Dynamic Fatigue of Flat Glass, Phase II: Final Report

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DEPARTMENT OF GLASS AND CERAMICS

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DYNAMIC FATIGUE OF FLAT GLASS
PHASE II

(67039)

FINAL REPORT

Submitted to:

National Research Council Canada,
Ottawa, Ontario

Canadian Pittsburg Industries, Glass Division
of PPG Industries Canada Ltd.,
Toronto, Ontario

Libbey-Owens-Ford Company,
Toledo, Ohio

Pilkington Glass Industries Ltd.,
Toronto, Ontario

Prepared by:
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February 25, 1981

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1. INTRODUCTION

This is the final report of Phase II of the research carried out by the Ontario Research Foundation under the contract entitled "Dynamic Fatigue of Flat Glass". Phase I,financed by the Federal Government of Canada, covered the design and construction of a unique test apparatus capable of applying a linearly increasing air pressure difference to glass panels 60" x 96" (1525 mm x 2440 mm) at rates ranging from less than 0.0015 psi/s (0.01 kPa/s) to more than 7.3 psi/s (50 kPa/s)[1]. Phase II of the project, supported jointly by three glass manufacturers (Canadian Pittsburgh Industries, Libbey-Owens-Ford, and Pilkington Glass Industries), and the Division of Building Research, National Research Council Canada, consisted of tests to destruction of 90 panels of annealed float glass nominally ¼" (6 mm) thick, using three different loading rates, 0.022, 0.22 and 2.2 psi/s (0.15, 1.5 and 15 kPa/s), as well as nondestructive tests on a strain gaged tempered glass panel with strain gages bound to its surface[2].

The underlying motive for the program was the need to relate the strength of windows under a '60-second load' to their capacity for resisting a series of short, sharp gusts and, in particular, the peak gust for which they are designed. When a model study is carried out in a boundary layer wind tunnel to generate information for cladding design, one occasionally finds peak pressures of extremely short duration and great magnitude. The appropriate design value depends on duration as well as magnitude.

The objective of the project was to generate data to determine the effect of rate of loading on the average strength of glass panels of the size 60" x 96" x ¼" (1525mm x 2440mm x 6mm) widely used in the building industry.

2. EXPERIMENTAL APPARATUS

2.1 Test Facility

The test facility, designed and constructed under Phase I of the project consists of three major components:

i) Glass plate test system.
ii) Loading and edge restraining system.
iii) Servo drive and data acquisition system.

A detailed description of the test facility is given in the Final Report of Phase I, submitted by ORF to the National Research Council Canada.

Photographs of the test facility are attached as Appendix A to this report. Schematics for the edge restraining system and the electronic set-up are also included.

The desired rate of loading of the glass panel was achieved by controlling the rate of movement of a hydraulically driven piston. The pressure difference across the panel was measured by a Schaevitz P1102-001 differential pressure transducer [0-10 psi (0-70 kPa) full scale].

Glass panels were restrained along all four edges between continuous ½" (12.7mm) wide Shore A 55 durometer neoprene gaskets, (a schematic is shown in Appendix A). The deflections were measured on the horizontal centre-line 3¼" (8.25 cm) from one support and at the mid point, using linear position potentiometers. X-Y plotters produced charts of Pressure Difference vs Time, and Centre Deflection vs Time. The former chart was used to determine the linear loading rate. Figures C1 to C3 show these charts for two different loading rates.

Strain gages used for nondestructive tests were manufactured by William T. Bean Inc., Detroit, Michigan, U.S.A. The 2-element gages were designated BAE-06-125TC-120 and the 3-element gages were designated BAE-06-125RA-120. These strain gages were attached to the glass panel using Eastman 910SL cement.

A Vishay 220 system was used to condition and scan the strain gages. The strain readings were fed into a Hewlett-Packard 9820A computer which calculated and provided a printout of the stresses and other relevant data. The procedure used for generating these results is included in Appendix B.

3. TEST PROCEDURE

3.1 Destructive Testing

3.1.1 Test Panel Preparation and Installation

A day before the testing glass panels were removed from the shipping pallet and washed with water to which 1% vinegar by volume was added. The glass panels were left at room temperature for at least 24 hours before being tested. The thickness was measured at six points along the perimeter of the panels.

In the manufacture of float glass, the bottom side is in contact with a bath of molten tin. This bottom surface was tested in tension. The top surface was taped with 3M #3701 polypropylene tape, 2" (5mm) wide and 0.002" (0.05mm) thick. Most of the glass area was covered, with the exception of a small portion near the centre to allow air release after the glass panel failed. Most of the possible fracture origins (hereinafter called PFOs) were captured. The panels were inspected for abnormal edge and surface flaws and the severely damaged samples were rejected. Five sets of results were discarded because break origins coincided with edge flaws, noticed during visual checking.

Panels were set vertically on two, 6" (150mm) long, Shore A 80 durometer, neoprene setting blocks at the quarter points of the 60" (1525mm) dimension. An edge restraining force of 5.7 pounds/inch (1N/mm) was maintained along the entire panel perimeter throughout each test. (See Figure A.2).

3.1.2 Tests

Ninety-six glass panels were tested between March 26th and June 5, 1980. During this period the room temperature ranged from 20 to 25°C while the relative humidity from 28 to 55%.

Each of the three manufacturers supplied four pallets of ten glass panels each for a total of one hundred and twenty test specimens. To minimize the handling of glass, all panels in a given pallet were tested consecutively. To minimize systematic errors, pallets from different manufacturers were mixed, as were the three loading rates. The order of testing is indicated by the dates in the glass failure data (Tables C2 to C10).

3.1.3 Precision of Measurements

As breaking pressure, time of failure, and deflection were recorded on an X-Y recorder, the precision of measurements were governed by the resolution attainable in reading the charts:

Quantity	Precision of Measurements
Breaking Pressure:	± 0.01 psi (0.07 kP)
Time: for 0.022 psi/s (0.15 kPa/s) rate	± 0.5 sec.
for 0.22 psi/s (1.5 kPa/s) rate	± 0.025 sec.
for 2.2 psi/s (15 kPa/s) rate	± 0.025 sec.
Deflection:	± 0.01" (0.25mm)

3.1.4 Mirror Radius

The glass panels were taped to retain the PFOs. The PFOs were identified by their position on the glass panel and their type (surface or edge). The numbering system and origins of the four quadrants are shown in Figure 1, which illustrates the system as viewed from the "chamber interior"* side.

The PFO pieces were labelled and saved. The mirror radius, r, was measured with an optical microscope and converted into stress values using the formula[3],

$$\sigma_p \text{ (psi)} = \frac{1950}{\sqrt{r(\text{in})}} \qquad (1)$$

In each test, the PFO with the lowest stress value was selected as the break origin.

3.1.4.1 Alternate Method for Selecting the Break Origin

Another way to select the break origin from several PFOs was developed, making the assumption that the quadrant in which a break origin is located shows fracture pattern with cross lines widely separated from each other. By comparison, the other three quadrants show a finely-meshed network. The break origin selected using this 'alternate method' differed from the PFO having the lowest stress value in five of the twenty-two cases suitable for comparison.

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* The side of the glass panel facing the hydraulically driven piston.

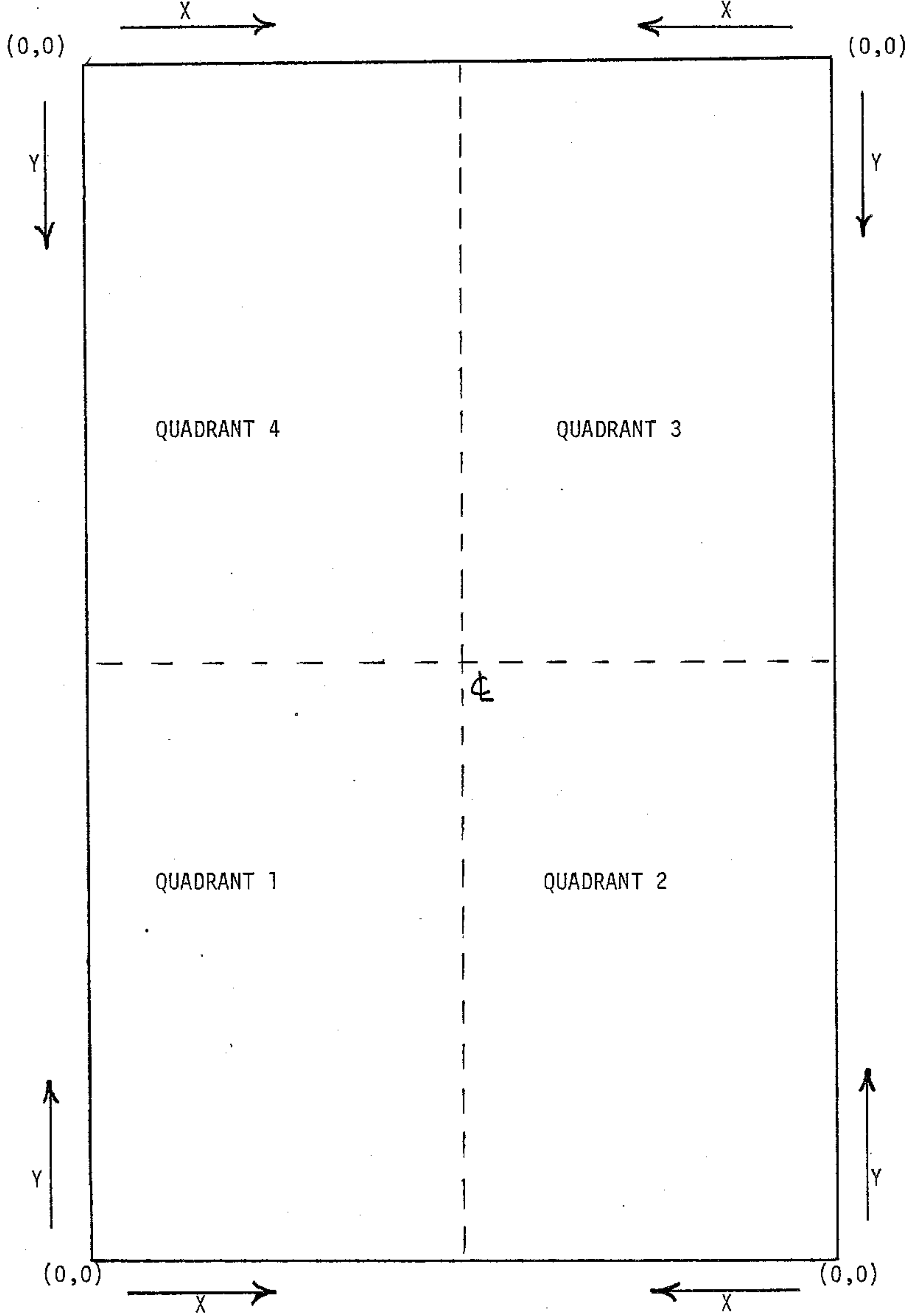

Figure 1: Quadrant System looking from the "chamber interior" side used for labelling PFOs

3.2 Nondestructive Testing

A tempered glass panel was proof-tested up to 1.25 psi (8.75 kP), strain gaged, and left in the test apparatus. Strain gages (thirty-five 3-element rosettes and six 2-element rosettes) were installed according to a layout shown in Appendix B1. The 3-element rosettes are labelled R1 to R35 while the 2-element rosettes are labelled B1 to B6. The following considerations were taken into account in placing the gages.

i) The gages should be located on straight grid lines horizontally, vertically, and along the 45^{o} diagonal for easy extraction of data by interpolation.

ii) Although 2-element rosettes should be adequate along the lines of symmetry (plate centre lines); a few 3-element rosettes should be installed along these lines to ensure that a line of symmetry does exist.

iii) Two gages should be located in the diagonally opposite quadrant to see whether the location of the quadrant,with respect to the setting blocks,has any affect on the strain readings.

The gage locations were cleaned and prepared with Micromeasurements M-Prep Neutralizer-5. The gages were bonded to the glass panel using Eastman 910SL cement,and a protective coating 'Micromeasurements M-COAT-A' (air drying polyurethane coating) was applied to each gage.

Fifty channels were available on the strain gage readout system. Three runs were made to read all the strain gages. Gage R8 was read in all three runs while R32 was common only to the first and third runs, and R29 was common to the second and third runs. The gages read in each run were interspersed with those of other runs so that gages in every run would be distributed over the entire strain gaged area.

Strain gages were not oriented in the same manner. For 3-element rosettes, however, ε_a is always along the long side of the glass panel, while ε_c is along the short side. Angles listed in Table D4 are with respect to the ε_a-axis. See Appendix B1 for details.

4. TEST RESULTS

4.1 Destructive Test Data

Data from destructive tests are given in Appendix C in imperial units. A conversion table (Table C1) for imperial units vs metric units is included for relevant quantities.

Tables C2 to C10 list the failure test data for the three loading rates and for each of the three manufacturers, termed A, B and C. Each of the tables includes test data, average thickness of the panel, centre and edge deflections and breaking load. Also listed are the break origin selected as PFO with the lowest stress value (largest mirror radius). For each break origin the following parameters are listed:

1. Type.
2. X, Y coordinates and angle of orientation.
3. σ_p (ksi) calculated using equation (1).

Table C11 lists the five cases in which, using the 'alternate method', a different PFO was selected as the break origin.

Tables C12 to C14 lists mean breaking pressures with standard deviations. Tables C15 to C17 lists the PFOs.

4.2 Nondestructive Test Data

Results from all nondestructive tests are summarized in Appendix D.

Tables D2 through D8 consist of data for all gages for each of the loading conditions. Stresses are recorded in ksi only up to the first decimal place, as variability was expected to be $\pm$ 0.2 ksi.

Table D4 lists the angle between the maximum principal strain axis and the ε_a-axis for 3-element rosettes.

Tables D6 to D8 list raw strain data used to calculate stress magnitude and orientation. See Appendix B for details.

Table D9 shows the reproducibility of the strain gage experiments. It lists experimental results of two runs done almost 2 months apart using an applied pressure of 1 psi. The quantity used for comparison is maximum principal stress. Differences between the two runs are also listed. The maximum deviation is 0.5 ksi for maximum principal stresses, calculated from strain values for rosettes R15 and R3.

For the three edge restraining forces of 2.85, 5.7 and 8.55 pounds/inch (0.5, 1, 1.5 N/mm), Table D10 shows that maximum principal stresses differ by 0.5 ksi or less.

References:

1. Stournaras, C.J., - Development and Evaluation of a Rig for the Study of Dynamic Fatigue in Flat Glass - Final Report (67005) for the National Research Council of Canada by the Ontario Research Foundation - July 3, 1979.

2. Department of Supply and Services (DSS) File No. 09SX 3155-9-4421 - A Study to Determine the Dynamic Fatigue of Flat Glass - Phase II - (See also Appendix C - Memorandum of Agreement between: National Research Council of Canada and CPI, Glass Division of PPG Industries Canada Ltd., and Libbey-Owens-Ford and Pilkington Brothers Canada Ltd., and Ontario Research Foundation - May 8, 1979).

3. Orr, L., "Practical Analysis of Fracture of Glass Windows" - Material Research and Standards, MTRSA, Vol. 12, No.1, 1972, pp. 21-23, 47

APPENDIX A

SCHEMATICS OF TEST FACILITY

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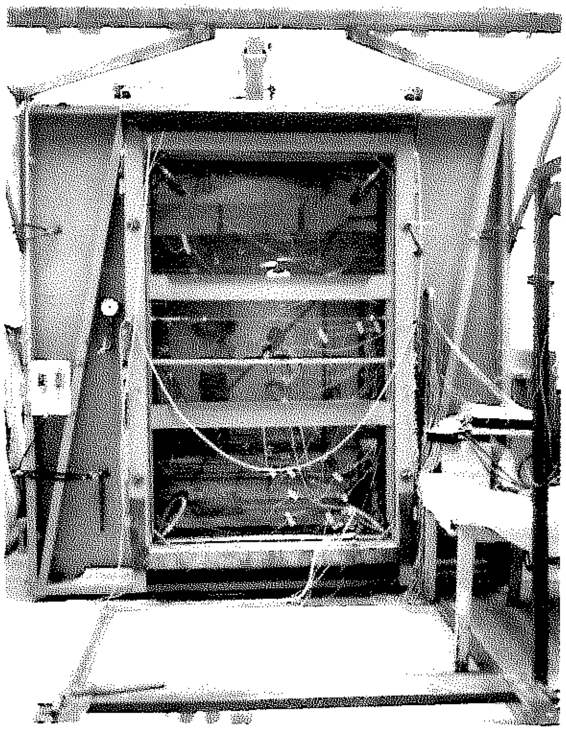
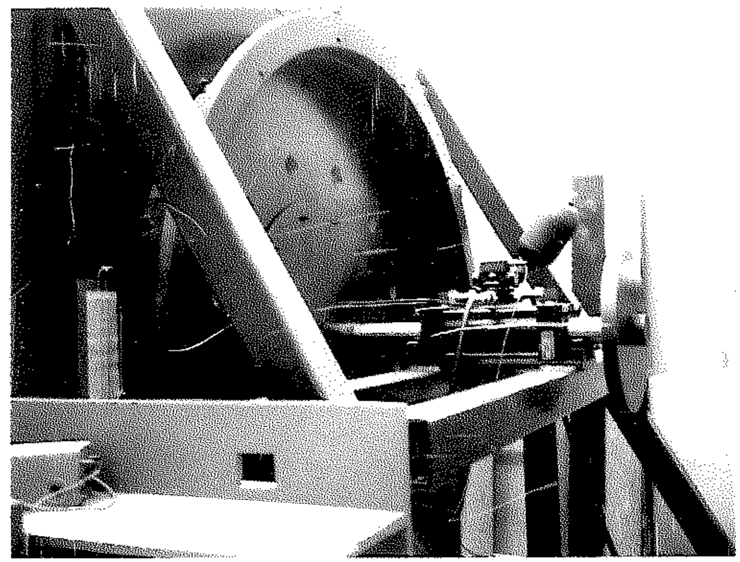
Figure A1: PHOTOGRAPHS OF THE GLASS TESTING APPARATUS



(a) Front view with tempered glass panel in place (All the wires are from the strain gages).



(b) Back view: showing 8-foot diameter piston with servo-valve assembly.

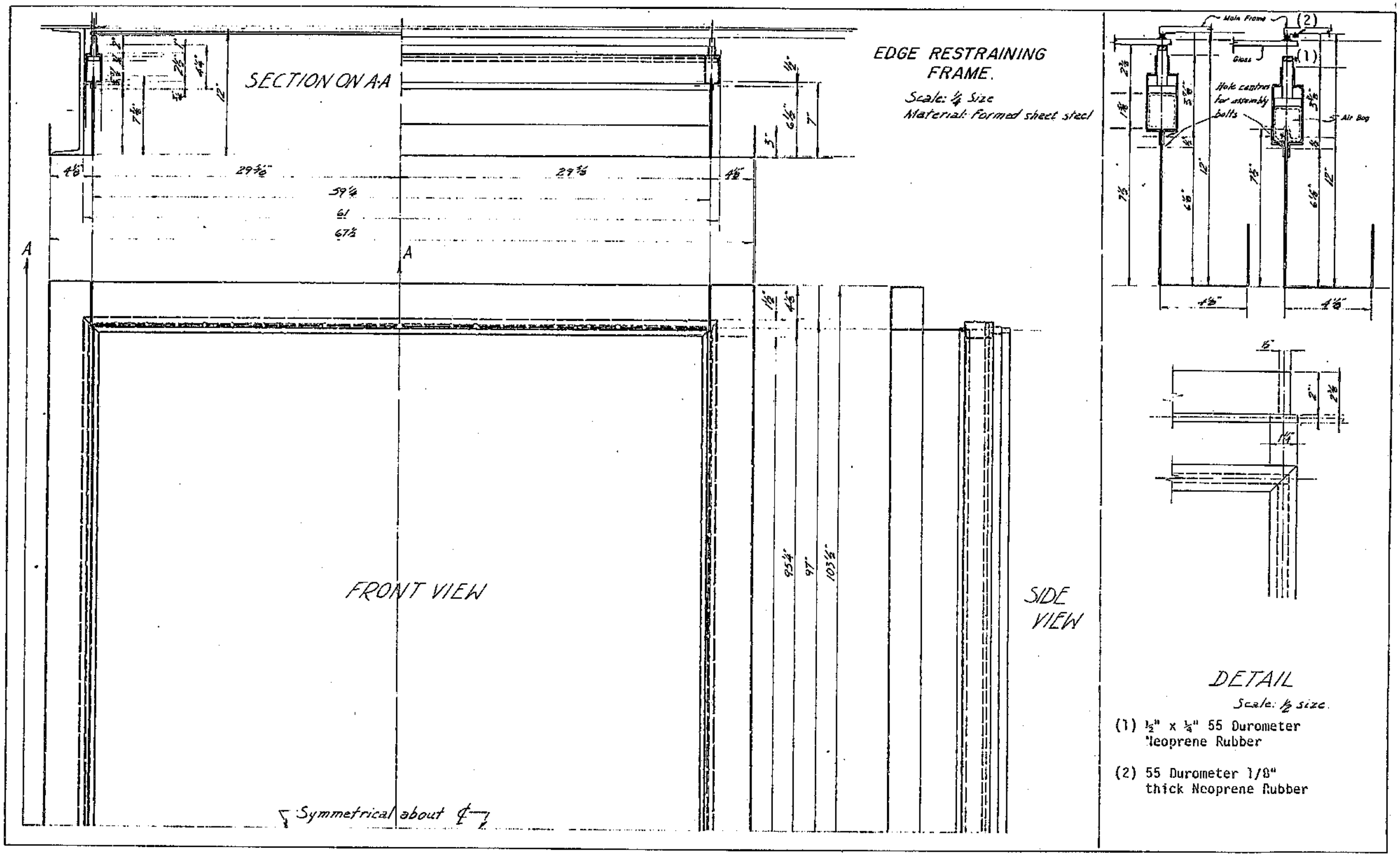


Figure A2: A Schematic of the Edge Restraining System

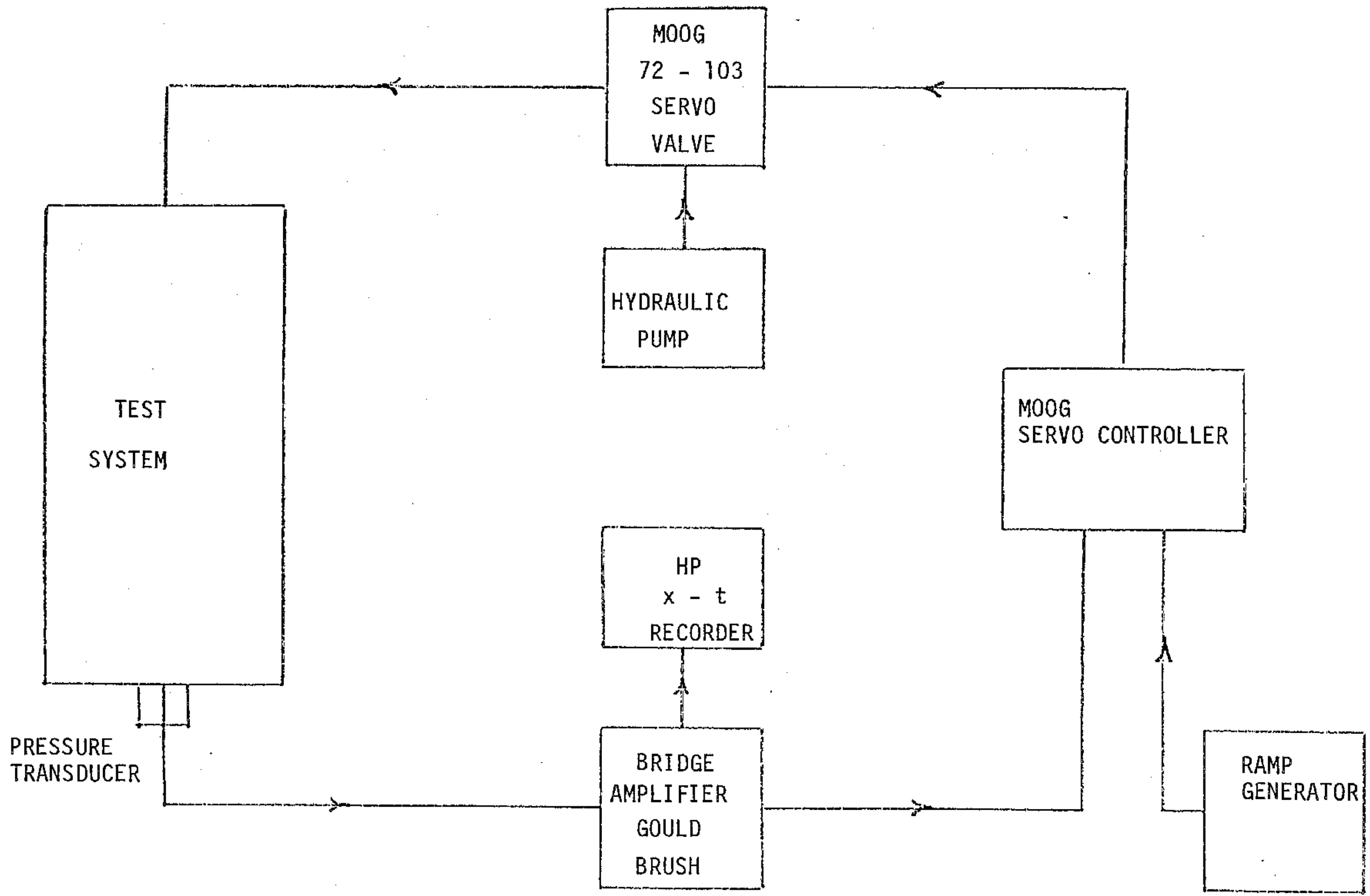


Figure A3. A Schematic of Electronics Set-up

APPENDIX B

STRAIN GAGES- LAYOUT AND PROCEDURE FOR CALCULATING STRESSES AND OTHER RELEVANT QUANTITIES

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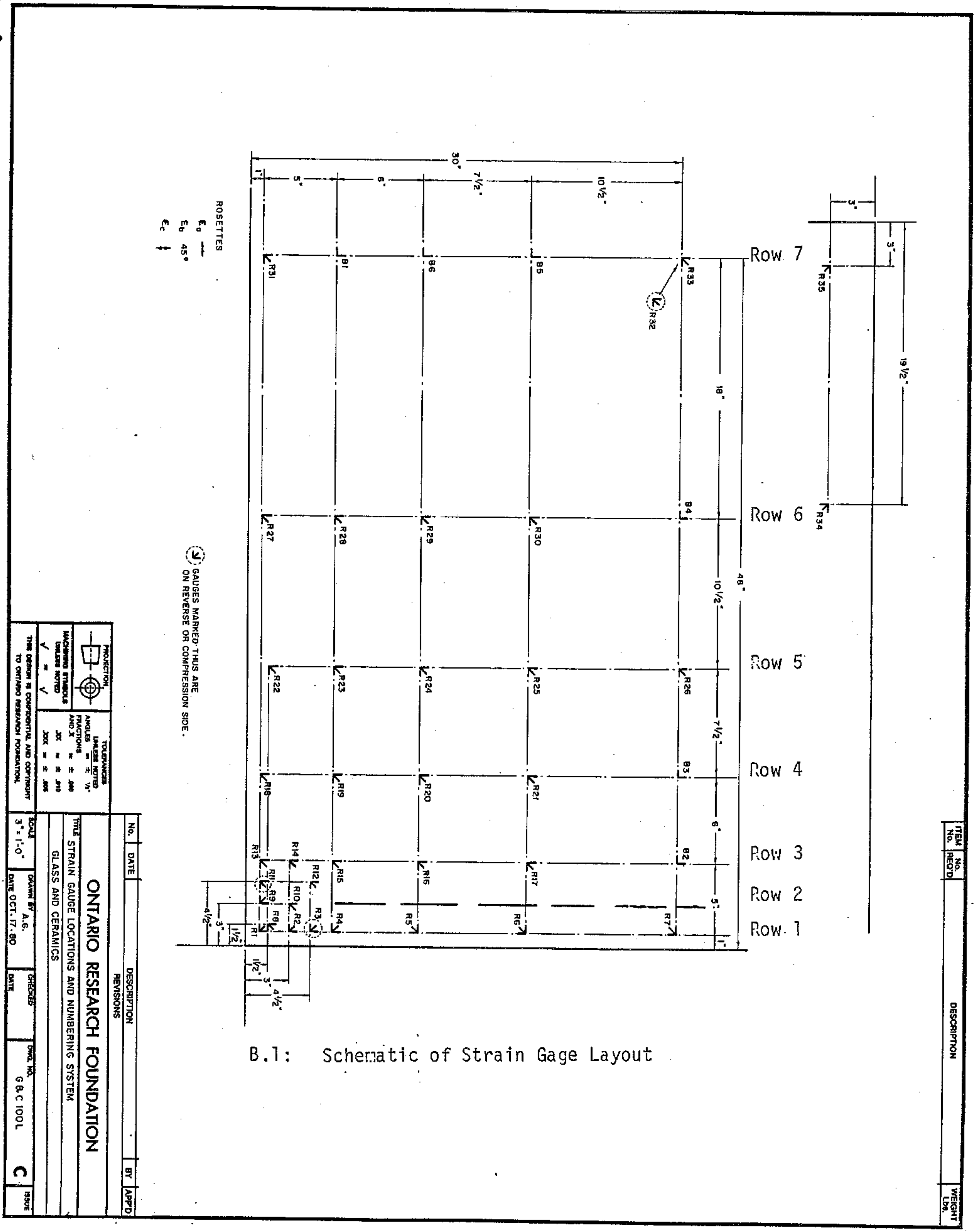

B.1: Schematic of Strain Gage Layout

B.2: SOLUTION OF ROSETTES

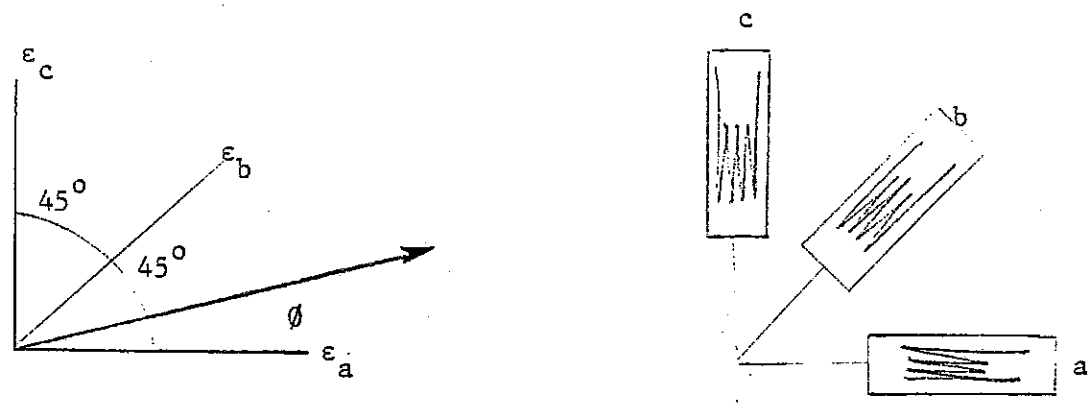

Figure 1

The 3 element rosette is used when the direction of the principal strain is unknown. The principal strains are given by the following:

$$\varepsilon_1 = \tfrac{1}{2} \left[(\varepsilon_a + \varepsilon_c) + \sqrt{(\varepsilon_a - \varepsilon_c)^2 + (2\,\varepsilon_b - \varepsilon_a - \varepsilon_c)^2} \right]$$

$$\varepsilon_2 = \tfrac{1}{2} \left[(\varepsilon_a + \varepsilon_c) - \sqrt{(\varepsilon_a - \varepsilon_c)^2 + (2\,\varepsilon_b - \varepsilon_a - \varepsilon_c)^2} \right]$$

where ε_1 = maximum principal strain

ε_2 = minimum principal strain

ε_a, ε_b and ε_c are the strain differences measured at the three elements a, b and c in Figure 1 above

The principal angle Ø is given by

$$\tan\ 2\,\text{Ø} = \frac{2\,\varepsilon_b - \varepsilon_a - \varepsilon_c}{\varepsilon_a - \varepsilon_c}$$

This solution of the above equation gives two values for the angle Ø. The angle $Ø_1$ being the angle between ε_a and the maximum principal strain ε_1 and $Ø_2$ which is the angle between ε_a and the axis of the minimum principal strain ε_2.

B.2. (continued)

The principal axis can be identified by applying the following rules.

If $\varepsilon_a > \varepsilon_c$ and $\varepsilon_a = \varepsilon_1$ then $\emptyset_1 = 0^o$

If $\varepsilon_a < \varepsilon_c$ and $\varepsilon_a = \varepsilon_2$ then $\emptyset_1 = \pm 90^o$

If $\varepsilon_a - \varepsilon_c = 0$ then $\emptyset_1$ is either $+45^o$ or -45^o

otherwise $\emptyset_1 = \frac{1}{2} \tan^{-1}\left(\frac{2\,\varepsilon_b - \varepsilon_a - \varepsilon_c}{\varepsilon_a - \varepsilon_c}\right)$ or

$$\frac{1}{2} \tan^{-1}\left(\frac{2\,\varepsilon_b - \varepsilon_a - \varepsilon_c}{\varepsilon_a - \varepsilon_c}\right) \pm 90^o$$

the choice of which angle corresponds to $\emptyset_1$ is as follows:-

$0 < \emptyset_1 < 90^o$ when $\varepsilon_b > \frac{1}{2}(\varepsilon_a + \varepsilon_c)$

$-90 < \emptyset_1 < 0$ when $\varepsilon_b < \frac{1}{2}(\varepsilon_a + \varepsilon_c)$

if $\varepsilon_a = \varepsilon_b = \varepsilon_c$ then $\emptyset_1$ is indeterminate

B.2. (continued)

The principal stresses may be established using the following:

$$\sigma_1 = E \left[\frac{\varepsilon_a + \varepsilon_c}{2\ (1-\ \mu)} + \frac{1}{2\ (1\ +\mu)} \sqrt{(\varepsilon_a - \varepsilon_c)^2 + (2\ \varepsilon_b - \varepsilon_a - \varepsilon_c)^2} \right]$$

$$\sigma_2 = E \left[\frac{\varepsilon_a + \varepsilon_c}{2\ (1-\ \mu)} - \frac{1}{2\ (1\ +\mu)} \sqrt{(\varepsilon_a - \varepsilon_c)^2 + (2\ \varepsilon_b - \varepsilon_a - \varepsilon_c)^2} \right]$$

where σ_1 is maximum principal stress (ksi)

σ_2 is minimum principal stress (ksi)

E = Youngs'modulus of elasticity (ksi)

μ = Poissons ratio

ε_a, ε_b and ε_c = strain differences measured at the three elements a, b and c in Figure 1 (page 19) (microinches/inch)

The maximum shear stress T is derived from the following:

$$T = E \left[\tfrac{1}{2} \sqrt{\frac{(\varepsilon_a - \varepsilon_c)^2 + (2\ \varepsilon_b - \varepsilon_a - \varepsilon_c)^2}{1+\mu}} \right] \quad \text{ksi}$$

2. 90° two element rosette (ksi)

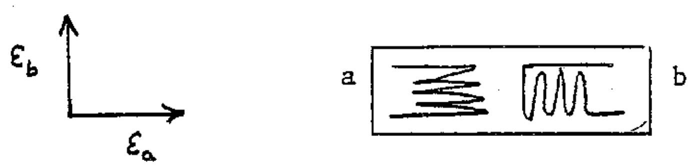

Figure 2

B.2. (continued)

The two element rosette is used when the principal directions are known. The two principal strains obtained from the gages can be used as follows to give the principal stresses.

$$\sigma_1 = \frac{E}{1 - \mu^2} (\varepsilon_a + \mu\varepsilon_b)$$

$$\sigma_2 = \frac{E}{1 - \mu^2} (\varepsilon_b + \mu\varepsilon_a)$$

where σ_1 = maximum principal stress (ksi)

σ_2 = minimum principal stress (ksi)

E = Youngs' modulus of elasticity (ksi)

μ = Poissons ratio

ε_a and ε_b = strains obtained from strain gage readings (microinches/inch)

Shear stress $\tau = \frac{\sigma_1 - \sigma_2}{2}$ (ksi)

Reference: "Experimental Stress Analysis", Dally and Riley, Chapter 16, Rosette Analysis.

B.3: SPECIFICATIONS FOR BAE SERIES

CONSTRUCTION

THE GAGE SHALL CONSIST OF A STABILIZED CONSTANTAN ETCHED FOIL GRID MOUNTED ON A FLEXIBLE POLYIMIDE BACKING, WITH A THICKNESS OF 0.001 INCH ±0.0002 INCH. THE FOIL GRID SHALL BE FREE OF IRREGULARITIES, SCRATCHES, AND DISCONTINUITIES AND THE BACKING SHALL BE FREE FROM WRINKLES, BUBBLES, OR HOLES TO THE EXTENT NECESSARY TO INSURE NO FUNCTIONAL DEFECTS. THE BACKING SHALL BE TREATED FOR OPTIMUM ADHESION WHEN USED WITH AN APPROPRIATE STRAIN GAGE ADHESIVE.

GAGE FACTOR *

THE NOMINAL GAGE FACTOR SHALL BE 2.04 ±2% FOR ALL 120 OHM AND 350 OHM GAGES REGARDLESS OF LOT NUMBER OR CONFIGURATION. ALL GAGES WITHIN A PARTICULAR LOT NUMBER SHALL BE WITHIN ±1%.

ELONGATION *

THE GAGE SHALL BE CAPABLE OF MEASURING STRAINS UP TO 3% ELONGATION WITH AN ACCURACY OF 5%.

RESISTANCE

GAGE RESISTANCES SHALL BE 120 ±.2 OHM OR 350 ±.5 OHM REGARDLESS OF GAGE TYPE OR LOT NUMBER.

TEMPERATURE COMPENSATION

THE TEMPERATURE COEFFICIENT OF THE GAGE WHEN BONDED TO SPECIFIED MATERIALS SHALL BE ZERO AT 75 DEGREES F, AND SHALL CONFORM TO THE CURVE SUPPLIED IN THE GAGE PACKAGE.

TEMPERATURE RANGE

THE GAGE SHALL BE CAPABLE OF OPERATION FROM -325 DEGREES F TO 400 DEGREES F. THE GAGE FACTOR AND APPARENT STRAIN CURVE MUST RETAIN THE SPECIFIED ROOM TEMPERATURE CHARACTERISTICS WHEN SUBJECTED TO +400 DEGREES F FOR A PERIOD OF ONE HOUR. RESISTANCE TO GROUND SHALL EXCEED 300 MEGOHMS AT 400 DEGREES F.

STABILITY

DRIFT AND CREEP COMBINED SHALL NOT EXCEED 1 MICROSTRAIN PER MINUTE WHEN SUBJECTED TO ±1000 MICROSTRAIN AT 400 DEGREES F WHEN INSTALLED WITH RECOMMENDED ADHESIVES AND TECHNIQUES.

FATIGUE LIFE

THE GAGE SHALL BE CAPABLE OF OPERATION AT ±1500 MICROSTRAIN FOR A MINIMUM OF 10 MILLION CYCLES WITHOUT CHANGE IN CHARACTERISTICS.

* SPECIFICATIONS SHALL APPLY TO 1/8" TO 1/2" GAGE LENGTHS.

APPENDIX C

DESTRUCTIVE TEST DATA

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FIGURES

TABLES

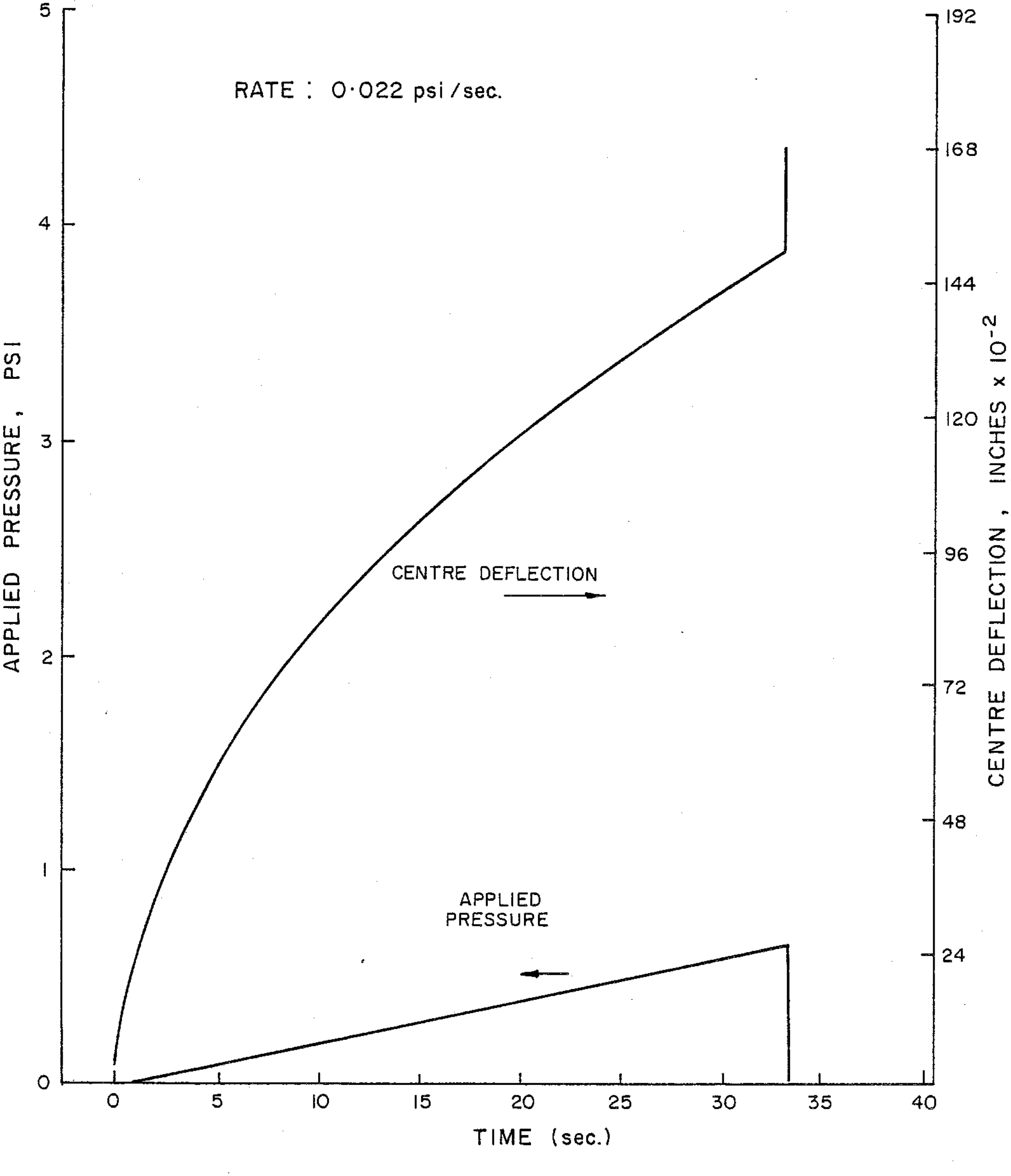

FIGURE C1. APPLIED PRESSURE vs TIME and CENTRE DEFLECTION vs TIME CURVES FOR 0·022 psi/s LOADING RATE

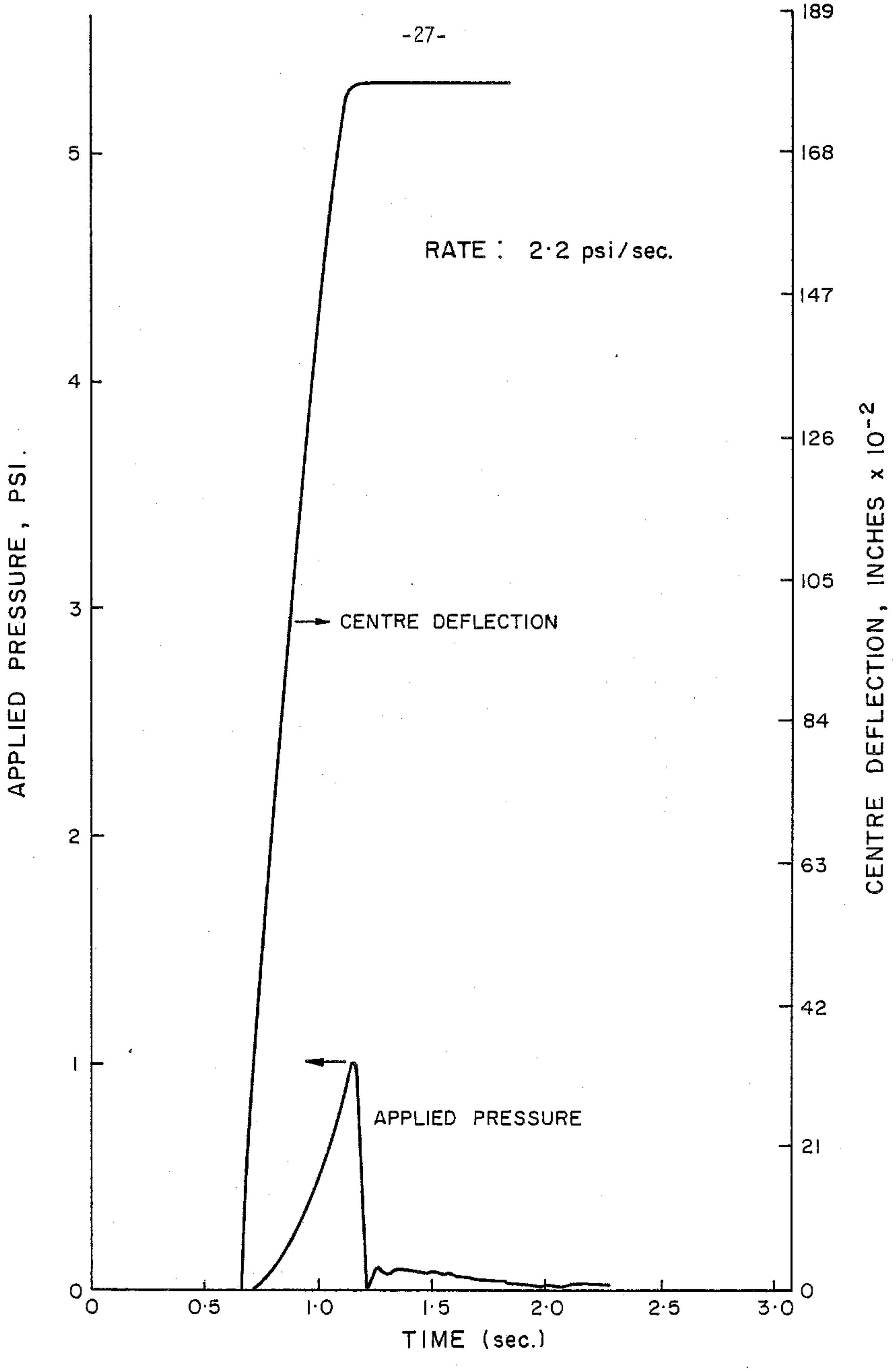

FIGURE C2. APPLIED PRESSURE vs TIME and CENTRE DEFLECTION vs TIME CURVES FOR 2·2 psi/s LOADING RATE.

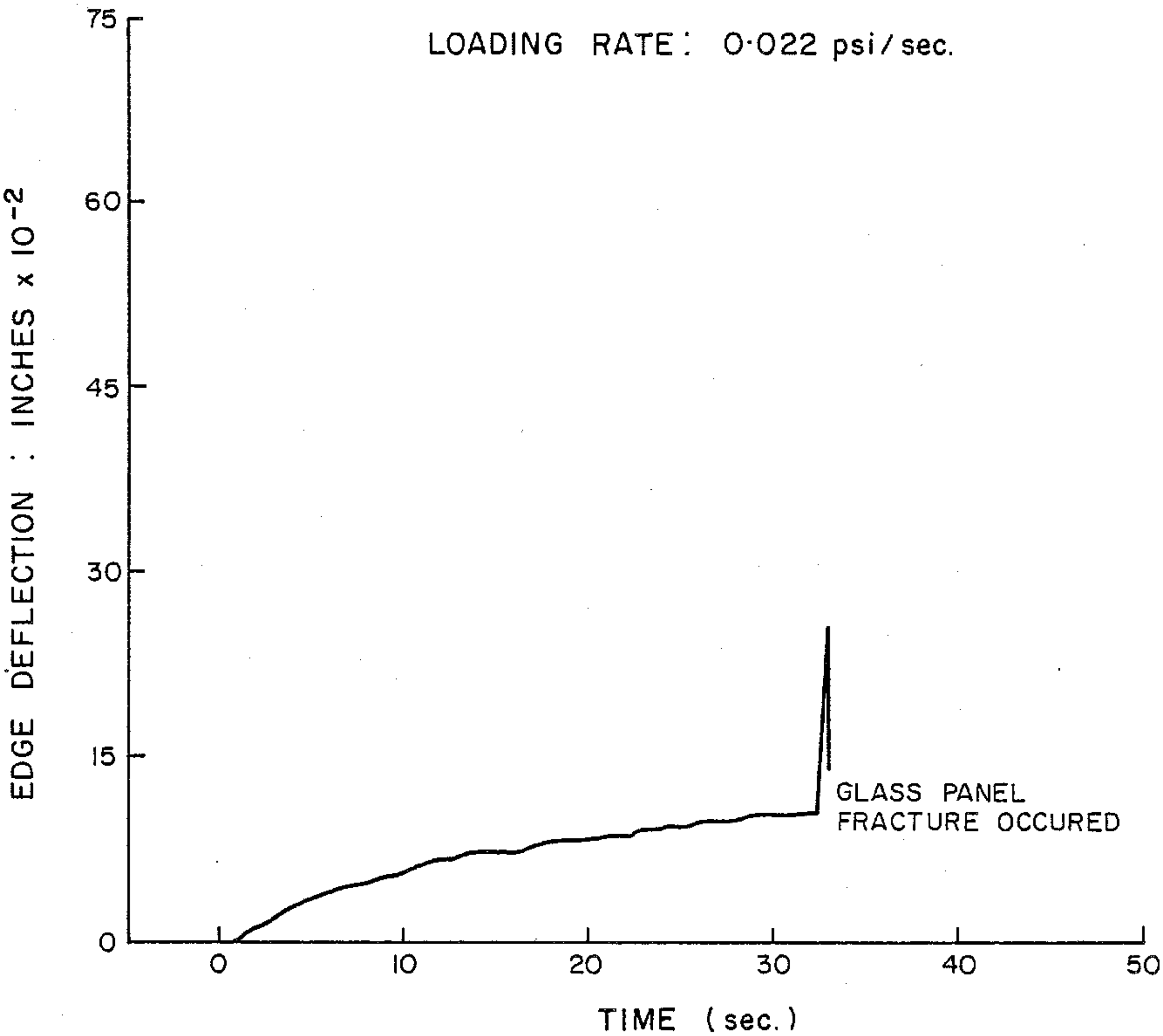

FIGURE C3. EDGE DEFLECTION vs TIME FOR 0·022 psi/s LOADING RATE.

Figure C4: Fracture Pattern of a glass panel (Test B-3 0.22 psi/s rate), as viewed from "chamber interior" side. Break origin is located on the edge in the upper right quadrant.

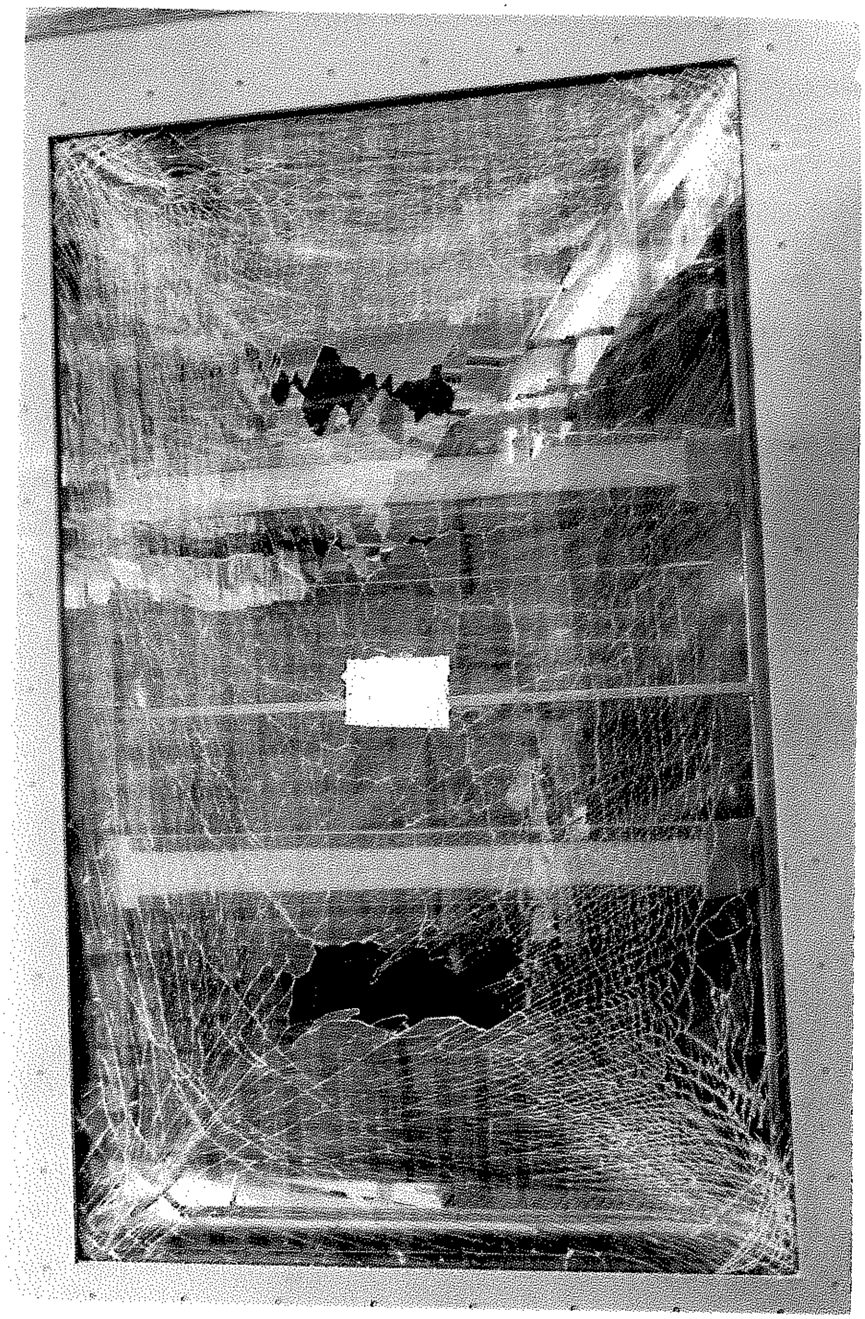

Figure C5: Fracture Pattern of a glass panel (Test C-1 0.022 psi/s rate), as viewed from "chamber Interior" side. Surface Break Origin is located in the lower left quadrant.

TABLE C1: CONVERSION TABLE

PARAMETER	IMPERIAL UNITS	METRIC UNITS
Mass	1 pounds	453.6g
Length	1 inch	2.54 cm.
Pressure	1 psi	6.9 kP
Stress	1 ksi	6.9 MP
Edge Restraining Force per unit length	1 pound/in	0.17 N/mm

TABLE C2 : GLASS FAILURE TEST DATA

RATE OF LOADING: 0.022 psi/sec

MFG.	Test No.	Date 1980	Measured Thickness (in.)	DEFLECTION		Breaking Pressure (psi)	BREAK ORIGIN				
				Centre (in.)	Edge (in.)		Type	Coordinates X in.	Coordinates Y in.	Angle Degree	Stress, σp, (ksi)
A	1	26 : 3	.2260	1.54	+	0.65	4E	2.4	0.0	Edge	6.7
	2	28 : 3	.2251	1.74	+	0.85	2E	3.2	0.0	Edge	19.5
	3	1 : 4	.2254	1.67	+	0.80	2S	7.5	10.8	61	7.4
	4	7 : 5	.2256	1.64	0.12	0.75	+	+	+	+	+
	5	8 : 5	.2253	1.91	0.11	1.15	1E	0.0	1.5	Edge	12.1
	6	9 : 5	.2250	1.88	0.13	1.05	4S	13.5	9.9	15	14.5
	7	3 : 6	.2252	1.93	0.09	1.00	3S	13.1	10.4	28	11.7
	8	3 : 6	.2247	1.90	0.05	1.00	1E	0.0	5.9	Edge	9.4
	9	5 : 6	.2241	1.97	0.11	1.05	1S	0.6	3.0	+	15.4
	10	5 : 6	.2240	1.84	0.09	0.90	4S	7.4	8.2	33	13.1

+ Not determined

TABLE C3: GLASS FAILURE TEST DATA

RATE OF LOADING: 0.022 psi/sec

MFG.	Test No.	Date 1980	Measured Thickness (in.)	DEFLECTION		Breaking Pressure (psi)	BREAK ORIGIN				
				Centre (in.)	Edge (in.)		Type	Coordinates X in.	Coordinates Y in.	Angle Degree	Stress, σp, (ksi)
B	1	3 : 4	.2329	1.37	+	0.65	1S	7.0	3.9	+	7.6
	2	9 : 4	.2313	1.52	+	0.90	4S	15.5	17.6	+	15.0
	3	10 : 4	.2315	1.30	0.11	0.65	4E	3.0	0.0	Edge	6.8
	4	14 : 5	.2317	1.69	0.02	0.93	1S	16.1	8.1	90	7.6
	5	15 : 5	.2313	1.34	0.07	0.58	4E	3.6	0.0	Edge	7.0
	6	16 : 5	.2315	1.57	0.07	0.80	3E	2.5	0.0	Edge	+
	7	21 : 5	.2317	1.42	+	0.65	4S	11.6	9.2	22	8.6
	8	22 : 5	.2317	1.59	0.08	0.83	3S	14.4	12.1	90	9.8
	9	26 : 5	.2314	1.43	0.07	0.65	1E	2.8	0.0	Edge	7.1
	10	26 : 5	.2314	1.59	0.11	0.80	1E	2.2	0.0	Edge	7.2

+ Not determined

TABLE C4: GLASS FAILURE TEST DATA

RATE OF LOADING: 0.022 psi/sec

MFG.	Test No.	Date 1980	Measured Thickness (in.)	DEFLECTION		Breaking Pressure (psi)	BREAK ORIGIN				
				Centre (in.)	Edge (in.)		Type	Coordinates X in.	Coordinates Y in.	Angle Degree	Stress, σp, (ksi)
C	1	10:4	.2284	1.53	0.12	0.77	1S	5.1	6.1	51	8.2
	2	15:4	.2283	1.53	0.10	0.72	2S	8.4	8.9	57	8.1
	3	16:4	.2298	1.20	0.07	0.54	1E	1.4	0.0	Edge	17.8
	4	16:4	.2285	1.59	0.11	0.76	1S	8.6	20.0	90	10.6
	5	17:4	.2284	1.48	0.11	0.68	4S	10.5	8.6	40	8.4
	6	30:4	.2276	1.39	0.09	0.58	1S	0.5	2.0	45	+
	7	1:5	.2280	1.49	0.10	0.67	4S	15.8	9.7	90	7.1
	8	6:5	.2278	1.69	0.06	0.88	3S	9.6	12.5	52	11.9
	9	27:5	.2277	1.51	0.03	0.68	3S	5.1	10.6	53	9.4
	10	28:5	.2274	1.66	0.05	0.85	2S	13.9	6.4	8	10.1
	11	28:5	.2276	1.52	0.06	0.70	4S	20.1	21.7	60	5.8

+ Not determined

TABLE C5 : GLASS FAILURE TEST DATA

RATE OF LOADING: 0.22 psi/sec

MFG.	Test No.	Date 1980	Measured Thickness (in.)	DEFLECTION		Breaking Pressure (psi)	BREAK ORIGIN				
				Centre (in)	Edge (in)		Type	Coordinates X in.	Coordinates Y in.	Angle Degree	Stress, σp, (ksi)
A	1	26:3	.2255	2.04	+	1.08	+	+	+	+	+
	2	27:3	.2256	1.92	+	1.05	1S	10.0	11.0	27	8.2
	3	1:4	.2258	2.01	+	1.15	1S	15.0	10.9	27	8.2
	4	7:5	.2255	1.96	0.13	1.08	2S	7.9	7.1	40	12.3
	5	8:5	.2257	1.90	0.16	1.03	2S	6.1	12.4	81	13.8
	6	9:5	.2245	+	0.12	1.25	4S	6.1	10.1	72	14.5
	7	10:5	.2252	1.83	0.09	0.95	2S	1.5	4.5	+	12.9
	8	2:6	.2238	2.01	0.11	1.13	1S	5.4	6.9	41	9.1
	9	4:6	.2242	1.89	0.07	0.95	4S	5.1	5.2	53	+
	10	4:6	.2241	1.92	0.08	1.00	2S	5.9	5.8	42	14.5

+ Not determined

TABLE C6 : GLASS FAILURE TEST DATA

RATE OF LOADING: 0.22 psi/sec

MFG.	Test No.	Date 1980	Measured Thickness (in.)	DEFLECTION		Breaking Pressure (psi)	BREAK ORIGIN				
				Centre (in)	Edge (in)		Type	Coordinates X in.	Coordinates Y in.	Angle Degree	Stress, σp, (ksi)
B	1	3:4	.2320	1.71	+	1.15	1E	3.4	0.0	Edge	12.3
	2	8:4	.2329	1.80	+	1.05	2S	8.5	9.1	40	9.5
	3	10:4	.2332	1.35	0.10	0.60	3E	1.2	0.0	Edge	7.1
	4	13:5	.2314	1.51	0.09	0.75	3E	3.6	0.0	Edge	6.4
	5	14:5	.2316	+	+	1.05	2E	2.4	0.0	Edge	10.1
	6	16:5	.2316	1.41	0.10	0.62	2E	+	+	+	+
	7	20:5	.2322	1.81	0.10	1.16	1S	6.1	17.3	72	13.1
	8	20:5	.2321	+	+	0.50	4E	0.0	1.5	Edge	14.5
	9	22:5	.2318	1.80	0.05	1.03	3E	0.0	1.0	Edge	+

+ Not determined

TABLE C7 : GLASS FAILURE TEST DATA

RATE OF LOADING: 0.22 psi/sec

MFG.	Test No.	Date 1980	Measured Thickness (in.)	DEFLECTION Centre (in.)	DEFLECTION Edge (in.)	Breaking Pressure (psi)	BREAK ORIGIN Type	Coordinates X in.	Coordinates Y in.	Angle Degree	Stress, σp, (ksi)
C	1	11:4	.2279	1.58	0.11	0.85	+	+	+	+	+
	2	15:4	.2286	1.48	0.11	0.66	2S	5.6	7.0	55	11.3
	3	16:4	.2282	1.37	0.08	0.68	3E	0.0	3.5	Edge	9.1
	4	30:4	.2276	1.55	0.09	0.75	3S	8.6	8.9	49	8.9
	5	30:4	.2277	+	+	1.01	4S	7.9	11.7	65	16.5
	6	1:5	.2276	1.71	+	0.92	1S	6.1	12.5	75	9.2
	7	2:5	.2275	1.46	0.10	0.65	4S	7.0	9.9	55	7.9
	8	6:5	.2281	1.75	0.12	0.95	2S	12.6	8.3	15	11.4
	9	26:5	.2274	1.19	0.02	0.42	2S	23.4	8.8	0	1.9
	10	28:5	.2280	1.52	0.07	0.70	+	+	+	+	+
	11	29:5	.2278	1.73	0.07	0.88	1S	7.5	6.6	40	12.3

+ Not determined

TABLE C8 : GLASS FAILURE TEST DATA

RATE OF LOADING: 2.2 psi/sec

MFG.	Test No.	Date 1980	Measured Thickness (in.)	DEFLECTION		Breaking Pressure (psi)	BREAK ORIGIN				
				Centre (in)	Edge (in)		Type	Coordinates X in.	Coordinates Y in.	Angle Degree	Stress, σp, (ksi)
A	1	28:3	.2250	2.06	+	1.22	4E	1.9	0.0	Edge	9.5
	2	1:4	.2254	2.11	+	1.30	+	+	+	+	+
	3	2:4	.2256	1.78	+	0.87	1S	6.0	5.7	37	19.5
	4	2:4	.2251	1.63	+	0.82	3S	15.5	4.6	0	7.8
	5	7:5	.2256	1.73	0.12	0.88	1S	10.8	8.3	38	12.3
	6	8:5	.2255	1.91	0.16	1.10	2S	6.1	6.1	55	13.8
	7	9:5	.2250	1.92	0.12	1.15	3E	0.0	4.5	Edge	19.5
	8	3:6	.2246	2.11	0.09	1.22	1E	0:0	2.5	Edge	15.9
	9	4:6	.2239	1.92	0.09	1.03	3S	11.0	8.0	28	12.3
	10	5:6	.2236	1.90	0.09	1.02	2S	3.6	15.6	84	8.3

+ Not determined

TABLE C9: GLASS FAILURE TEST DATA

RATE OF LOADING: 2.2 psi/sec

MFG.	Test No.	Date 1980	Measured Thickness (in.)	DEFLECTION		Breaking Pressure (psi)	BREAK ORIGIN				
				Centre (in)	Edge (in)		Type	Coordinates X in.	Coordinates Y in.	Angle Degree	Stress, σp, (ksi)
B	1	3:4	.2326	1.74	+	1.07	1E	3.9	0.0	Edge	8.3
	2	9:4	.2336	1.35	0.10	0.70	1E	0.0	2.5	Edge	6.2
	3	17:4	.2323	1.42	0.10	0.79	3E	1.0	0.0	Edge	+
	4	13:5	.2320	1.69	0.10	0.92	3E	1.5	0.0	Edge	7.6
	5	14:5	.2316	1.47	0.08	0.70	3S	10.4	9.9	42	9.6
	6	15:5	.2309	1.79	0.13	1.05	3S	10.1	11.9	60	11.4
	7	16:5	.2318	1.88	0.15	1.13	1S	9.8	17.9	90	12.3
	8	20:5	.2318	1.85	0.12	1.18	2S	13.5	25.1	80	12.3
	9	21:5	.2320	1.76	0.02	1.01	3S	13.7	8.6	12	11.9
	10	22:5	.2319	1.83	0.05	1.10	4S	6.4	7.1	32	18.6

\+ Not determined

TABLE C10: GLASS FAILURE TEST DATA

RATE OF LOADING: 2.2 psi/sec

MFG.	Test No.	Date 1980	Measured Thickness (in.)	DEFLECTION Centre (in.)	DEFLECTION Edge (in.)	Breaking Pressure (psi)	BREAK ORIGIN Type	Coordinates X in.	Coordinates Y in.	Angle Degree	Stress, σp, (ksi)
C	1	11:4	.2283	1.75	0.11	0.98	+	+	+	+	+
	2	11:4	.2282	1.68	0.12	1.07	3S	4.4	6.0	57	9.2
	3	15:4	.2286	1.76	0.13	1.00	3S	5.1	10.4	74	15.4
	4	1:5	.2280	1.81	0.12	1.08	1E	+	+	Edge	11.1
	5	2:5	.2278	1.65	0.08	0.73	4S	11.1	8.6	33	8.0
	6	6:5	.2280	1.68	0.10	0.84	2S	5.6	9.0	60	11.9
	7	27:5	.2279	1.29	+	0.53	3E	0.0	11.2	Edge	+
	8	27:5	.2279	1.47	+	0.65	4S	7.8	11.0	50	9.9
	9	29:5	.2276	+	+	0.78	1S	9.4	8.1	34	9.3
	10	29:5	.2271	1.57	+	0.78	1E	4.6	0.0	Edge	8.0

+ Not determined

TABLE C11: DIFFERENT BREAK ORIGINS SELECTED USING THE 'ALTERNATE METHOD'

Rate of Loading	Mfg.	Test No.	BREAK ORIGIN				
			Type	Coordinates		Angle Degree	Stress, σp, (ksi)
				X in.	Y in.		
0.22	A	4	1S	4.6	1.6	50	12.9
0.22	A	8	3S	9.2	6.2	18	18.6
0.22	B	7	3E	0.0	4.7	Edge	19.5
0.22	C	5	3S	2.6	3.9	128	17.1
2.2	B	8	3S	5.2	9.4	67	14.5

TABLE C 12: MEAN AND STANDARD DEVIATION BREAKING PRESSURE

Rate of Loading (psi/s)	Mfg.	Type of Breaking	No. of Data Points	Breaking Pressure (psi) Mean	Standard Deviation
0.022	A	Edge	6	0.91	0.19
		Surface	4	0.94	0.11
		ALL	10	0.92	0.16
	B	Edge	4	0.73	0.09
		Surface	6	0.76	0.15
		ALL	10	0.74	0.12
	C	Edge	2	0.56	0.03
		Surface	9	0.75	0.08
		ALL	11	0.71	0.09
	ALL	Edge	12	0.79	0.20
		Surface	19	0.79	0.13
		ALL	31	0.79	0.16

TABLE C13: MEAN AND STANDARD DEVIATION BREAKING PRESSURE

				Breaking Pressure (psi)	
Rate of Loading (psi/s)	Mfg.	Type of Breaking	No. of Data Points	Mean	Standard Deviation
0.22	A	Edge	2	1.01	0.09
		Surface	8	1.08	0.09
		ALL	10	1.07	0.09
	B	Edge	8	0.86	0.27
		Surface	1	1.05	-
		ALL	9	0.88	0.26
	C	Edge	1	0.68	-
		Surface	9	0.78	0.19
		ALL	10	0.77	0.18
	ALL	Edge	11	0.87	0.24
		Surface	18	0.93	0.21
		ALL	29	0.91	0.22

TABLE C 14: MEAN AND STANDARD DEVIATION BREAKING PRESSURE

Rate of Loading (psi/s)	Mfg.	Type of Breaking	No. of Data Points	Breaking Pressure (psi) Mean	Standard Deviation
2.2	A	Edge	3	1.20	0.04
		Surface	7	1.0	0.17
		ALL	10	1.06	0.16
	B	Edge	5	0.91	0.16
		Surface	5	1.02	0.19
		ALL	10	0.97	0.18
	C	Edge	3	0.80	0.28
		Surface	7	0.86	0.16
		ALL	10	0.84	0.18
	ALL	Edge	11	0.96	0.23
		Surface	19	0.96	0.17
		ALL	30	0.96	0.19

TABLE C15: POSSIBLE FRACTURE ORIGINS

RATE OF LOADING: 0.022 psi/s

Mfg.	Test No.	Total Number of Break Origins	Type	LOCATION X in	LOCATION Y in	LOCATION Angle Degree	Mirror Radius 10^{-3} in	Stress (ksi)
A	1	1	4E	2.4	0.0	Edge	84	6.7
	2	1	2E	3.2	0.0	Edge	10	19.5
	3	1	2S	7.5	10.8	61	69	7.4
	4	2	2S	7.1	9.6	+	+	+
			1S	6.1	9.1	58	10	19.5
	5	2	4S	5.7	5.4	41	4	30.8
			1E	0.0	1.5	Edge	26	12.1
	6	2	4S	13.5	9.9	15	18	14.5
			1S	8.9	8.1	34	4	30.8
	7	1	3S	13.1	10.4	28	28	11.7
	8	1	1E	0.0	5.9	Edge	43	9.4
	9	1	1S	0.6	3.0	+	16	15.4
	10	1	4S	7.4	8.2	33	22	13.1
B	1	1	1S	7.0	3.9	+	65	7.6
	2	2	1S	9.2	5.5	43	+	+
			4S	15.5	17.6	+	17	15.0
	3	1	4E	3.0	0.0	Edge	83	6.8
	4	1	1S	16.1	8.1	90	65	7.6
	5	1	4E	3.6	0.0	Edge	77	7.0
	6	1	3E	2.5	0.0	Edge	+	+
	7	1	4S	11.6	9.2	22	52	8.6
	8	1	3S	14.4	12.1	90	40	9.8
	9	1	1E	2.8	0.0	Edge	75	7.1
	10	1	1E	2.2	0.0	Edge	74	7.2
C	1	1	1S	5.1	6.1	51	56	8.2
	2	3	2S	8.4	8.9	57	58	8.1
			3S	11.0	11.0	47	36	10.3
			4S	4.0	4.4	42	+	+
	3	1	1E	1.4	0.0	Edge	12	17.8
	4	1	1S	8.6	20.0	90	34	10.6
	5	1	4S	10.5	8.6	40	54	8.4
	6	1	1S	0.5	2.0	45	+	+
	7	1	4S	15.8	9.7	90	75	7.1
	8	1	3S	9.6	12.5	52	27	11.9
	9	1	3S	5.1	10.6	53	43	9.4
	10	1	2S	13.9	6.4	8	37	10.1
	11	1	4S	20.1	21.7	60	113	5.8

TABLE C16: POSSIBLE FRACTURE ORIGINS

RATE OF LOADING: 0.22 psi/s

Mfg.	Test No.	Total Number of Break Origins	Type	LOCATION			Mirror Radius 10^{-3} in	Stress (ksi)
				X in	Y in	Angle Degree		
A	1	3	4S	17.6	26.4	+	+	+
			1S	9.4	10.4	+	20	13.8
			3S	9.1	8.0	+	+	+
	2	1	1S	10.0	11.0	27	57	8.2
	3	2	1S	15.0	10.9	27	57	8.2
			2S	6.1	14.0	47	+	+
	4	2	2S	7.9	7.1	40	25	12.3
			1S	4.6	1.6	50	23	12.9
	5	1	2S	6.1	12.4	81	20	13.8
	6	3	4S	6.1	10.1	72	18	14.5
			3S	6.4	11.1	65	6	25.2
			2S	5.6	6.1	55	4	30.8
	7	1	2S	1.5	4.5	+	23	12.9
	8	2	3S	9.2	6.2	18	11	18.6
			1S	5.4	6.9	41	46	9.1
	9	1	4S	5.1	5.2	53	+	+
	10	1	2S	5.9	5.8	42	18	14.5
B	1	1	1E	3.4	0.0	Edge	25	12.3
	2	2	3S	5.9	16.4	82	25	12.3
			2S	8.5	9.1	40	42	9.5
	3	1	3E	1.2	0.0	Edge	76	7.1
	4	1	3E	3.6	0.0	Edge	92	6.4
	5	1	2E	2.4	0.0	Edge	37	10.1
	6	1	2E	+	+	+	+	+
	7	2	3E	0.0	4.7	Edge	10	19.5
			1S	6.1	17.3	72	22	13.1
	8	1	4E	0.0	1.5	Edge	18	14.5

TABLE C16: POSSIBLE FRACTURE ORIGINS (continued)

RATE OF LOADING: 0.22 psi/s

Mfg.	Test No.	Total Number of Break Origins	Type	LOCATION X in	Y in	Angle Degree	Mirror Radius 10^{-3}in	Stress (ksi)
	9	1	3E	0.0	1.0	Edge	+	+
C	1	4	4S	15.6	21.0	47	62	7.8
			4S	5.1	8.9	62	50	8.7
			1S	7.4	6.1	58	22	13.1
			2S	4.6	6.1	+	+	+
	2	1	2S	5.6	7.0	55	30	11.3
	3	1	3E	0.0	3.5	Edge	46	9.1
	4	3	4S	15.1	8.9	18	47	9.0
			3S	8.6	8.9	49	48	8.9
			1S	2.0	13.3	+	30	11.3
	5	3	4S	7.9	11.7	65	14	16.5
			3S	2.6	3.9	128	13	17.1
			2S	8.1	9.9	61	5	27.6
	6	2	1S	6.1	12.5	75	45	9.2
			4S	6.1	4.1	49	+	+
	7	1	4S	7.0	9.9	55	61	7.9
	8	2	3S	10.4	4.7	30	13	17.1
			2S	12.6	8.3	15	29	11.4
	9	1	2S	23.4	8.8	0	1055	1.9
	10	2	4S	3.3	4.0	45	+	+
			2S	10.5	12.9	49	17	15.0
	11	2	4S	8.3	9.7	50	20	13.8
			1S	7.5	6.6	40	25	12.3

TABLE C17: POSSIBLE FRACTURE ORIGINS

RATE OF LOADING: 2.2 psi/s

Mfg.	Test No.	Total Number of Break Origins	Type	LOCATION			Mirror Radius 10^{-3} in	Stress (ksi)
				X_{in}	Y_{in}	Angle Degree		
A	1	3	4E	1.9	0.0	Edge	41	9.5
			1S	7.2	10.0	74	25	12.3
			2S	5.6	1.0	+	+	+
	2	4	4S	7.0	6.0	43	18	14.5
			3S	8.0	5.2	137	55	8.3
			2S	8.1	9.5	40	+	+
			1S	10.6	12.0	159	16	15.4
	3	1	1S	6.0	5.7	37	10	19.5
	4	1	3S	15.5	4.6	0	62	7.8
	5	1	1S	10.8	8.3	38	25	12.3
	6	1	2S	6.1	6.1	55	20	13.8
	7	1	3E	0.0	4.5	Edge	10	19.5
	8	2	3S	6.1	6.7	38	5	27.6
			1E	0.0	2.5	Edge	15	15.9
	9	1	3S	11.0	8.0	28	25	12.3
	10	1	2S	3.6	15.6	84	55	8.3
B	1	2	1E	3.9	0.0	Edge	55	8.3
			3S	4.5	16.4	+	22	13.1
	2	1	1E	0.0	2.5	Edge	99	6.2
	3	1	3E	1.0	0.0	Edge	+	+
	4	2	1E	4.5	0.0	Edge	55	8.3
			3E	1.5	0.0	Edge	65	7.6
	5	1	3S	10.4	9.9	42	41	9.6
	6	1	3S	10.1	11.9	60	29	11.4
	7	1	1S	9.8	17.9	90	25	12.3
	8	3	3S	5.2	9.4	67	18	14.5
			2S	13.5	25.1	80	25	12.3
			1S	9.9	18.1	80	14	16.5
	9	1	3S	13.7	8.6	12	27	11.9
	10	1	4S	6.4	7.1	32	11	18.6

TABLE C17: POSSIBLE FRACTURE ORIGINS (continued)

RATE OF LOADING: 2.2 psi /s

Mfg.	Test No.	Total Number of Break Origins	Type	LOCATION			Mirror Radius 10^{-3}in	Stress (ksi)
				X_{in}	Y_{in}	Angle Degree		
C	1	3	1S	10.3	17.0	90	20	13.8
			2S	6.0	6.6	44	67	7.5
			3S	5.0	5.4	+	+	+
	2	3	2S	11.0	12.6	50	45	9.2
			3S	4.4	6.0	57	45	9.2
			4S	10.5	6.0	138	32	10.9
	3	3	4S	2.5	3.3	50	+	+
			3S	5.1	10.4	74	16	15.4
			2S	15.5	12.6	40	11	18.6
	4	4	4S	6.1	10.9	41	+	+
			3S	9.0	4.6	35	6	25.2
			2S	6.9	7.3	49	7	23.3
			1E	+	+	Edge	31	11.1
	5	3	4S	11.1	8.6	33	59	8.0
			3S	11.1	8.7	40	33	10.8
			2S	7.9	7.1	53	15	15.9
	6	1	2S	5.6	9.0	60	27	11.9
	7	1	3E	0.0	11.2	Edge	+	+
	8	1	4S	7.8	11.0	50	39	9.9
	9	1	1S	9.4	8.1	34	44	9.3
	10	2	3S	10.0	3.9	31	28	11.6
			1E	4.6	0.0	Edge	60	8.0

APPENDIX D

NONDESTRUCTIVE TEST DATA

TABLE OF CONTENTS

TABLE D1: GAGE LOCATIONS

Gage No.	Location in inches(1)		Gage No.	Location in inches(1)	
	X	Y		X	Y
B1	6.0	48.0	R16	12.0	6.0
B2	30.0	6.0	R17	19.5	6.0
B3	30.0	12.0	R18	1.0	12.0
B4	30.0	30.0	R19	6.0	12.0
B5	19.5	48.0	R20	12.0	12.0
B6	12.0	48.0	R21	19.5	12.0
R1	1.0	1.0	R22	1.5	19.5
R2	3.0	1.0	R23	6.0	19.5
R3	4.5	1.0	R24	12.0	19.5
R4	6.0	1.0	R25	19.5	19.5
R5	12.0	1.0	R26	30.0	19.5
R6	19.5	1.0	R27	1.0	30.0
R7	30.0	1.0	R28	6.0	30.0
R8	1.5	1.5	R29	12.0	30.0
R9	1.0	3.0	R30	19.5	30.0
R10	3.0	3.0	R31	1.0	48.0
R11	1.0	4.5	R32	30.0	48.0
R12	4.5	4.5	R33	30.0	48.0
R13	1.0	6.0	R34	57.0	76.5
R14	3.0	6.0	R35	57.0	93.0
R15	6.0	6.0			

NOTE:

1. X and Y axes are respectively taken to be along short and long sides of the glass panel. The origin is at lower left hand corner looking from the "chamber interior" side.

TABLE D2: MAXIMUM PRINCIPAL STRESS

Applied Pressure (psi)	0.15	0.2	0.4	0.7	1.0	1.15	1.30	Strain Gage Rows (See 8.1)
Gage No.	MAXIMUM PRINCIPAL STRESS (ksi ± 0.2)							
R1	2.5	3.3	6.2	10.1	13.5	15.0	16.7	
R2	3.2	4.0	6.9	10.5	14.3	16.0	17.4	→ 1
R4	2.3	2.9	5.0	7.3	9.1	10.0	10.7	
R5	1.5	1.7	2.2	2.4	2.6	3.0	3.2	
R6	0.4	0.4	0.5	0.9	1.3	1.4	1.5	
R7	0.0	0.3	0.6	0.7	0.9	1.0	1.1	
R9	3.1	3.8	6.7	10.2	14.1	15.8	17.1	→ 2
R10	2.6	3.4	6.3	10.1	13.6	15.4	17.5	
R13	2.4	3.1	5.4	8.0	10.0	11.0	11.8	
R14	2.4	3.1	5.6	9.0	12.4	14.1	15.9	
R15	2.3	2.9	5.7	10.2	14.3	15.9	17.8	→ 3
R16	2.0	2.5	4.9	8.3	11.3	12.8	14.1	
R17	1.8	2.3	4.2	6.1	8.0	8.6	9.2	
B2	1.5	1.9	3.2	4.5	5.5	6.1	6.6	
R18	1.7	1.9	2.3	2.3	2.3	2.4	2.5	
R19	2.3	2.8	5.2	8.5	12.4	13.9	15.0	
R20	2.4	3.1	6.0	9.4	11.7	12.8	13.7	→ 4
R21	2.6	3.3	5.6	7.9	9.7	10.5	11.2	
B3	2.8	3.2	4.6	5.9	7.2	7.9	8.3	
R22	0.6	0.6	1.0	1.5	2.0	2.2	2.4	
R23	1.9	2.4	4.4	6.6	8.9	9.6	10.4	
R24	2.6	3.4	5.9	8.5	10.5	11.4	12.3	→ 5
R25	3.2	3.7	5.0	6.4	7.9	8.4	8.9	
R26	2.8	3.2	4.3	5.3	6.1	6.5	6.8	
R27	0.0	0.1	0.4	0.6	0.8	1.0	1.1	→ 6
R28	1.8	2.2	3.6	5.2	7.1	7.8	8.5	
R29	2.7	3.3	5.2	7.4	9.2	10.1	10.9	
R30	3.1	3.5	4.7	6.0	6.9	7.5	7.9	
B4	2.6	2.8	3.8	4.8	5.8	6.2	6.5	
R31	0.1	0.2	0.4	0.6	0.9	1.0	1.1	
B1	1.4	1.8	3.0	4.5	6.3	6.9	7.4	
B6	2.6	3.1	4.7	6.6	8.7	9.4	10.0	→ 7
B5	2.9	3.3	4.5	5.7	6.8	7.1	7.4	
R33	2.5	2.8	4.2	5.6	6.7	7.3	7.8	
R3	2.4	2.9	5.0	6.6	7.4	8.2	8.5	
R8	2.6	3.3	6.4	10.2	13.4	15.2	16.8	
R11	2.2	3.3	5.3	6.4	7.4	8.0	8.4	
R12	2.5	3.1	5.9	10.0	13.9	15.9	17.9	
R32	0.4	0.4	1.2	2.4	3.2	3.6	4.0	
R34	1.1	1.5	2.9	4.6	6.0	6.7	7.3	
R35	2.6	3.5	6.7	10.7	14.4	16.4	18.5	

TABLE D3: MINIMUM PRINCIPAL STRESS

Applied Pressure (psi)	0.15	0.2	0.4	0.7	1.0	1.15	1.30	Strain Gage Rows (See 8.1)
Gage No.	MINIMUM PRINCIPAL STRESS (ksi ± 0.2)							
R1	-0.7	-0.9	-1.8	-3.1	-4.3	-4.7	-5.2	
R2	-2.1	-2.6	-4.4	-6.3	-7.9	-8.3	-8.5	
R4	-2.3	-2.7	-4.3	-5.4	-5.8	-6.1	-6.3	→1
R5	-1.5	-1.2	-1.7	-3.0	-4.3	-5.1	-5.9	
R6	-1.5	-1.8	-3.2	-5.2	-7.6	-8.6	-9.4	
R7	-1.6	-2.4	-4.1	-6.3	-8.0	-8.7	-9.4	
R9	-2.1	-2.6	-4.4	-6.2	-7.5	-7.8	-7.9	
R10	-2.1	-2.7	-4.8	-6.0	-6.3	-5.9	-5.5	→2
R13	-2.0	-2.6	-4.1	-5.3	-5.8	-5.7	-6.0	
R14	-2.1	-2.4	-3.3	-2.9	-1.5	-0.6	0.3	
R15	-1.7	-1.3	-0.8	1.5	4.6	5.7	7.2	→3
R16	-0.5	-0.1	1.6	3.7	5.1	5.7	6.2	
R17	0.4	0.5	0.6	0.3	-0.1	-0.4	-0.5	
B2	-0.1	-0.4	-1.7	-2.1	-2.8	-3.2	-3.6	
R18	-1.7	-1.9	-2.6	-3.6	-4.9	-5.7	-6.5	
R19	-0.5	-0.2	1.3	3.0	4.6	5.1	5.4	
R20	0.9	1.8	4.5	7.4	9.6	10.7	11.6	→4
R21	1.7	2.2	3.4	4.5	5.3	5.7	6.0	
B3	1.1	1.0	1.1	1.2	1.5	1.6	1.7	
R22	-1.2	-1.3	-2.6	-4.9	-6.7	-7.5	-8.3	
R23	0.2	0.3	0.3	0.1	-0.3	-0.6	-0.7	
R24	1.5	1.9	3.1	4.3	5.3	5.8	6.3	→5
R25	2.8	3.3	4.7	6.0	6.8	6.9	7.1	
R26	2.0	2.0	2.6	3.3	3.8	4.3	4.5	
R27	-1.7	-2.3	-4.1	-6.4	-8.3	-9.2	-10.2	
R28	-0.4	-0.5	-1.1	-1.8	-2.4	-2.7	-3.0	
R29	1.0	1.1	1.6	2.2	2.7	3.0	3.4	→6
R30	2.1	2.4	3.4	4.6	5.5	6.1	6.5	
B4	2.6	2.8	3.3	3.8	4.2	4.2	4.3	
R31	-2.0	-2.7	-4.5	-6.8	-8.8	-9.7	-10.6	
B1	-0.8	-1.1	-1.6	-2.4	-3.2	-3.7	-4.0	
B6	0.6	0.7	1.0	1.5	2.0	2.1	2.3	→7
B5	1.8	2.1	3.2	4.4	5.7	6.1	6.5	
R33	2.2	2.5	3.3	3.7	3.9	4.1	4.2	
R3	-2.4	-2.5	-5.2	-9.7	-13.8	-16.0	-18.1	
R8	-1.3	-1.3	-2.8	-4.8	-6.2	-6.9	-7.4	
R11	-2.4	-3.1	-5.8	-9.8	-13.8	-16.0	-18.0	
R12	-2.2	-2.2	-3.0	-2.4	-0.4	0.4	1.6	
R32	-2.1	-2.3	-2.6	-2.6	-2.5	-2.5	-2.4	
R34	-0.5	-0.6	-1.4	-2.7	-4.0	-4.6	-5.2	
R35	-2.1	-2.7	-4.5	-5.8	-5.8	-5.5	-5.0	

TABLE D4: ANGLE, IN DEGREES, BETWEEN MAXIMUM PRINCIPAL STRAIN AND ε_a-AXIS FOR 3 ELEMENT ROSETTES

Applied Pressure (psi)	0.15	0.2	0.4	0.7	1.0	1.15	1.30	Strain Gage Rows (See 8.1)
Gage No.	PRINCIPAL ANGLE IN DEGREES							
*R1	-47	-47	-47	-46	-46	-46	-46	
*R2	-47	-47	-47	-47	-48	-48	-48	
*R4	-45	-45	-45	-45	-44	-44	-43	→1
R5	45	48	55	65	74	76	78	
R6	27	22	9	3	1	0	0	
R7	-87	-85	-87	-89	-90	-89	-89	
*R9	-44	-44	-44	-44	-43	-43	-43	→2
R10	45	45	45	45	45	45	45	
R13	42	41	41	40	41	41	41	
R14	43	43	44	45	47	47	48	
R15	46	47	46	46	47	46	46	→3
R16	40	36	27	17	12	11	10	
R17	21	14	5	4	3	3	3	
B2	-	-	-	-	-	-	-	
R18	43	44	49	58	66	68	71	
R19	50	52	61	69	74	75	76	
R20	46	46	48	50	50	50	51	→4
R21	16	7	0	-2	-5	-5	-6	
B3	-	-	-	-	-	-	-	
R22	57	68	80	84	86	86	86	
R23	69	75	83	85	86	86	86	
R24	75	80	84	86	88	88	89	→5
R25	64	62	76	-62	-49	-47	-46	
R26	2	4	4	3	3	3	4	
R27	82	84	86	87	87	87	87	
R28	88	88	89	89	89	89	89	
R29	89	89	89	89	89	89	89	→6
R30	87	85	86	-86	-80	-78	-74	
B4	-	-	-	-	-	-	-	
R31	-89	-89	-90	90	89	89	89	
B1	-	-	-	-	-	-	-	→7
B6	-	-	-	-	-	-	-	
B5	-	-	-	-	-	-	-	
R33	85	34	7	-1	-1	0	0	
*R3	44	45	44	43	41	41	40	
R8	49	48	48	48	48	48	48	
R11	-45	-49	-48	-48	-49	-50	-50	
R12	46	47	46	46	47	47	47	
R32	-1	-4	-3	0	0	-1	-1	
R34	-69	-76	-85	-87	-87	-88	-87	
R35	-44	-44	-44	-44	-44	-44	-44	

* Positive angles for these gages are measured in clockwise direction from the ε_a -axis. For others they are in counter clock-wise direction.

TABLE D5: MAXIMUM SHEAR STRESS

Applied Pressure (psi) / Gage No.	0.15	0.2	0.4	0.7	1.0	1.15	1.30	Strain Gage Rows (See 8.1)
	MAXIMUM SHEAR STRESS (ksi ± 0.2)							
R1	1.6	2.1	4.0	6.6	8.9	9.8	11.0	
R2	2.6	3.3	5.6	8.4	11.1	12.1	13.0	→ 1
R4	2.3	2.8	4.6	6.3	7.4	8.0	8.5	
R5	1.5	1.4	1.9	2.7	3.5	4.0	4.5	
R6	1.0	1.1	1.9	3.1	4.4	5.0	5.4	
R7	0.8	1.3	2.4	3.5	4.5	4.8	5.2	
R9	2.6	3.2	5.5	8.2	10.8	11.8	12.5	
R10	2.4	3.1	5.6	8.1	10.0	10.6	11.5	→ 2
R13	2.2	2.8	4.8	6.7	7.9	8.4	8.9	
R14	2.2	2.8	4.4	6.0	6.9	7.4	7.8	
R15	2.0	2.1	3.2	4.3	4.9	5.1	5.3	
R16	1.3	1.3	1.7	2.3	3.1	3.5	3.9	→ 3
R17	0.7	0.9	1.8	2.9	4.1	4.5	4.9	
B2	0.8	1.2	2.2	3.3	4.2	4.7	5.1	
R18	1.7	1.9	2.5	3.0	3.6	4.1	4.5	
R19	1.4	1.5	1.9	2.7	3.9	4.4	4.8	
R20	0.8	0.6	0.8	1.0	1.0	1.0	1.0	→ 4
R21	0.4	0.5	1.1	1.7	2.2	2.4	2.6	
B3	0.9	1.1	1.7	2.3	2.9	3.2	3.3	
R22	0.9	1.0	1.8	3.2	4.4	4.8	5.4	
R23	0.9	1.1	2.0	3.3	4.6	5.1	5.6	
R24	0.5	0.7	1.4	2.1	2.6	2.8	3.0	→ 5
R25	0.2	0.2	0.1	0.2	0.5	0.8	0.9	
R26	0.4	0.6	0.8	1.0	1.1	1.1	1.1	
R27	0.8	1.2	2.2	3.5	4.6	5.1	5.6	
R28	1.0	1.4	2.4	3.5	4.8	5.3	5.7	
R29	0.8	1.1	1.8	2.6	3.2	3.5	3.8	→ 6
R30	0.5	0.5	0.7	0.7	0.7	0.7	0.7	
B4	0.0	0.0	0.2	0.5	0.8	1.0	1.1	
R31	1.0	1.5	2.5	3.7	4.9	5.4	5.9	
B1	1.1	1.5	2.3	3.5	4.8	5.3	5.7	→ 7
B6	1.0	1.2	1.8	2.5	3.3	3.6	3.9	
B5	0.6	0.6	0.6	0.6	0.6	0.5	0.4	
R33	0.2	0.1	0.5	0.9	1.4	1.6	1.8	
R3	2.4	2.7	5.1	8.2	10.6	12.1	13.3	
R8	2.0	2.3	4.6	7.5	9.8	11.1	12.1	
R11	2.3	3.2	5.6	8.1	10.6	12.0	13.3	
R12	2.4	2.7	4.5	6.2	7.2	7.7	8.1	
R32	1.2	1.3	1.9	2.5	2.8	3.0	3.2	
R34	0.8	1.1	2.1	3.7	5.0	5.6	6.3	
R35	2.3	3.1	5.6	8.3	10.1	11.0	11.8	

TABLE D 6: STRAIN NO.1 ε_a

Applied Pressure (psi)	0.15	0.2	0.4	0.7	1.0	1.15	1.30	Strain Gage Rows (See 8.1)
Gage No.	STRAIN (MICROINCHES/INCH)							
R1	54	72	137	226	305	337	378	
R2	20	24	42	73	121	141	165	
R4	-3	2	23	77	147	192	245	→ 1
R5	-4	2	-56	-227	-411	-504	-601	
R6	26	45	111	197	286	322	349	
R7	-158	-233	-414	-630	-798	-871	-946	
R9	42	55	114	199	327	399	458	→ 2
R10	24	32	52	166	280	377	465	
R13	49	68	139	229	304	342	353	
R14	32	46	110	228	365	444	513	→ 3
R15	16	45	166	418	681	810	942	
R16	85	138	362	683	959	1099	1223	
R17	150	207	390	586	777	849	906	
B2	146	195	332	478	598	666	727	
R18	11	4	-56	-204	-387	-479	-572	
R19	41	58	123	193	251	269	279	→ 4
R20	126	183	385	617	787	877	945	
R21	210	270	475	670	822	902	963	
B3	250	288	419	544	671	742	781	
R22	-70	-109	-262	-503	-692	-775	-861	
R23	1	-9	-56	-128	-215	-259	-288	→ 5
R24	102	120	176	238	292	323	350	
R25	218	253	355	453	549	581	609	
R26	232	263	360	448	507	549	570	
R27	-160	-226	-406	-628	-821	-921	-1018	
R28	-72	-99	-186	-282	-388	-437	-472	→ 6
R29	41	38	41	54	70	80	93	
R30	138	158	231	319	396	447	483	
B4	201	213	298	388	480	519	545	
R31	-197	-271	-451	-677	-878	-974	-1064	
81	159	199	330	492	679	754	814	→ 7
86	239	282	434	610	802	875	935	
85	247	275	369	460	542	562	582	
R33	160	208	334	461	568	628	673	
R3	9	17	6	-39	-72	-85	-105	
R8	21	49	81	127	166	174	201	
R11	-12	-49	-96	-222	-419	-526	-644	
R12	1	18	83	256	463	569	689	
R32	83	89	170	288	366	404	440	
R34	-50	-80	-194	-364	-518	-590	-666	
R35	32	49	114	229	374	463	562	

TABLE D 7: STRAIN NO. 2 ε_b

Applied Pressure (psi)	0.15	0.2	0.4	0.7	1.0	1.15	1.30	Strain Gage Rows (See B.1)
Gage No.	STRAIN (MICROINCHES/INCH)							
R1	-120	-157	-311	-515	-701	-779	-868	
R2	-274	-336	-570	-831	-1063	-1147	-1200	
R4	-273	-329	-521	-677	-755	-812	-843	1
R5	178	188	237	224	156	154	111	
R6	52	39	-32	-126	-224	-276	-304	
R7	-71	-103	-160	-224	-280	-312	-336	
R9	-276	-338	-569	-818	-1026	-1103	-1144	2
R10	303	393	716	1111	1455	1641	1832	
R13	282	352	609	881	1085	1195	1278	
R14	278	351	615	937	1230	1393	1545	
R15	259	305	568	954	1288	1435	1594	3
R16	206	240	403	606	768	864	931	
R17	143	159	220	287	356	375	397	
B2	-42	-78	-181	-298	-392	-449	-492	
R18	201	221	274	267	224	211	180	
R19	234	273	440	653	889	985	1058	
R20	218	265	486	752	932	1021	1086	
R21	194	224	344	453	523	568	593	4
B3	44	33	11	-5	-11	-14	-13	
R22	77	56	13	-49	-100	-115	-133	
R23	146	164	237	320	408	438	467	
R24	192	233	373	515	622	681	725	
R25	247	281	376	447	494	498	506	5
R26	185	205	275	340	390	429	450	
R27	-36	-56	-109	-176	-230	-255	-280	
R28	62	75	109	152	207	222	241	
R29	143	175	268	373	464	511	558	6
R30	204	235	320	389	443	489	508	
B4	193	210	242	264	+280	279	282	
R31	-80	-103	-156	-222	-282	-319	-346	
B1	-111	-147	-219	-332	-449	-508	-548	
B6	2	1	0	4	11	8	12	7
B5	111	137	216	307	405	445	476	
R33	182	216	294	349	397	437	456	
R3	283	331	591	843	1000	1137	1207	
R8	283	351	675	1091	1431	1632	1798	
R11	-283	-367	-676	-1088	-1481	-1720	-1929	
R12	293	351	638	1023	1357	1547	1721	
R32	-70	-92	-75	-10	24	32	52	
R34	-43	-27	10	25	25	17	12	
R35	-260	-338	-583	-795	-873	-894	-891	

TABLE D 8: STRAIN NO. 3 ε_c

Applied Pressure (psi)	0.15	0.2	0.4	0.7	1.0	1.15	1.30	Strain Gage Rows (See B.1)
Gage No.	STRAIN(MICROINCHES/INCH)							
R1	84	109	194	301	395	454	505	
R2	61	81	151	242	368	453	513	
R4	1	11	37	72	101	106	97	→ 1
R5	-2	35	95	177	279	343	392	
R6	-107	-149	-312	-525	-766	-877	-954	
R7	38	78	144	203	258	281	306	
R9	28	34	59	101	171	211	246	→ 2
R10	17	25	63	144	268	357	446	
R13	-15	-28	-35	-24	13	66	94	
R14	-8	2	66	233	457	586	727	
R15	26	72	204	465	746	843	975	→ 3
R16	27	46	127	224	286	313	332	
R17	22	12	-28	-96	-178	-220	-248	
B2	-	-	-	-	-	-	-	
R18	-16	-9	28	104	190	227	269	
R19	95	141	365	679	1030	1180	1287	
R20	129	188	401	655	832	917	991	→ 4
R21	123	146	213	270	311	336	354	
B3	-	-	-	-	-	-	-	
R22	22	57	139	246	335	370	411	
R23	155	212	412	633	950	951	1027	→ 5
R24	215	286	503	730	906	997	1074	
R25	243	276	382	480	569	595	619	
R26	131	130	162	208	245	277	296	
R27	30	54	120	193	256	289	325	
R28	179	225	374	546	743	823	894	
R29	241	299	473	670	835	921	1000	
R30	257	287	386	493	547	595	618	→ 6
B4	-	-	-	-	-	-	-	
R31	48	79	141	209	277	307	337	
B1	-	-	-	-	-	-	-	
B6	-	-	-	-	-	-	-	→ 7
B5	-	-	-	-	-	-	-	
R33	197	197	229	241	235	245	241	
R3	-11	13	-22	-202	-410	-505	-624	
R8	80	102	186	288	384	459	513	
R11	-5	65	52	-42	-65	-78	-91	
R12	23	51	135	324	558	676	808	
R32	-211	-229	-277	-300	-308	-324	-323	
R34	92	142	307	503	667	749	829	
R35	11	17	47	137	279	369	469	

TABLE D9: REPRODUCIBILITY OF DATA FOR APPLIED PRESSURE OF 1 PSI

Gage No.	Maximum Principal Stress (ksi)			Gage No.	Maximum Principal Stress (ksi)		
	Run #1	Run #2	Difference		Run #1	Run #2	Difference
B1	6.3	6.1	0.2	R16	11.3	11.4	-0.1
B2	5.5	5.6	-0.1	R17	8.0	7.8	0.2
B3	7.2	7.3	-0.1	R18	2.3	2.4	-0.1
B4	5.8	5.8	0.0	R19	12.4	12.1	0.3
B5	6.8	6.7	0.1	R20	11.7	11.8	-0.1
B6	8.7	8.4	0.3	R21	9.7	9.8	-0.1
				R22	2.0	2.0	0.0
				R23	8.9	8.7	0.2
R1	13.5	13.4	0.1	R24	10.5	10.5	0.0
R2	14.3	14.1	0.2	R25	7.9	7.8	0.1
R3	7.4	7.9	-0.5	R26	6.1	6.2	0.1
R4	9.1	9.2	-0.1	R27	0.8	0.8	0.0
R5	2.6	2.9	-0.3	R28	7.1	6.9	0.2
R6	1.3	1.3	0.0	R29	9.2	9.2	0.0
R7	0.9	0.8	0.1	R30	6.9	7.1	-0.2
R8	13.4	13.6	-0.2	R31	0.9	0.9	0.0
R9	14.1	13.8	0.3	R32	3.2	3.2	0.0
R10	13.6	13.7	-0.1	R33	6.7	6.8	-0.1
R11	7.4	7.7	-0.3	R34	6.0	6.0	0.0
R12	13.9	13.9	0.0	R35	14.4	14.5	-0.1
R13	10.0	10.2	-0.2				
R14	12.4	12.4	0.0				
R15	14.3	13.8	-0.5				

TABLE D 10: COMPARISON OF MAXIMUM PRINCIPAL STRESS (MPS) FOR VARIOUS EDGE RESTRAINING FORCES

Applied Pressure = 0.7 psi

Gage No.	EDGE RESTRAINING FORCE (ksi)				
	2.85 pounds/in	5.7 pounds/in		8.55 pounds/in	
	MPS	MPS	Diff w.r.t. 2.85 case	MPS	Diff. w.r.t. 2.85 case
B1	4.8	4.5	-0.3	4.8	0.0
B2	4.4	4.5	-0.1	4.4	0.0
B3	6.1	5.9	-0.2	6.0	-0.1
B4	5.0	4.8	-0.2	5.0	0.0
B5	5.9	5.7	-0.2	5.9	0.0
B6	6.9	6.6	-0.3	6.9	0.0
R1	9.8	10.1	0.3	10.0	0.2
R2	10.9	10.5	-0.4	10.9	0.0
R3	6.4	6.6	0.2	6.6	0.2
R4	7.3	7.3	0.0	7.3	0.0
R5	2.3	2.4	0.1	2.3	0.0
R6	1.0	0.9	-0.1	0.9	-0.1
R7	0.7	0.7	0.0	0.6	-0.1
R8	10.0	10.2	0.2	10.1	0.1
R9	10.5	10.2	-0.3	10.7	0.2
R10	10.0	10.1	0.1	10.0	0.0
R11	6.1	6.4	0.3	6.5	0.4
R12	9.9	10.0	0.1	9.9	0.0
R13	8.0	8.0	0.0	8.0	0.0
R14	9.0	9.0	0.0	8.9	-0.1
R15	10.1	10.2	0.1	10.0	-0.1
R16	8.3	8.3	0.0	8.2	-0.1
R17	6.4	6.1	-0.3	6.4	0.0
R18	2.4	2.3	-0.1	2.3	-0.1
R19	9.0	8.5	-0.5	9.0	0.0
R20	9.3	9.4	0.1	9.3	0.0
R21	7.9	7.9	0.0	7.9	0.0
R22	1.5	1.5	0.0	1.4	-0.1
R23	6.9	6.6	-0.3	6.9	0.0
R24	8.5	8.5	0.0	8.5	0.0
R25	6.5	6.4	-0.1	6.6	0.1
R26	5.3	5.3	0.0	5.3	0.0
R27	0.6	0.6	0.0	0.5	-0.1
R28	5.5	5.2	-0.3	5.5	0.0
R29	7.4	7.4	0.0	7.4	0.0
R30	5.9	6.0	0.1	5.9	0.0
R31	0.6	0.6	0.0	0.6	0.0
R32	2.7	2.4	-0.3	2.6	-0.1
R33	5.5	5.6	0.1	5.5	0.0
R34	4.6	4.6	0.0	4.5	-0.1
R35	10.4	10.7	0.3	10.6	0.2