION

Stress-strain curves for test crystals number 3 and 5 were developed using the raw measured data from the three (3) times limit pressure load tests. The enclosed tabulations reveal the procedure for this calculation.

TEST CRYSTAL #3 STRESS-STRAIN

| DATA POINT | $\Delta P$ (PSI) | $\sigma$ ACTUAL (PSI) | $\sigma$ PRESS. ONLY (PSI) | $G_c$ CENTER DISP. (IN) | $E_{sec} \times 10^6$ SECANT MOD. (PSI) | $\epsilon \times 10^{-5}$ STRAIN (IN/IN) |
|---|---|---|---|---|---|---|
| 1 | 0.0 | 31 | 0 | 0.0 | - | - |
| 2 | 0.076 | 60 | 29 | 0.0085 | 4.44 | 1.351 |
| 3 | 0.191 | 115 | 84 | 0.0024 | 3.95 | 2.911 |
| 4 | 0.293 | 170 | 139 | 0.0041 | 3.55 | 4.788 |
| 5 | 0.385 | 212 | 181 | 0.0055 | 3.47 | 6.109 |
| 6 | 0.499 | 268 | 237 | 0.0081 | 3.06 | 8.758 |
| 7 | 0.539 | 285 | 254 | 0.0090 | 2.97 | 9.596 |
| 8 | 0.600 | 315 | 284 | 0.0111 | 2.68 | 11.753 |
| 9 | 0.646 | 335 | 304 | 0.01325 | 2.42 | 13.84 |
| 10 | 0.693 | 360 | 329 | 0.01655 | 2.08 | 17.30 |
| 11 | 0.744 | 385 | 354 | 0.0215 | 1.72 | 22.38 |
| 12 | 0.791 | 405 | 374 | 0.0289 | 1.36 | 29.78 |
| 13 | 0.891 | 452 | 421 | 0.0646 | 0.68 | 65.98 |
| 14 | 0.934 | 475 | 444 | 0.0657 | 0.706 | 67.28 |
| 15 | 0.787 | 405 | 374 | 0.0638 | 0.612 | 66.17 |
| 16 | 0.585 | 305 | 274 | 0.06115 | 0.475 | 64.21 |
| 17 | 0.391 | 210 | 179 | 0.05835 | 0.332 | 63.25 |
| 18 | 0.197 | 120 | 89 | 0.0558 | 0.175 | 68.57 |
| 19 | 0.0 | 31 | 0 | 0.05255 | - | - |

NOTE:
$\sigma_{actual}$ = press. only + gravity.
$G_c$ = measured center deflection
$E_{sec}$ = 49665.29 delta P/$G_c$
$\epsilon$ = $\sigma$ press. only/$E_{sec}$ (data plotted in $\sigma$ actual versus $\epsilon$ )

TEST CRYSTAL #5 STRESS-STRAIN

| DATA POINT | $\Delta P$ (PSI) | $\sigma$ ACTUAL (PSI) | $\sigma$ PRESS ONLY (PSI) | $G_c$ CENTER DISP. (IN) | $E_{sec} \times 10^6$ SECANT MOD. (PSI) | $\epsilon \times 10^{-5}$ STRAIN (IN/IN) |
|---|---|---|---|---|---|---|
| 1 | 0.0 | 31 | 0 | 0.0 | - | - |
| 2 | 0.092 | 72 | 41 | 0.0012 | 3.80 | 1.07 |
| 3 | 0.209 | 130 | 99 | 0.0027 | 3.84 | 2.57 |
| 4 | 0.295 | 170 | 139 | 0.004 | 3.66 | 3.79 |
| 5 | 0.398 | 209 | 178 | 0.0076 | 2.60 | 6.84 |
| 6 | 0.500 | 265 | 234 | 0.0111 | 2.23 | 10.49 |
| 7 | 0.539 | 285 | 254 | 0.0168 | 1.59 | 15.9 |
| 8 | 0.591 | 310 | 279 | 0.02025 | 1.45 | 19.2 |
| 9 | 0.638 | 335 | 304 | 0.02845 | 1.11 | 27.3 |
| 10 | 0.694 | 360 | 329 | 0.0373 | 0.92 | 35.7 |
| 11 | 0.750 | 385 | 354 | 0.0492 | 0.75 | 47.2 |
| 12 | 0.792 | 405 | 374 | 0.06095 | 0.64 | 58.4 |
| 13 | 0.837 | 428 | 397 | 0.07875 | 0.53 | 75.2 |
| 14 | 0.888 | 453 | 422 | 0.09495 | 0.46 | 91.7 |
| 15 | 0.958 | 488 | 457 | 0.1133 | 0.42 | 108.8 |
| 16 | 0.995 | 505 | 474 | 0.1271 | 0.38 | 124.7 |
| 17 | 0.801 | 410 | 379 | 0.12415 | 0.32 | 118.4 |
| 18 | 0.596 | 313 | 282 | 0.12165 | 0.24 | 117.5 |
| 19 | 0.390 | 214 | 183 | 0.1186 | 0.16 | 114.3 |
| 20 | 0.196 | 120 | 89 | 0.11535 | 0.084 | 105.9 |
| 21 | 0.0 | 31 | 0 | 0.11205 | - | - |

APPROVAL

MECHANICAL TESTING OF LARGE THALLIUM DOPED SODIUM IODIDE SINGLE CRYSTALS

By Henry M. Lee

The information in this report has been reviewed for technical content. Review of any information concerning Department of Defense or nuclear energy activities or programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

A. A. McCOOL
Director, Structures and Propulsion Laboratory



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