NBS Technical Note 1211

Interlaboratory Comparison of Force Calibrations Using ASTM Method E74-74

Robert W. Peterson
Linwood Jenkins
Richard A. Mitchell

Mechanical Production Metrology Division
Center for Manufacturing Engineering
National Engineering Laboratory
National Bureau of Standards
Gaithersburg, MD 20899

April 1985

U.S. Department of Commerce
Malcolm Baldrige, Secretary
National Bureau of Standards
Ernest Ambler, Director

CONTENTS

LIST OF FIGURES

INTERLABORATORY COMPARISON OF FORCE CALIBRATIONS USING ASTM METHOD E74-74

R. W. Peterson, L. Jenkins, and R. A. Mitchell

A comparison of force calibrations performed by the National Bureau of Standards and 27 other laboratories located in the United States is reported. Force sensors of four different capacities were calibrated in both tension and compression, repeatedly by NBS with deadweight and one time each by the other participating laboratories. The force sensor capacities were 0.5, 5, 20, and 100 klbf (2.2, 22, 89, and 445 kN). Deadweight machines (with and without force multiplication) and force sensor transfer standards (used in a testing machine or a loading frame) were the force standards represented in the study. The force calibration procedure used was Method E74-74 of the American Society for Testing and Materials.

Key Words: Force; force calibration; force sensor; interlaboratory comparison; laboratory intercomparison; load cell.

1. INTRODUCTION

This report documents an intercomparison study of force calibrations performed by the National Bureau of Standards (NBS) and 27 other laboratories located in the United States. The participating laboratories represent load cell and proving ring manufacturers, defense and aerospace contractors, other large and small private industries, and federal government agencies. The intercomparison was conducted under the joint sponsorship of NBS and the Calibration Subcommittee of Committee E28 on Mechanical Testing of the American Society for Testing and Materials (ASTM). Although the initial phase of this intercomparison study, involving NBS and six other laboratories, has been reported earlier [1][1], this report covers the entire study.

2. PROGRAM DESCRIPTION

Two packages of force-measuring instruments were circulated among the 27 laboratories and NBS. Package One consisted of 0.5 and 5 klbf (2.2 and 22 kN) force sensors and one readout instrument. Package Two consisted of 20 and 100 klbf (89 and 445 kN) sensors and one readout instrument. The force sensors were commercially-produced load cells instrumented with resistance strain gages.The readout instruments were commercially-produced dc-excitation load cell indicators. All 27 laboratories calibrated the two lower capacity force sensors. Only 19 of these laboratories calibrated the two higher capacity force sensors in both compression and tension; most of the remaining laboratories did not have the capability to calibrate to the higher capacities.

[1]Numbers in brackets indicate the literature references at the end of this report.

All calibrations were performed using ASTM Method E74-74 [2]. This procedure calls for a total of at least 30 load applications, at least 10 of which are of different magnitude. Loads of each magnitude are applied at least twice. If possible, every 10 percent interval of the force range is represented in the loading program. The response of the force sensor to the applied loads is indicated by the net output or "deflection"[2] of the readout instrument. The 30 or more force-versus-"deflection" data points are fitted, by the method of least squares, to the second-degree polynomial calibration equation

$$\text{Deflection} = A + BL + CL^2 \qquad (1)$$

in which L represents the applied force and the coefficients A, B, and C are determined by the fitting process. The standard deviation of the differences between the measured "deflections" and the predicted "deflections" given by the calibration equation is computed as a measure of the precision of the calibration.

NBS performed an initial calibration on each package, and then recalibrated the package after it had been calibrated by not more than three of the other laboratories. NBS also analyzed the calibration data from all of the laboratories. A report was sent to each laboratory giving an analysis of their data in comparison with the results of the corresponding before and after NBS calibrations that bracketed their calibration. An example of such a report is given in the Appendix. These reports, issued soon after the recalibration by NBS, enabled each laboratory to evaluate its own calibration process. In a few cases this self-evaluation led to a modification in the laboratory calibration process, to correct an apparent problem, followed by a recalibration by the laboratory. In such cases of recalibration by a laboratory, only the latter calibration is included in the results presented here.

3. RESULTS

Figures 1 through 8 are plots of results that are representative of the entire intercomparison program. Each vertical bar in these plots represents a single calibration at one laboratory. The coordinates of the midpoint of each calibration bar correspond to the date of calibration and to the net sensor output or "deflection" at capacity load as computed by the calibration equation, eq. 1. The units of the vertical scale correspond to the arbitrary units of the readout instrument used. The length of each calibration bar is ±2.4 times the standard deviation (i.e. total length is 4.8 standard deviations) of the calibration data relative to the fitted calibration equation, a quantity used in

[2]"Deflection" is defined in ASTM Method E74-74 [2] as the difference between the reading of an instrument under load and the reading at zero or tare load.

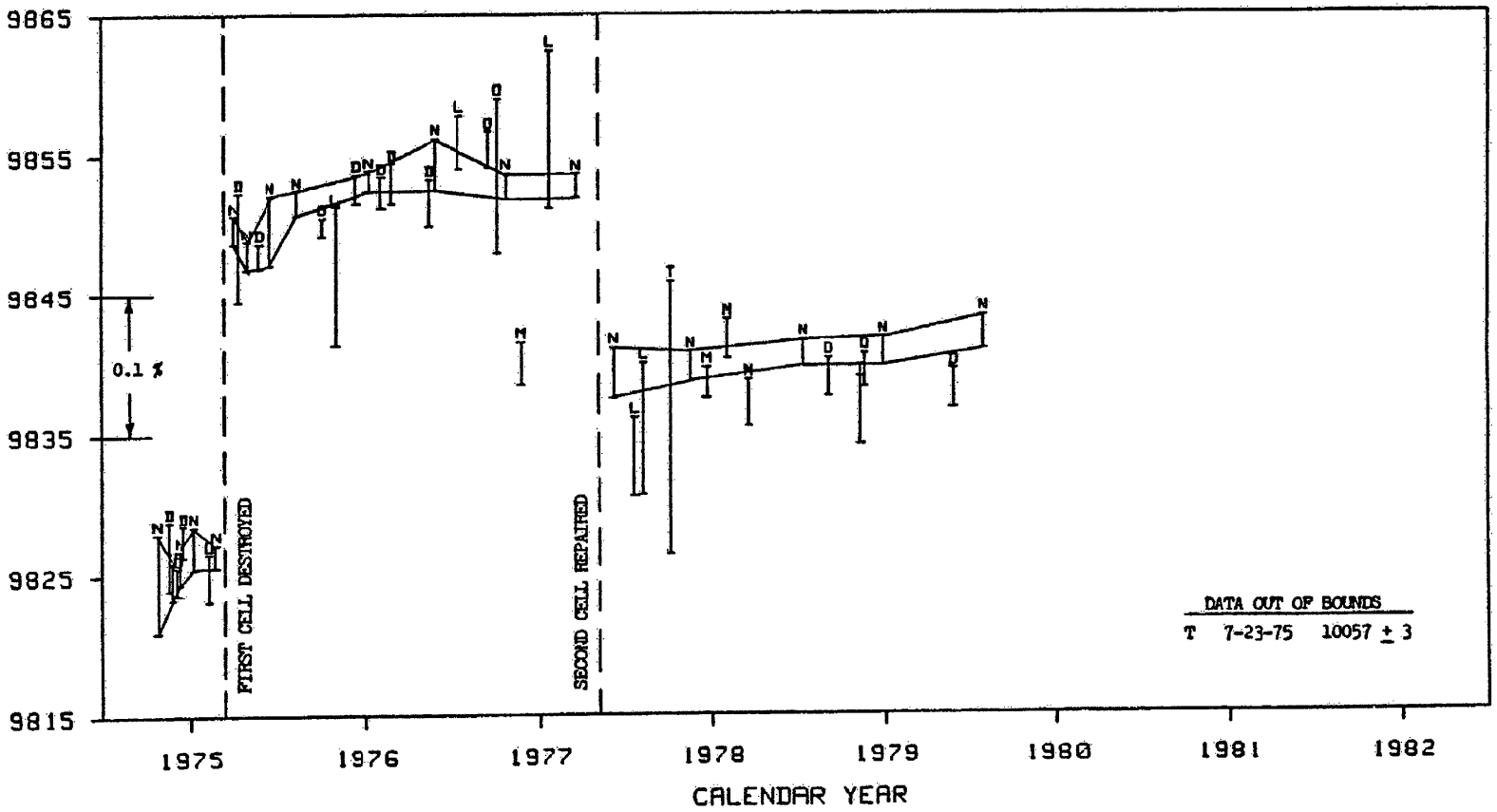


Figure 1 - Calculated response at capacity load (± 2.4 standard deviations) from the compression calibration of a 0.5 klbf (2.2 kN) force sensor) at NBS and at 27 other laboratories.

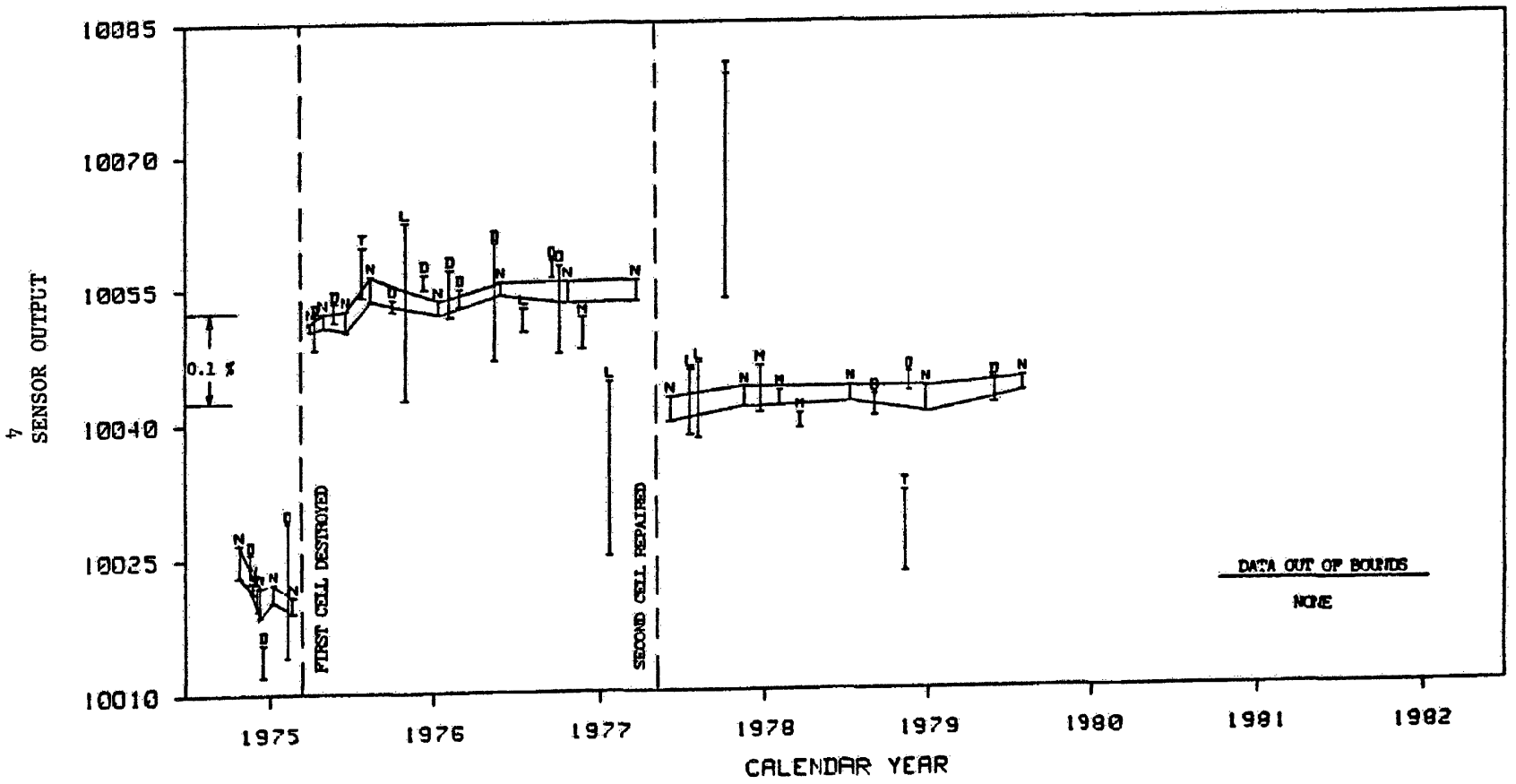


Figure 2 - Calculated response at capacity load (± 2.4 standard deviations) from the tension calibration of a 0.5 klbf (2.2 kN) force sensor at NBS and at 27 other laboratories.

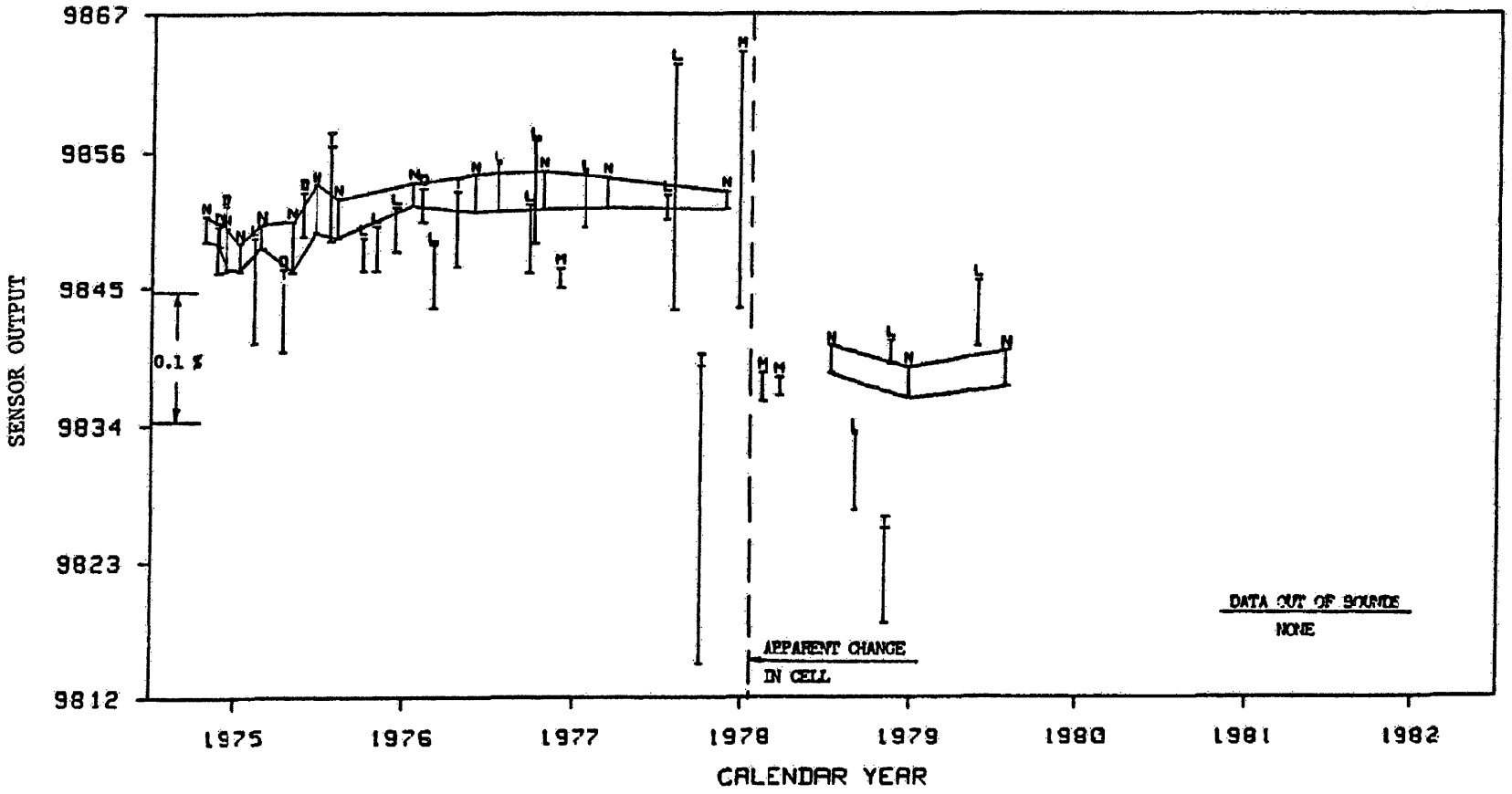


Figure 3 - Calculated response at capacity load (± 2.4 standard deviations) from the compression calibration of a 5 klbf (22 kN) force sensor at NBS and at 27 other laboratories.

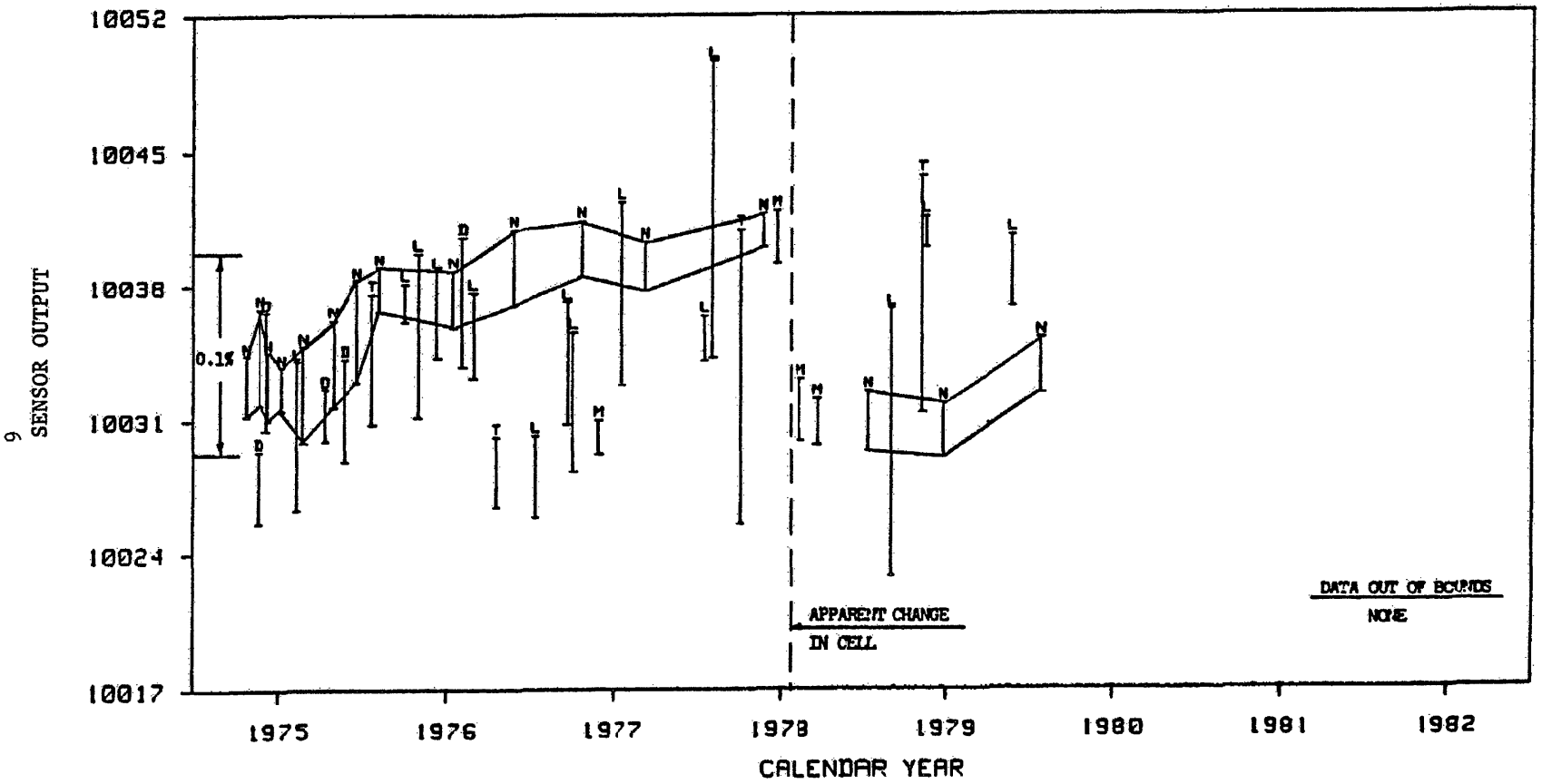


Figure 4 - Calculated response at capacity load (± 2.4 standard deviations) from the tension calibration of a 5 klbf (22 kN) force sensor at NBS and at 27 other laboratories.

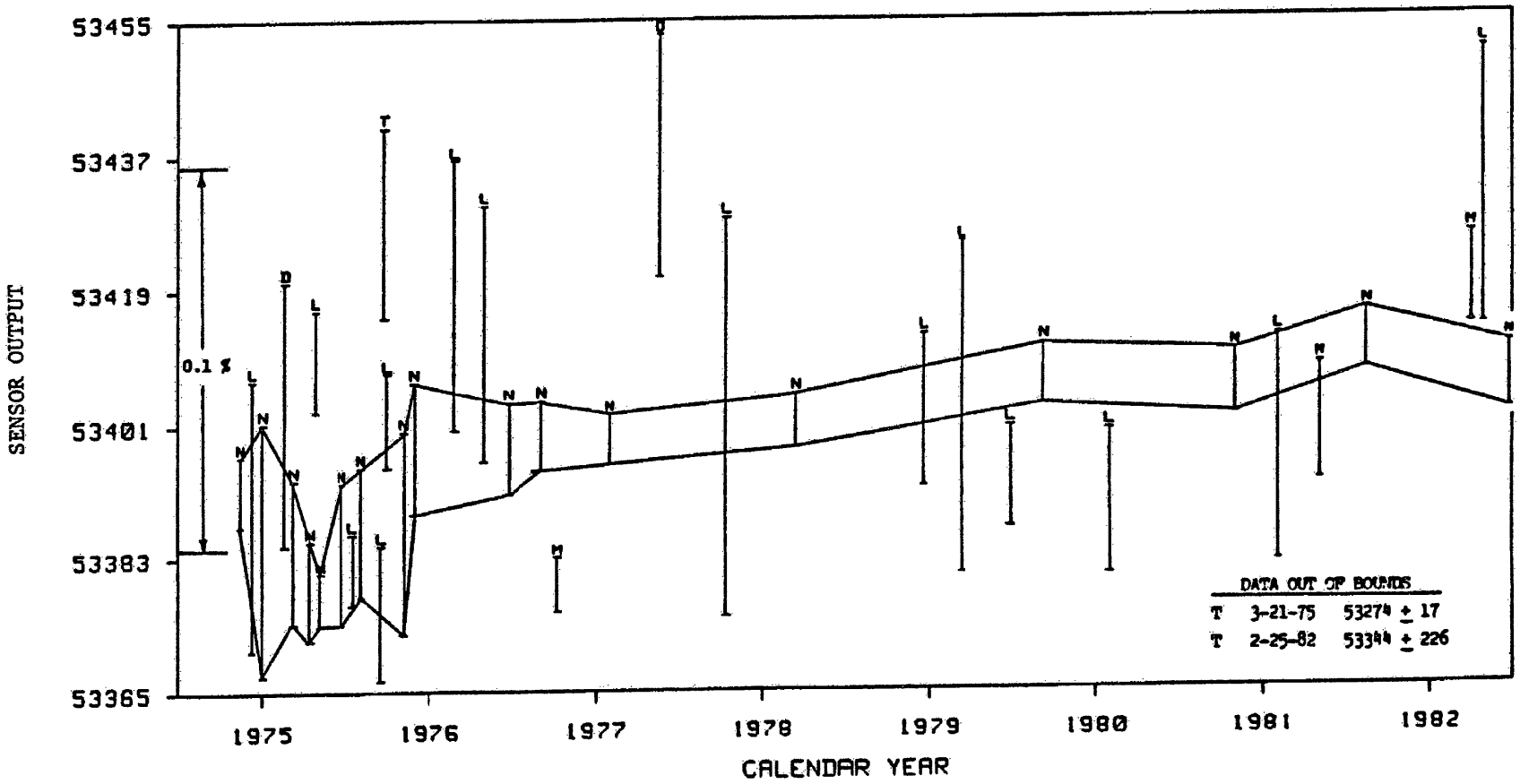


Figure 5 - Calculated response at capacity load (± 2.4 standard deviations) from the compression calibration of a 20 klbf (89 kN) force sensor at NBS and at 22 other laboratories.

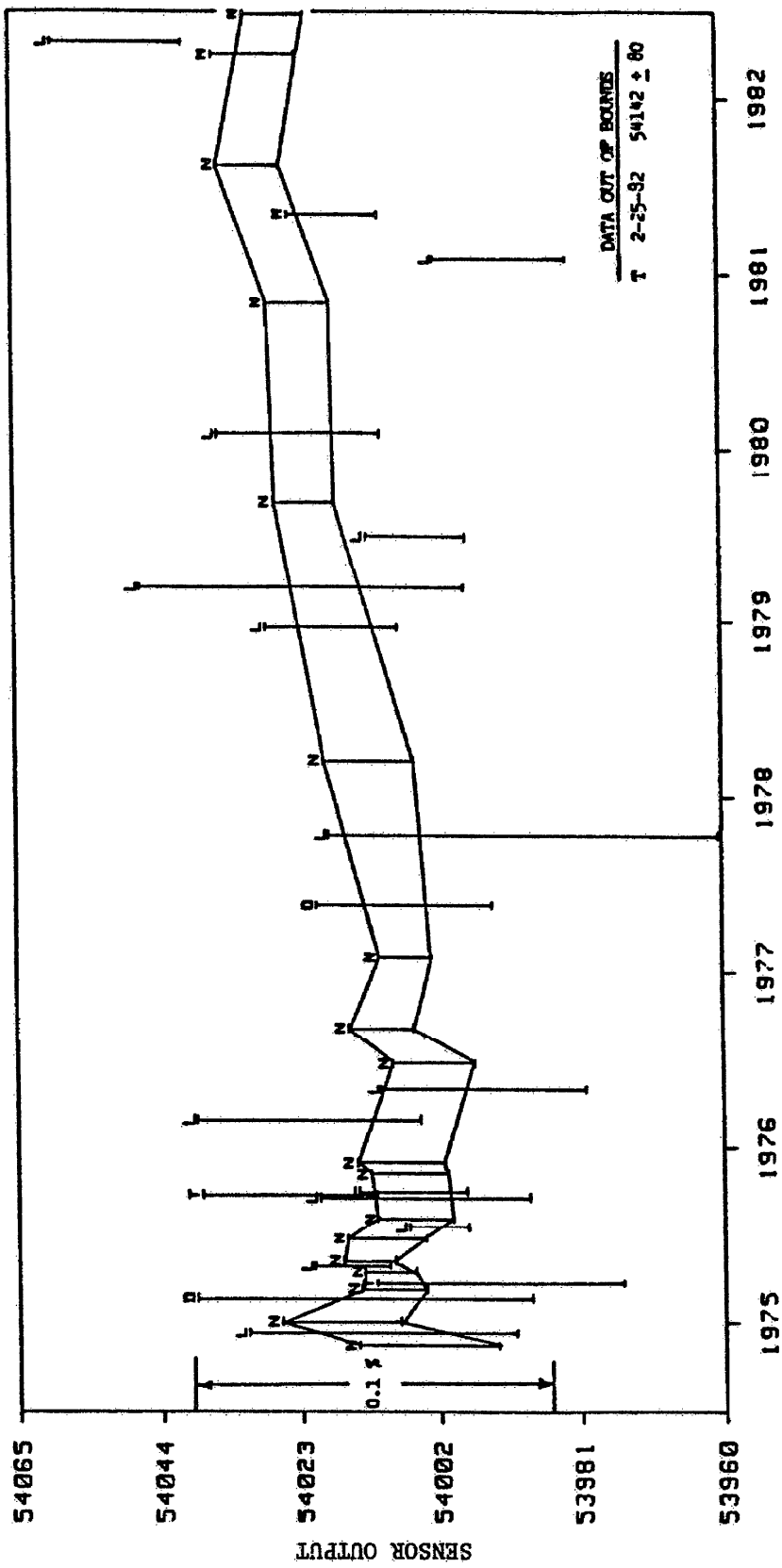


Figure 6 - Calculated response at capacity load (± 2.4 standard deviations) from the tension calibration of a 20 klbf (89 kN) force sensor at NBS and at 21 other laboratories.

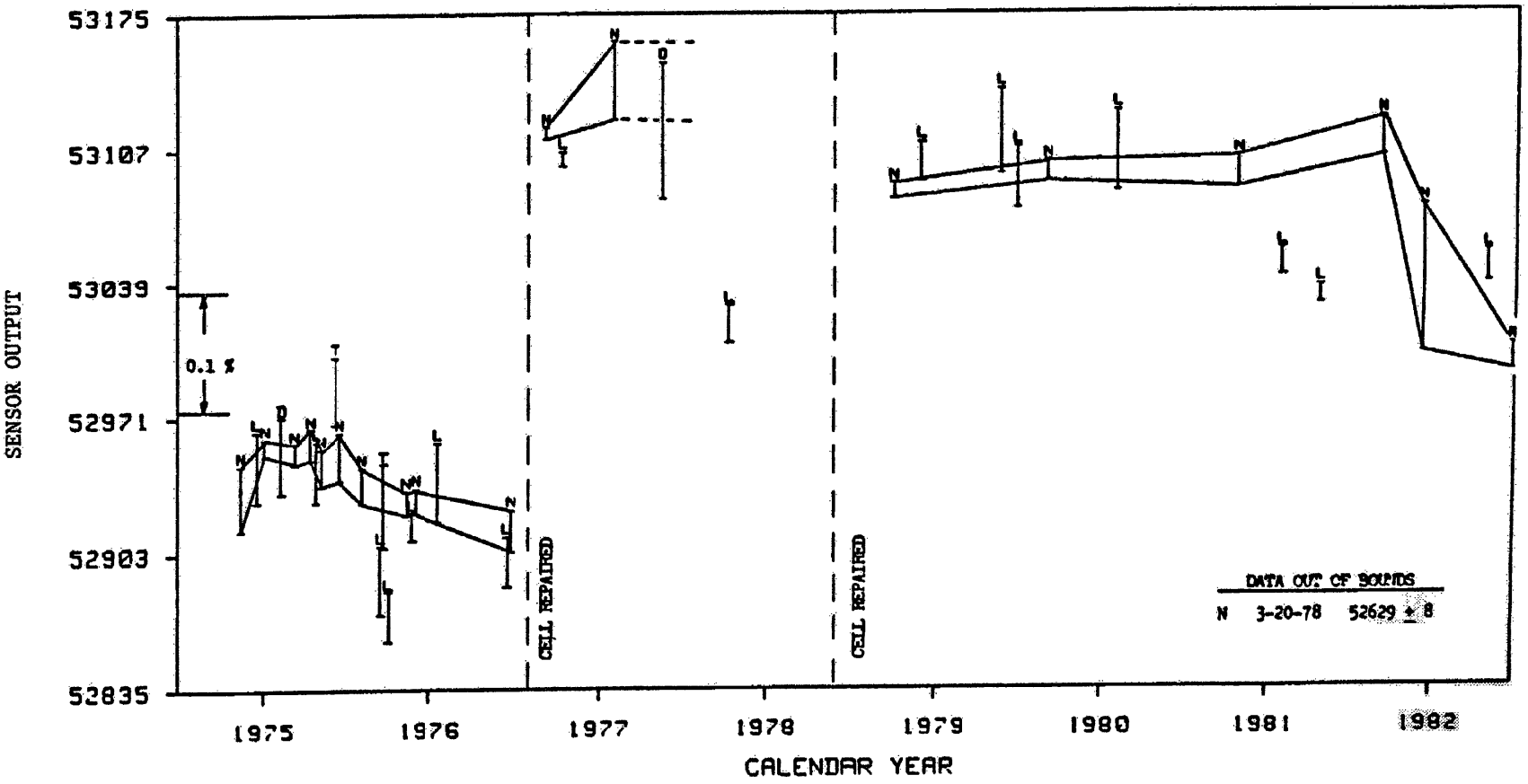


Figure 7 - Calculated response at capacity load (± 2.4 standard deviations) from the compression calibration of a 100 klbf (445 kN) force sensor at NBS and at 20 other laboratories.

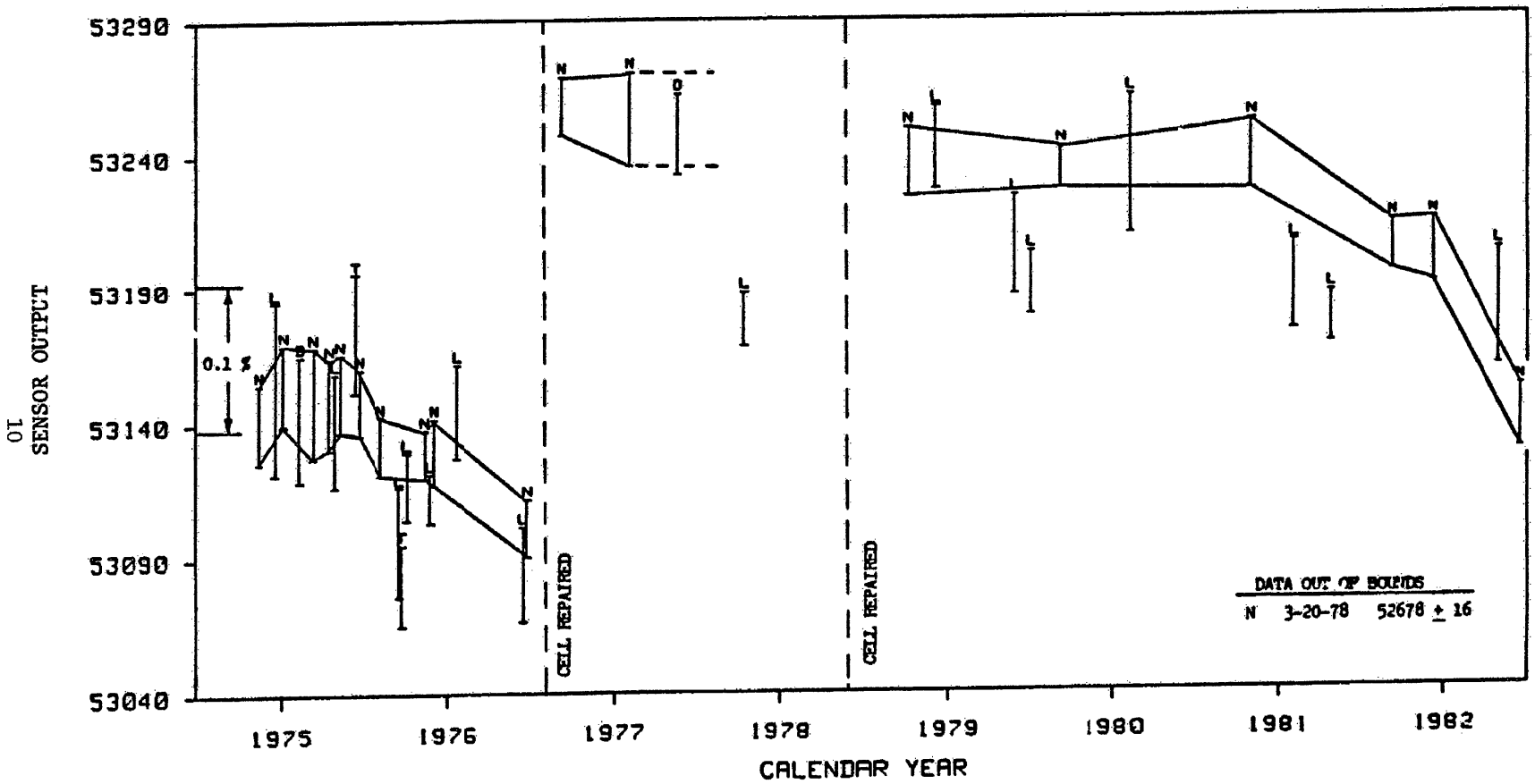


Figure 8 - Calculated response at capacity load (± 2.4 standard deviations) from the tension calibration of a 100 klbf (445 kN) force sensor at NBS and at 19 other laboratories.

the ASTM force calibration procedure [2] to compute the loading ranges over which the force sensor may be used in calibrating either testing machines or other force sensors. The letter symbol above each calibration bar identifies the type of machine used to apply the calibration loads, as follows:

N - NBS deadweight

D - Deadweight (other than NBS)

M - Deadweight with lever or hydraulic multiplication

L - Loading frame (with force sensor standard)

T - Testing machine (with force sensor standard)

The ends of the calibration bars representing the repeated NBS deadweight calibrations are connected with straight lines forming a segmented band. This NBS band is a useful reference since it represents a large number of calibrations by the same laboratory over the duration of the program. Gross discontinuities in the NBS band are labeled on the plots and explained in the text below. The calendar year horizontal-coordinate labels are centered on January 1 of the year. Each participating laboratory can identify its results by its calibration date. The 0.1% reference on the vertical scale of each plot represents a percentage of sensor output at capacity load and is included to facilitate comparison of plots having different scales. Calibration results that are outside the range of a plot are indicated in the lower right corner by machine symbol, date, sensor output, and calibration bar length.

3.1 Sensor Stability

The segmented NBS bands in figs. 1 through 8 indicate the stability of the force sensors over the duration of the program. There is some evidence of long-term drift in each of the plots. In most cases the amount of drift is not serious, although it does demonstrate the importance of periodic recalibration of the force sensors by one laboratory in a long-term intercomparison such as this.

Three of the force sensors exhibited more serious instability as indicated by the gross discontinuities evident in the NBS band (figs. 1, 2, 3, 4, 7, and 8). An explanation of these problems with each of these three sensors follows.

0.5 klbf (2.2 kN) Sensor - The force sensor used at the beginning of the program was destroyed by overloading in February 1975. The replacement sensor had a different response curve, which explains the first discontinuity (figs. 1 and 2). In the Spring of 1977, this replacement sensor was repaired to correct a condition which allowed its internal overload-protection mechanism to interfere with its normal response at a point slightly below capacity load. The repair resulted in a change in the sensor response curve, which explains the 1977 discontinuity.

5 klbf (22 kN) Sensor - This force sensor (figs. 3 and 4), underwent a significant change in response sometime between the November 1977 and July 1978 NBS calibrations. Judging from the calibration results from the other laboratories, it appears that the change occurred between the December 1977 and February 1978 calibrations. The cause of the change is not known.

100 klbf (445 kN) Sensor - This force sensor (figs. 7 and 8) was first repaired in 1976 to correct what was thought to be excessive drift during the first two years of the program. As a result of this repair the response of the sensor, at capacity load, increased by about 0.3 percent. About two years later, the sensor again required repair as indicated by a shift of about one percent in the NBS calibration results (data out of bounds in figs. 7 and 8). The cause of this change in response is not known. Sometime after the November 1980 NBS calibration, the response of this sensor again indicated a significant instability. During the December 1981 NBS calibrations, sensor response at capacity load varied by as much as 0.13 percent between loading runs of the same calibration. It was decided that a third repair of the sensor was not justified at that stage of the intercomparison program. Laboratories participating in the program during that period were notified of the problem, and it was suggested that if they chose to calibrate this sensor they should view the results with much skepticism.

3.2 Relative Results

The segmented NBS bands (figs. 1 through 8) serve as a useful reference for comparison of the results from all the participating laboratories. Most of the results from the other laboratories appear to be distributed about the NBS band and about 69 percent of their calibration bars overlap the NBS band. In some cases, however, the calibrations by the other laboratories are not bracketed by before and after NBS calibration of an apparently stable force sensor, for example the three calibrations of the 5 klbf (22kN) sensor in 1977-1978. Table 1 summarizes the conditions of overlap (OL) for all calibrations by the other laboratories that are clearly bracketed (BR) by before and after NBS calibrations of an apparently stable sensor. Totals and percentages are given for the different types of loading machines used in the calibrations.

Table 1 - Summary of Results

	0.5 klbf (2.2 kN)				5 klbf (22 kN)				20 klbf (89 kN)				100 klbf (445 kN)						
CAL	COMP		TENS		COMP		TENS		COMP		TENS		COMP		TENS		TOTALS		
MACH	BR	OL	BR	OL	BR	OL	BR	OL	BR	OL	BR	OL	BR	OL	BR	OL	*BR	*OL	PCT
D	15	14	15	12	5	4	5	4	2	1	2	2	1	1	1	1	46	39	85
L	5	3	5	3	14	9	14	8	14	10	14	11	12	10	11	8	89	62	70
M	4	3	4	2	1	0	1	0	3	1	2	2	0	0	0	0	15	8	53
T	3	1	3	1	4	2	4	3	3	0	3	2	2	1	2	1	24	11	46
TOTALS	27	21	27	18	24	15	24	15	22	12	21	17	15	12	14	10	174	120	69

*BR = Number of non-NBS calibrations that were "BRACKETED" by NBS calibration.

*OL = Number of non-NBS calibrations that were "BRACKETED" by NBS calibration and that "OVERLAPPED", or extended into, the NBS band.

It is not surprising that the most frequent overlap with NBS resulted from the deadweight calibrations (D) and that the least frequent overlap resulted from the calibrations done in testing machines (T). Figures 1 through 8, however,

APPENDIX

ANALYSIS OF ROUND-ROBIN DATA, ASTM E74-74

CELL NO. 82625, INDICATOR NO. 2235
CAPACITY 20000 LBF COMPRESSION AND TENSION APRIL 1, 1982

A S T M CALIBRATION CURVE DATA - COMPRESSION

* * * * * * * *

A CALIBRATION EQUATION OF THE FORM,

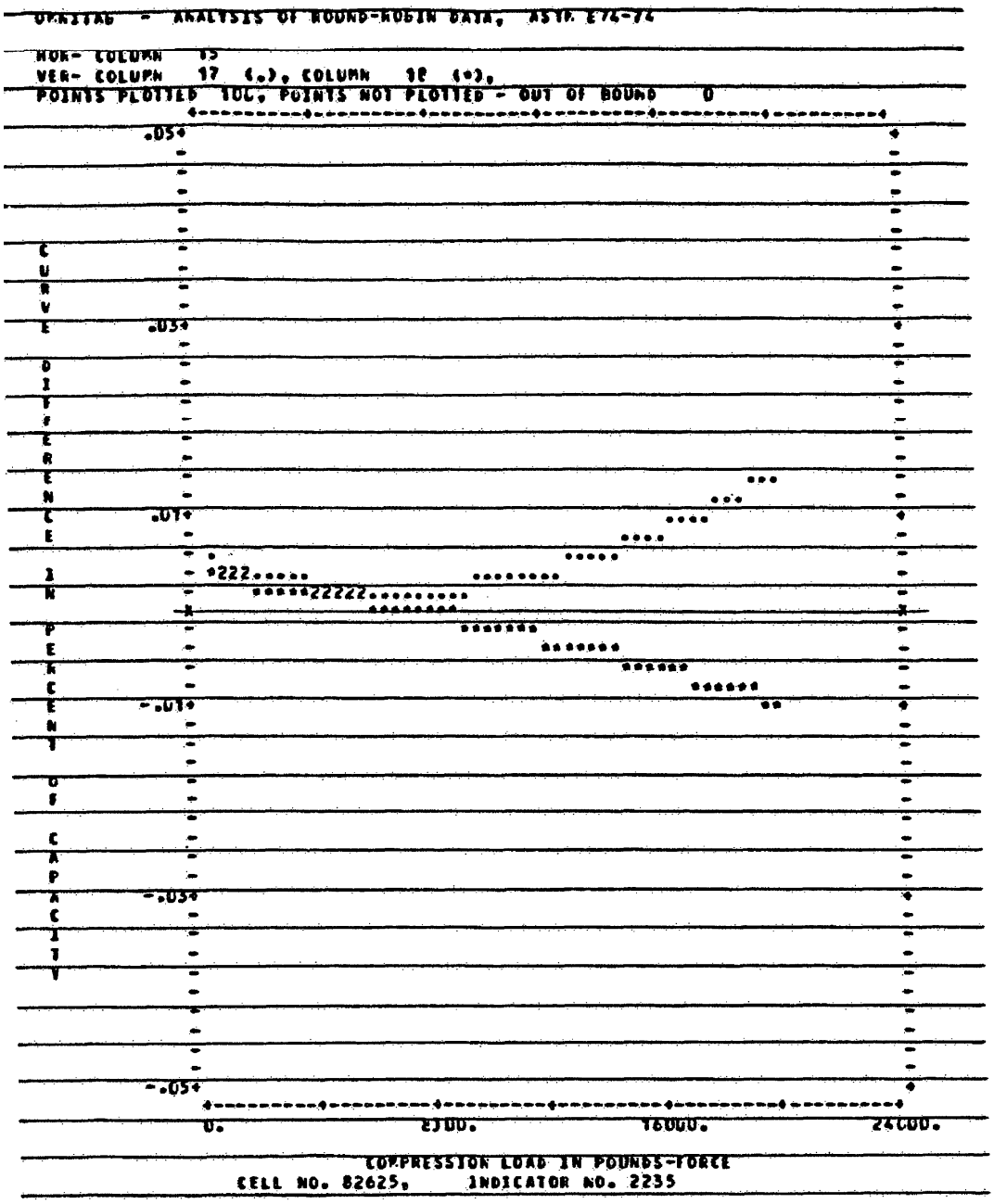
DEFLECTION = (A) + (B)(LOAD) + (C)(LOAD SQUARED)

WAS FITTED TO THE OBSERVED DATA BY THE METHOD OF LEAST SQUARES. THE COEFFICIENTS, STANDARD DEVIATION, AND UNCERTAINTY (AS DEFINED BY ASTM METHOD E 74-74) FOR THE PREVIOUS NBS CALIBRATION, THE CALIBRATION IN YOUR LABORATORY, AND A CHECK CALIBRATION AT NBS AFTER THE INSTRUMENT WAS RETURNED, ARE SHOWN BELOW.

	A	B	C (LOG FORMAT)	ST.DV. UNITS	UNCERT. LBF	DIFF.* PERCENT
PREVIOUS NBS	2.04	2.684960	-.72385-006	1.66	1.49	.000
YOUR LABORATORY	5.09	2.684444	-.68572-006	2.53	2.27	.015
NBS CHECK	4.12	2.684720	-.72982-006	1.90	1.70	-.010

THE GRAPH ON PAGE 2 SHOWS THE DIFFERENCE BETWEEN YOUR CALIBRATION EQUATION (.) AND THE PREVIOUS NBS EQUATION (ZERO AXIS). THE NBS CHECK CALIBRATION CURVE (o) IS SHOWN FOR COMPARISON. ANY 2'S PLOTTED ON THE GRAPH SIGNIFY TWO COINCIDENTAL CURVE VALUES.

* LARGEST DIFFERENCE FROM PREVIOUS NBS CALIBRATION. VALUES ARE FROM FITTED CURVES.


GRAFTAB - ANALYSIS OF ROUND-ROBIN DATA, ASTM E74-74
HOR- COLUMN 15
VER- COLUMN 17 (.), COLUMN 18 (*),
POINTS PLOTTED 100, POINTS NOT PLOTTED - OUT OF BOUND 0
.05
.03
.01
-.01
-.03
-.05
CURVE DIFFERENCE IN CAPACITY
0.
8000.
16000.
24000.
COMPRESSION LOAD IN POUNDS-FORCE
CELL NO. 82625, INDICATOR NO. 2235

ANALYSIS OF ROUND-ROBIN DATA, ASTM E74-74

CELL NO. 82625, INDICATOR NO. 2235
CAPACITY 20000 LBF COMPRESSION AND TENSION APRIL 1, 1982

LAB CALIBRATION IN COMPRESSION				CORRESPONDING CURVE DEFLECTIONS	
CALIB. LOAD (LBF)	OBSERVED DEFLECT.	CURVE DEFLECT.	DEVIATIONS FROM CURVE	NBS PREVIOUS	NBS CHECK
1200.000	3225.	3225.4	-.4	3222.9	3224.7
2800.000	7515.	7516.2	-1.2	7514.2	7515.6
4150.000	11130.	11133.7	-3.7	11132.2	11133.1
5545.000	14871.	14869.2	1.8	14867.9	14868.5
6950.000	18630.	18628.9	1.1	18627.5	18627.7
8500.000	22775.	22773.3	1.7	22771.9	22771.5
9800.000	26249.	26246.8	2.2	26245.1	26244.3
11300.000	30248.	30251.7	-3.7	30249.7	30248.3
12455.000	33333.	33333.5	-.5	33330.9	33329.1
14000.000	37452.	37452.9	-.9	37449.6	37447.2
15250.000	40785.	40783.4	1.6	40779.3	40776.4
17000.000	45436.	45442.5	-6.5	45437.2	45433.4
18450.000	49298.	49299.7	-1.7	49293.1	49288.8
19520.000	52147.	52144.2	2.8	52136.6	52131.8
20000.000	53423.	53419.7	3.3	53411.7	53406.6
1200.000	3225.	3225.4	-.4	3222.9	3224.7
2800.000	7513.	7516.2	-3.2	7514.2	7515.6
4150.000	11135.	11133.7	1.3	11132.2	11133.1
5545.000	14875.	14869.2	5.8	14867.9	14868.5
6950.000	18631.	18628.9	2.1	18627.5	18627.7
8500.000	22775.	22773.3	1.7	22771.9	22771.5
9800.000	26246.	26246.8	-.8	26245.1	26244.3
11300.000	30250.	30251.7	-1.7	30249.7	30248.3
12455.000	33333.	33333.5	-.5	33330.9	33329.1
14000.000	37454.	37452.9	1.1	37449.6	37447.2
15250.000	40783.	40783.4	-.4	40779.3	40776.4
17000.000	45440.	45442.5	-2.5	45437.2	45433.4
18450.000	49300.	49299.7	.3	49293.1	49288.8
19520.000	52145.	52144.2	.8	52136.6	52131.8
20000.000	53420.	53419.7	.3	53411.7	53406.6