NBSIR 76-1145

Interlaboratory Comparison of Force Calibrations Using ASTM Method E74-74

Phase I

R. W. Peterson and R. L. Bloss

Engineering Mechanics Section
Mechanics Division
Institute for Basic Standards
National Bureau of Standards
Washington, D.C. 20234

August 1976

Summary Report
Covering Period 6/1/74 to 8/1/75

U. S. DEPARTMENT OF COMMERCE

NATIONAL BUREAU OF STANDARDS

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U.S. DEPARTMENT OF COMMERCE, Elliot L. Richardson, *Secretary*

Edward O. Vetter, *Under Secretary*

Dr. Betsy Ancker-Johnson, *Assistant Secretary for Science and Technology*

NATIONAL BUREAU OF STANDARDS, Ernest Ambler, *Acting Director*

CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTERLABORATORY COMPARISON OF FORCE CALIBRATIONS USING ASTM METHOD E74-74

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ABSTRACT

This report covers the first phase of an intercomparison of force calibrations coordinated by the National Bureau of Standards in conjunction with Committee E28.01 of the American Society for Testing and Materials. Results obtained show that the provisions of ASTM Method E74-74, "Standard Methods of Calibration of Force-Measuring Instruments for Verifying the Load Indication of Testing Machines" can be met by a variety of calibration laboratories. In general, uncertainties computed from the data are of the magnitude expected based upon the NBS results. An important by-product of the program is the mechanism for self-evaluation by each laboratory of its own force calibration capability.

Key Words: Force; force calibration; interlaboratory comparison; load cell; static force.

1. SCOPE

This report covers the first phase of an intercomparison of force calibrations coordinated by the National Bureau of Standards in conjunction with Committee E28.01 of the American Society for Testing and Materials. The objectives of the program are to evaluate ASTM E74-74, "Standard Methods of Calibration of Force-Measuring Instruments for Verifying the Load Indication of Testing Machines," and to familiarize calibration laboratories with its contents. An important by-product of the program is the mechanism for self-evaluation by each laboratory of its own force calibration capability.

2. PROGRAM DESCRIPTION

At the conception of this program, approximately thirty organizations having force calibration capability expressed an interest in participating. These laboratories represent large and small industrial companies, load cell and proving ring manufacturers, DOD and NASA contractors, and federal government agencies. In order to identify problems and provide an intermediate evaluation of the program, an introductory phase was initiated. This first phase is the subject of this report.

Six laboratories, representing a variety of functions and capabilities, participated in Phase I. Two packages of force-measuring instruments were circulated among the six laboratories and NBS. Package One consisted of 500 lbf* and 5000 lbf capacity load cells with an indicator. Package Two consisted of 20 000 and 100 000 lbf capacity load cells with an indicator. NBS performed calibrations on each package before and after they were calibrated by each of the other laboratories. In order that each laboratory could quickly evaluate the results of their calibration, a preliminary data analysis was furnished which compared their data to the before and after NBS calibrations. An example is shown in Figure 1. These data are further examined in this report and will also be included as part of the larger study now underway.

3. TEST PROCEDURE

The participants were requested to calibrate each of the load cells in strict accordance with Section 6 of ASTM Method E74-74.** The load cells were to be treated as tension and compression devices for which calibration equations were to be established. It was further requested that information on the calibration standards and procedures used be submitted to NBS as part of the calibration record. The information requested is shown in Appendix A.

4. ANALYSIS OF DATA

According to ASTM E74-74, a "continuous-reading" device is calibrated by sampling load measurements over its range in order to describe the force-to-deflection relationship. The calibration data are usually fitted to a second-degree curve of the form $D = A + BL + CL^2$ by the method of least squares. In this equation D is the deflection, L is the

---

* Since the rated capacity of the devices used in this study and the nominal load values were given in U. S. Customary units (lbf), these units are retained throughout this report. Conversion to SI units can be made using the relationship 1 lbf = 4.44822 Newtons.

** Can be obtained from The American Society for Testing and Materials, 1916 Race Street, Philadelphia, Pa. 19103.

CAPACITY 100,000 LBF COMPRESSION AND TENSION FEBRUARY 11, 197?

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	-2.11	.529812	-.23049-08	1.79	8.10	.000
YOUR LABORATORY	-6.29	.530175	-.59149-08	7.86	35.61	-.008
NBS CHECK	-2.10	.529827	-.27801-08	2.03	9.20	-.006

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

** DIFFERENCE, AT CAPACITY LOAD, FROM PREVIOUS NBS VALUE. VALUES ARE FROM FITTED CURVES.

Figure 1a. OMNITAB analysis of Round-Robin data, ASTM E74-74.

ABS- COLUMN 15
ORD- COLUMN 17 (.), COLUMN 18 (*),
NO. OF PTS. PLOTTED 100 NO. NOT PLOTTED (OUT OF BOUNDS) 0

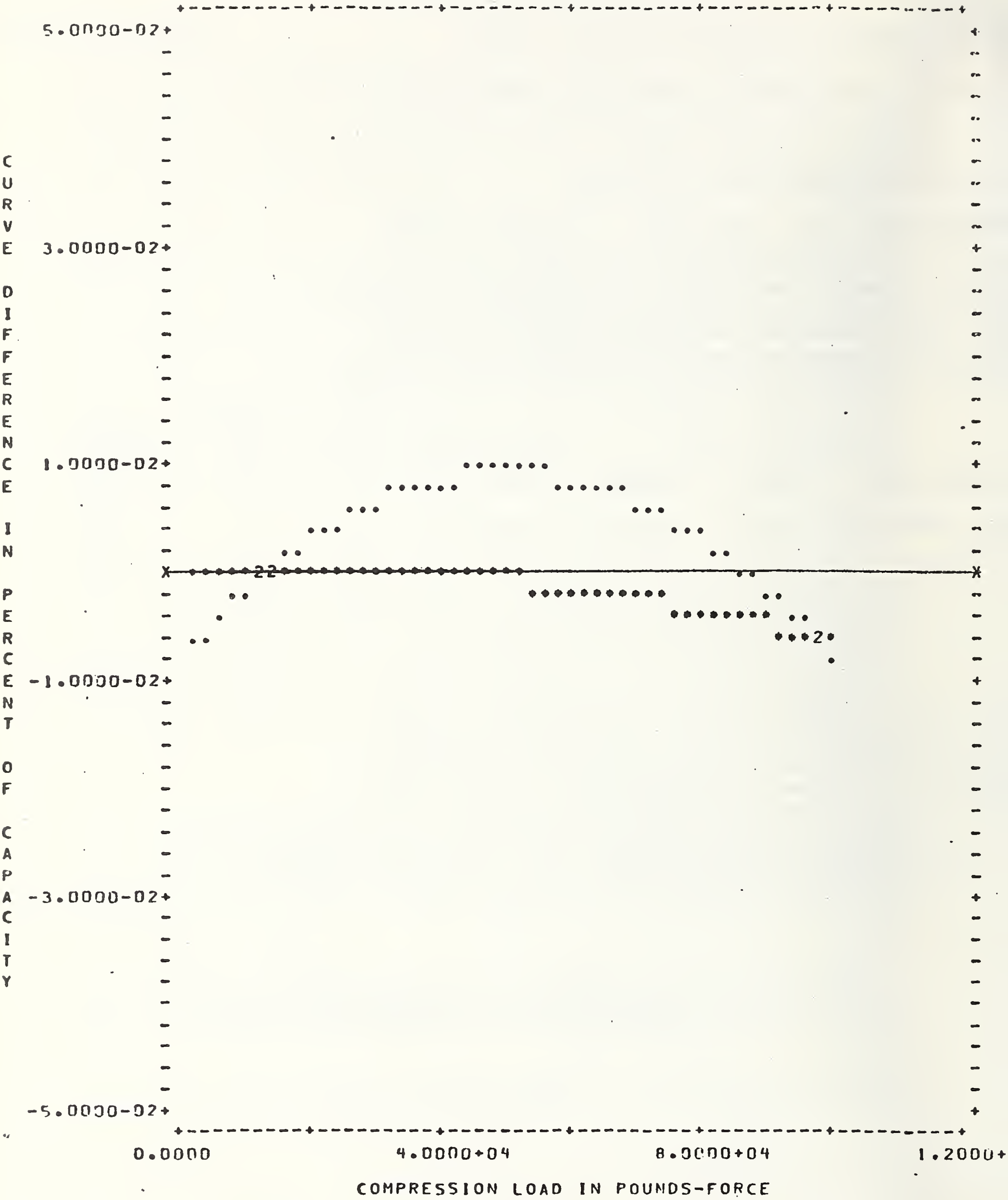

Figure 1b. OMNITAB analysis of Round-Robin data, ASTM E74-74.

load and A, B, and C are coefficients determined by the curve fitting process. The equation of this curve is then taken as representing the force-deflection characteristics of the device. The probable uncertainty in a measurement subsequently made with the device is assumed to relate to the agreement of the experimental calibration readings and the equation. The method of computing this uncertainty is given in Section 7 of E74-74. This curve fitting process was followed with the data from each laboratory for each load cell. Using the same process, a curve was fitted to all of the data taken at NBS with each load cell (from four to eight sets of calibration data). The equation of this curve, the "NBS base equation," was then used to compare with all other results. The standard deviation used to determine the uncertainty of the base equation is computed from the residuals of the combined data relative to the base equation. Although a number of ways for comparing the various calibration equations to the NBS base equations were explored, no completely satisfactory method has been found. Tables 1 through 4 show the differences at four force values and the uncertainty values based upon the laboratory and NBS calibrations. Base curve values are from the combined results of from four to eight calibrations made at NBS over a period of ten months. The values for the other laboratories are based upon one calibration. It should be noted that two 500 lbf capacity load cells were used since one was damaged midway through the program.

The laboratory and NBS base equations cannot be considered to be statistically different at the 99 percent confidence level unless the difference between the curves is greater than the combined uncertainties. This occurred in 7 of the 44 calibrations. However, this does not address the level of uncertainty that is acceptable. The response to this question must be based upon the accuracy required of measurements to be made with the device. Method E74-74 establishes two instrument classes based upon the uncertainty -- Class AA with an uncertainty of less than 0.05 percent of load and Class A with an uncertainty of less than 0.25 percent of load. These classes are established for particular applications, and other levels of uncertainty could be specified for other uses. The usefulness of a device calibrated by a particular system would then depend upon the measurement requirements.

The difference between the equations of the individual calibrations of each laboratory and the NBS base equation are also shown in Figures 2 through 9. The $\pm 2.4\ \sigma$ marks correspond to the 99 percent confidence interval for the NBS base. The uncertainties of the laboratory values are not plotted, but they can be found in Tables 1 through 4.

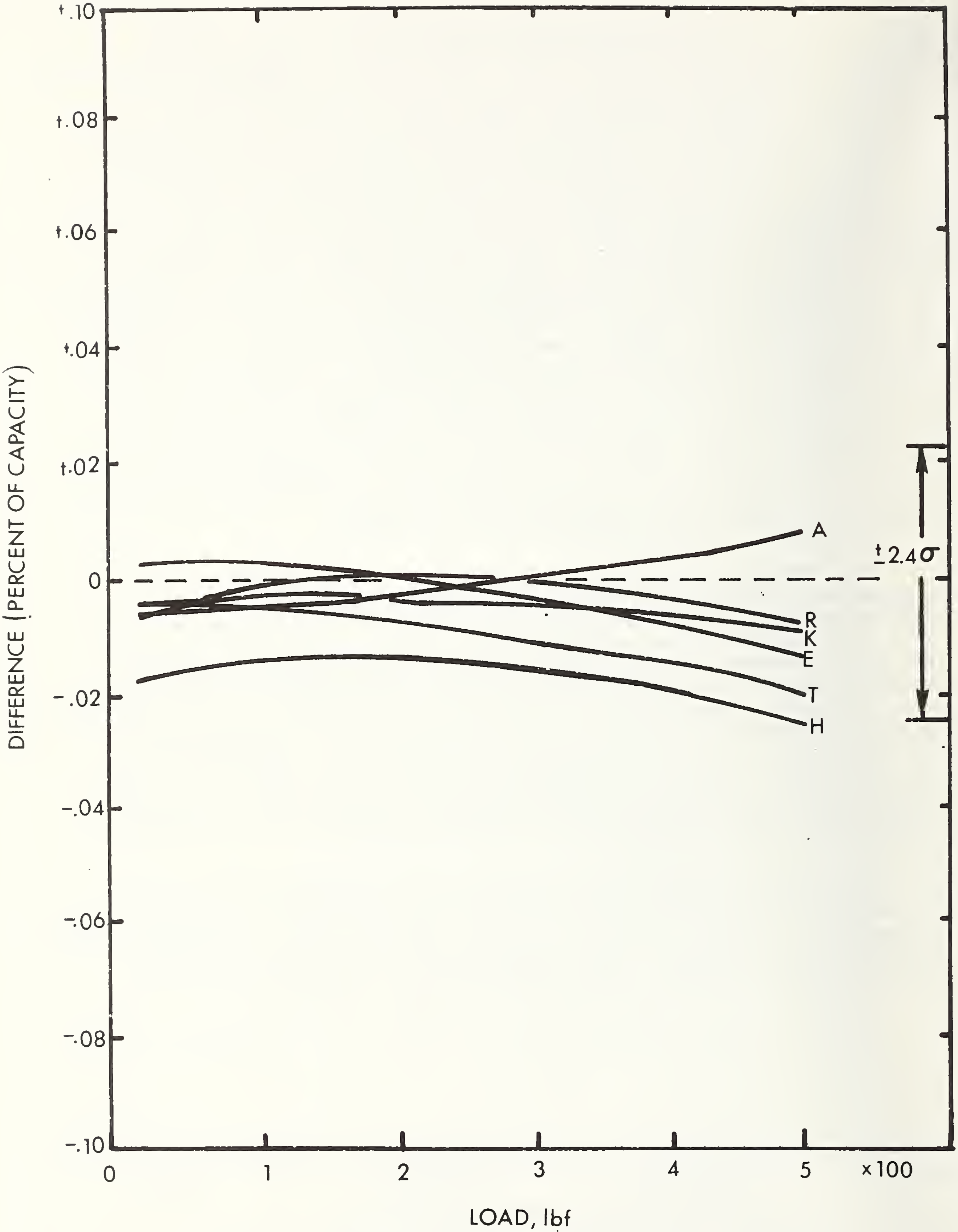

Figure 2. Difference between curve values and NBS base value in compression.

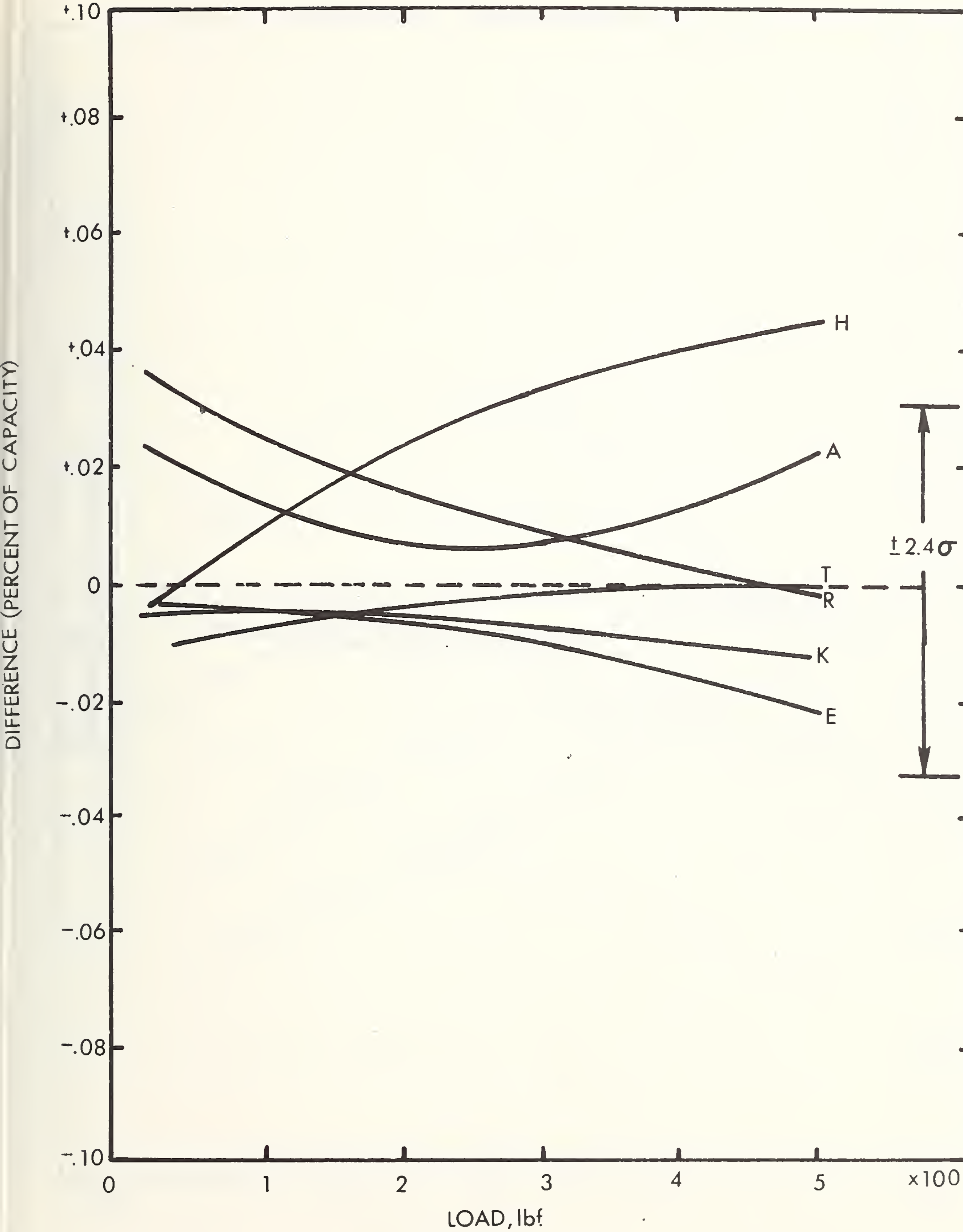

Figure 3. Difference between curve values and NBS base value in tension.

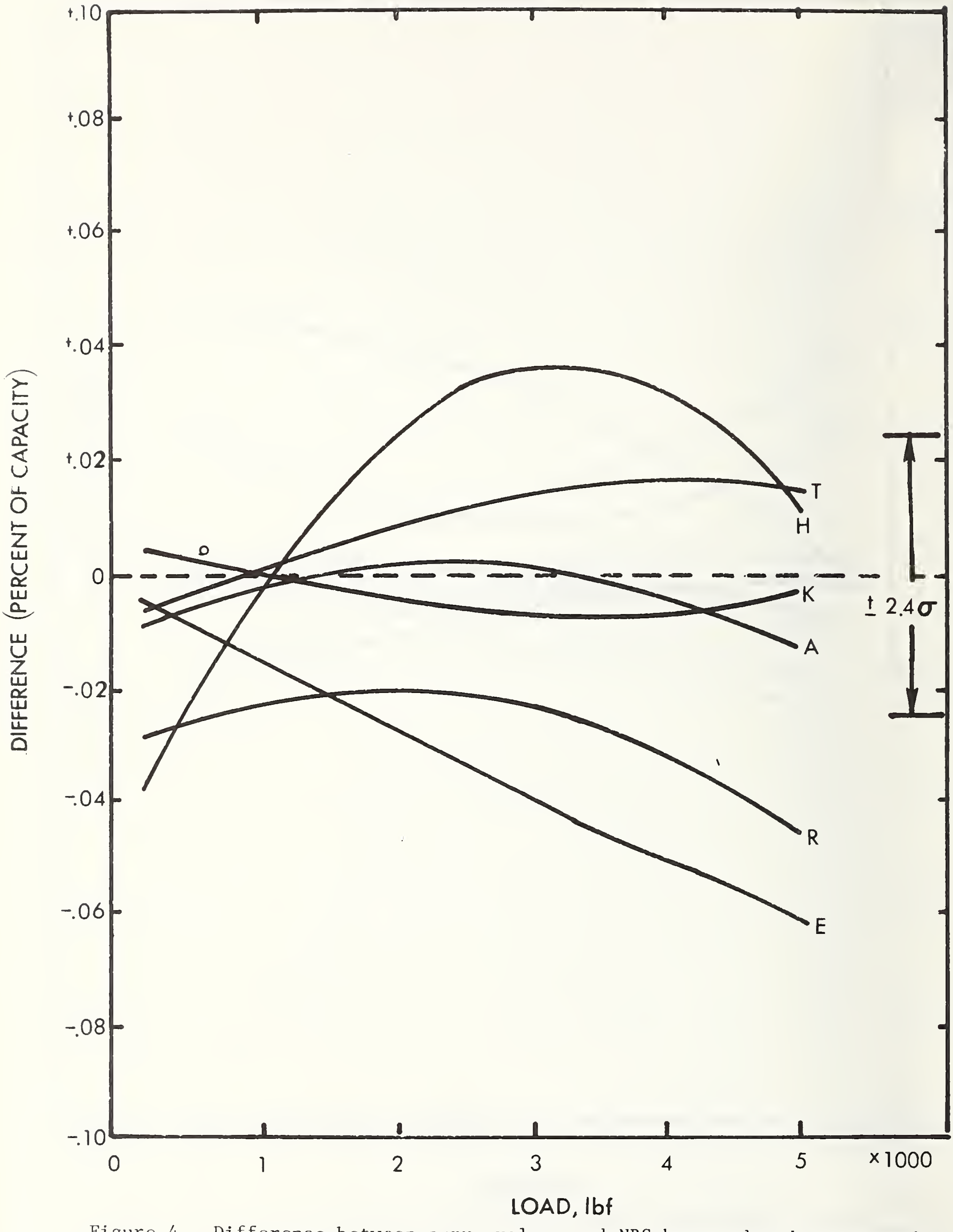

Figure 4. Difference between curve values and NBS base value in compression.

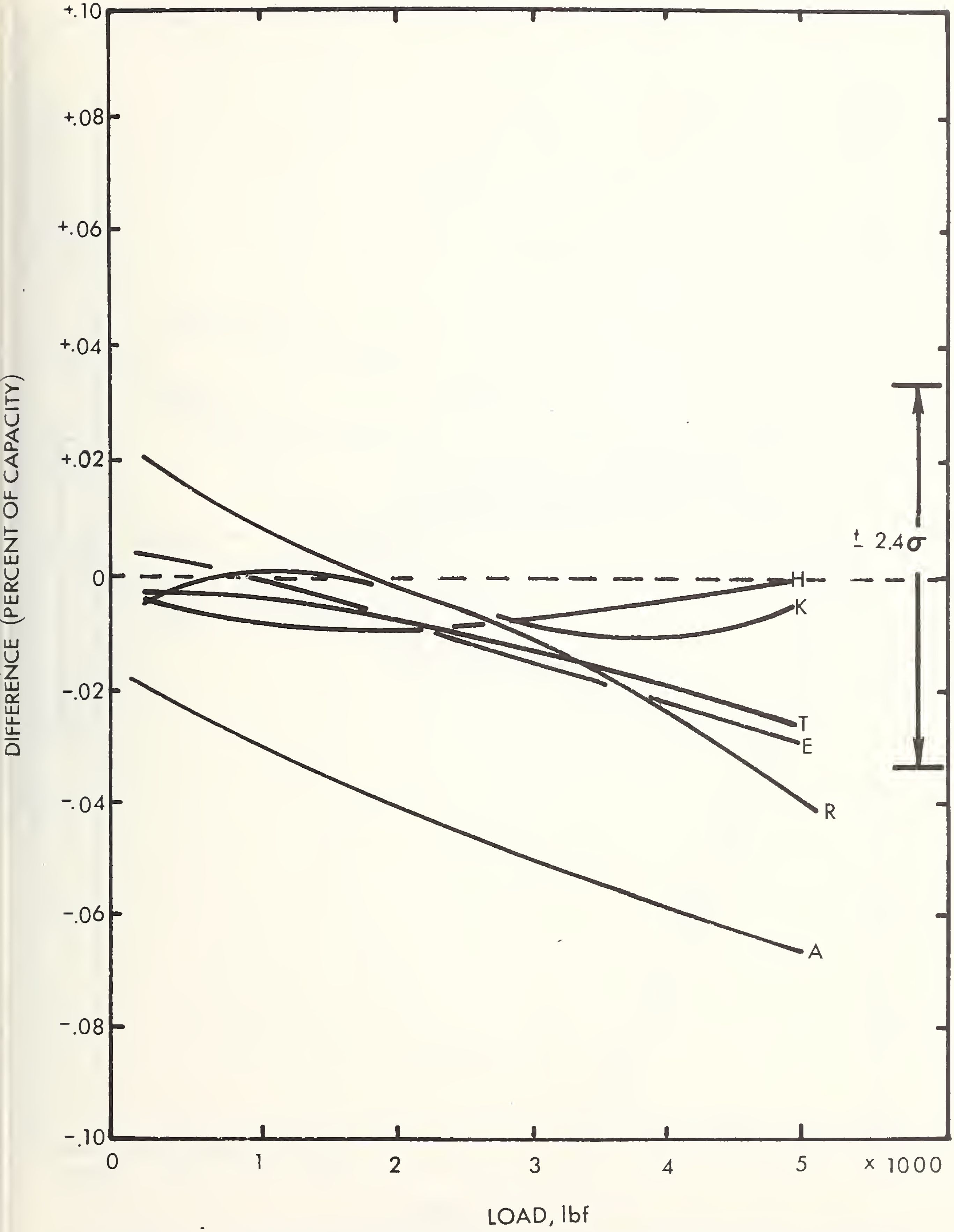

Figure 5. Difference between curve values and NBS base value in tension.

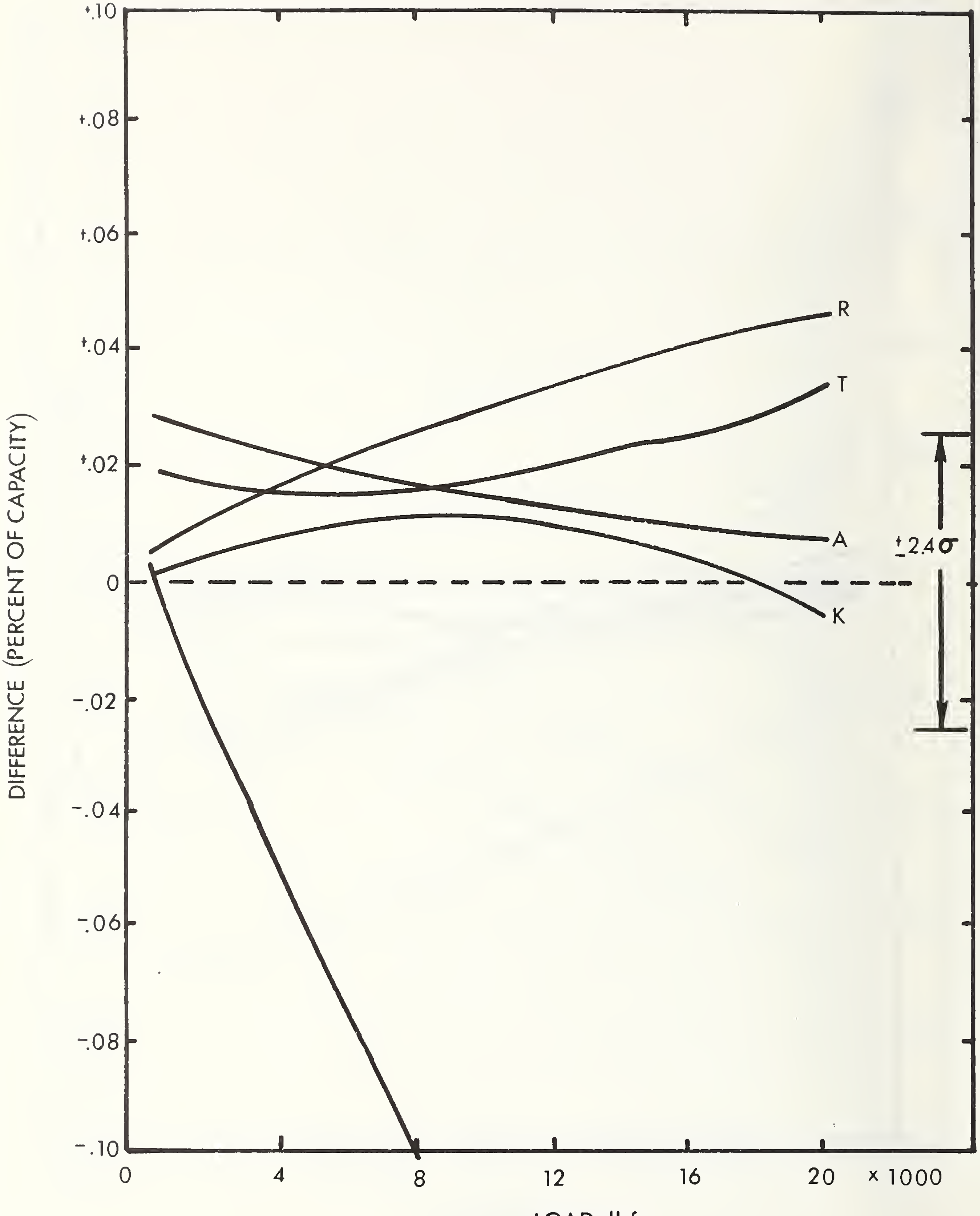

Figure 6. Difference between curve values and NBS base value in compression.

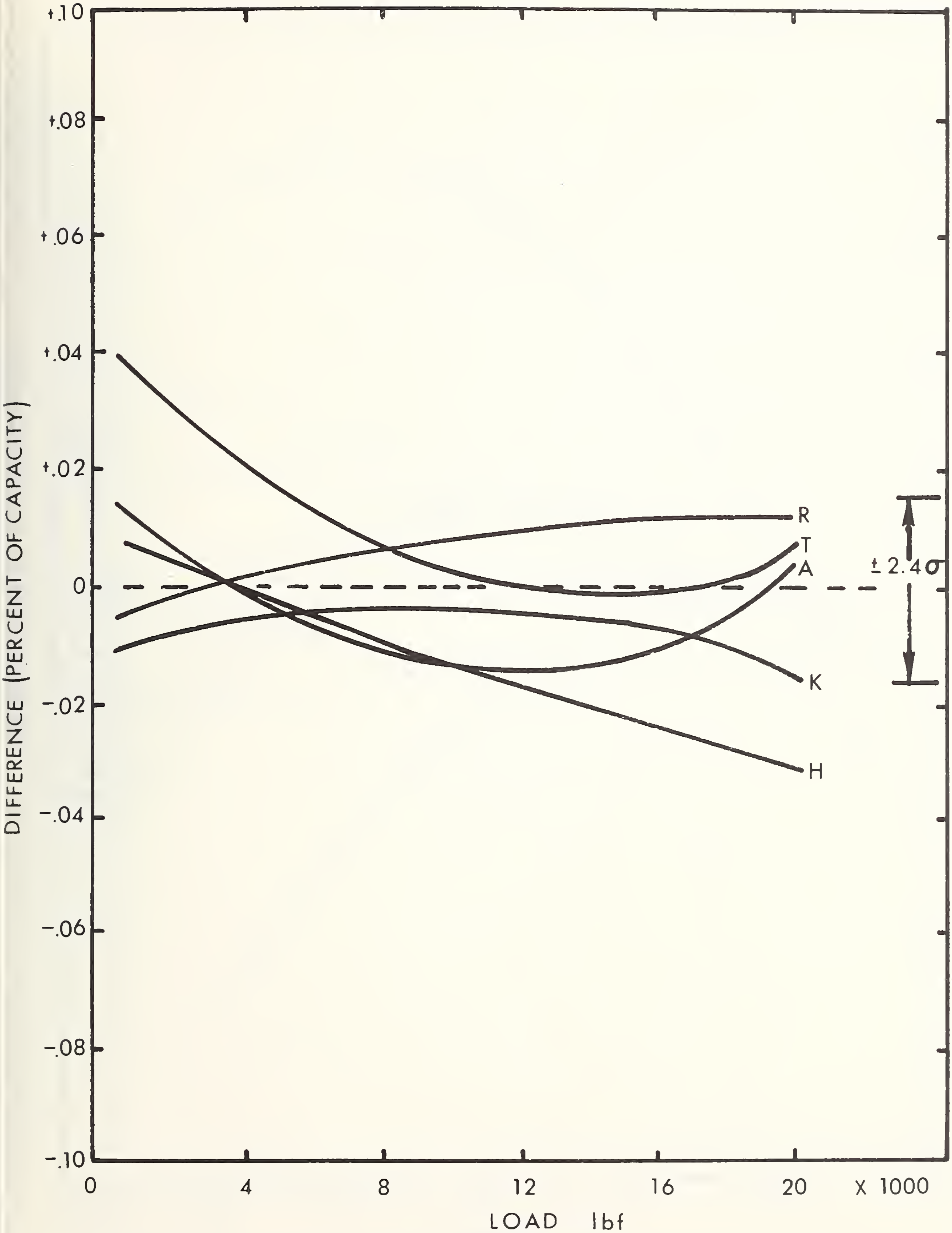

Figure 7. Difference between curve values and NBS base value in tension.

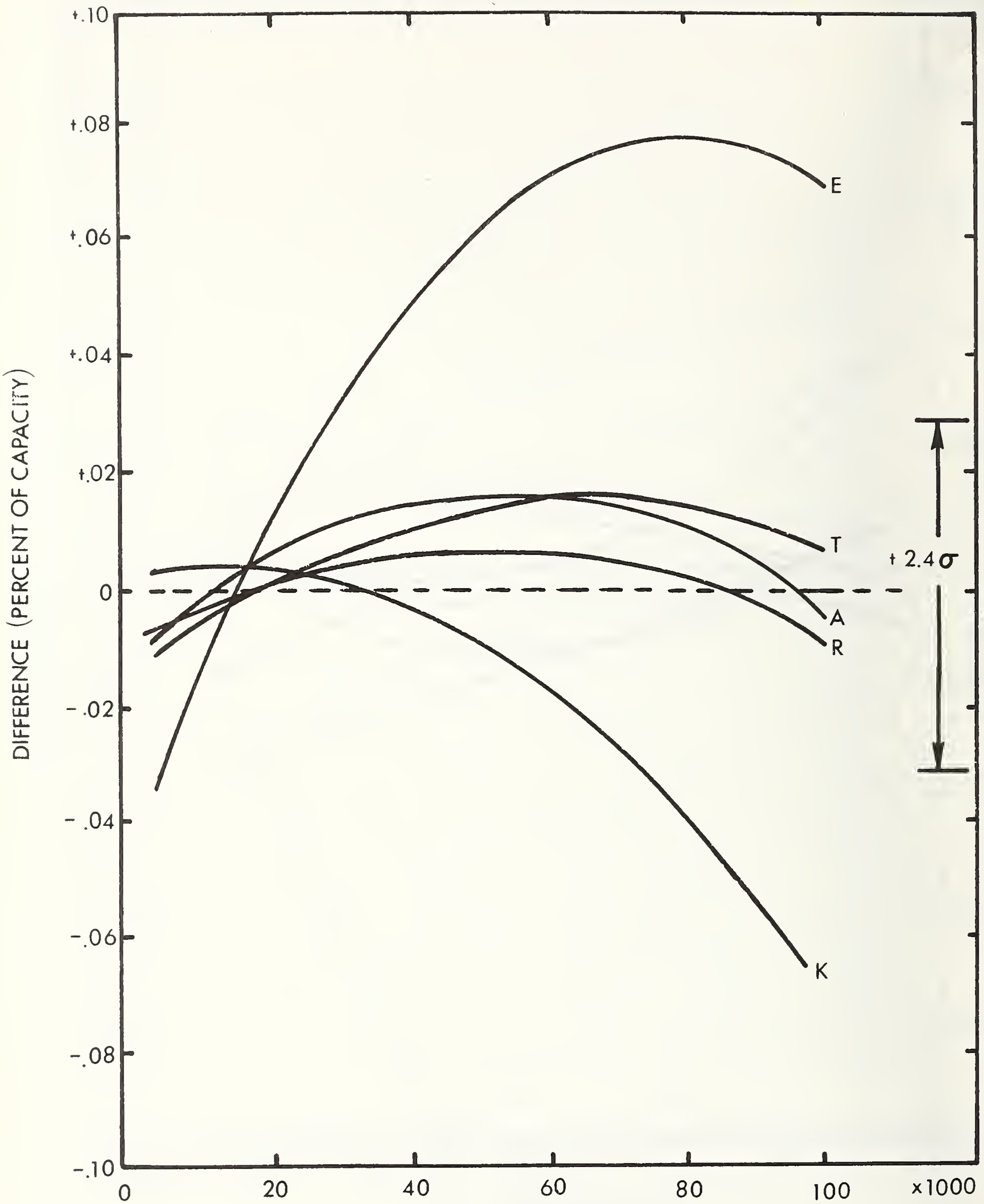

Figure 8. Difference between curve values and NBS base value in compression.

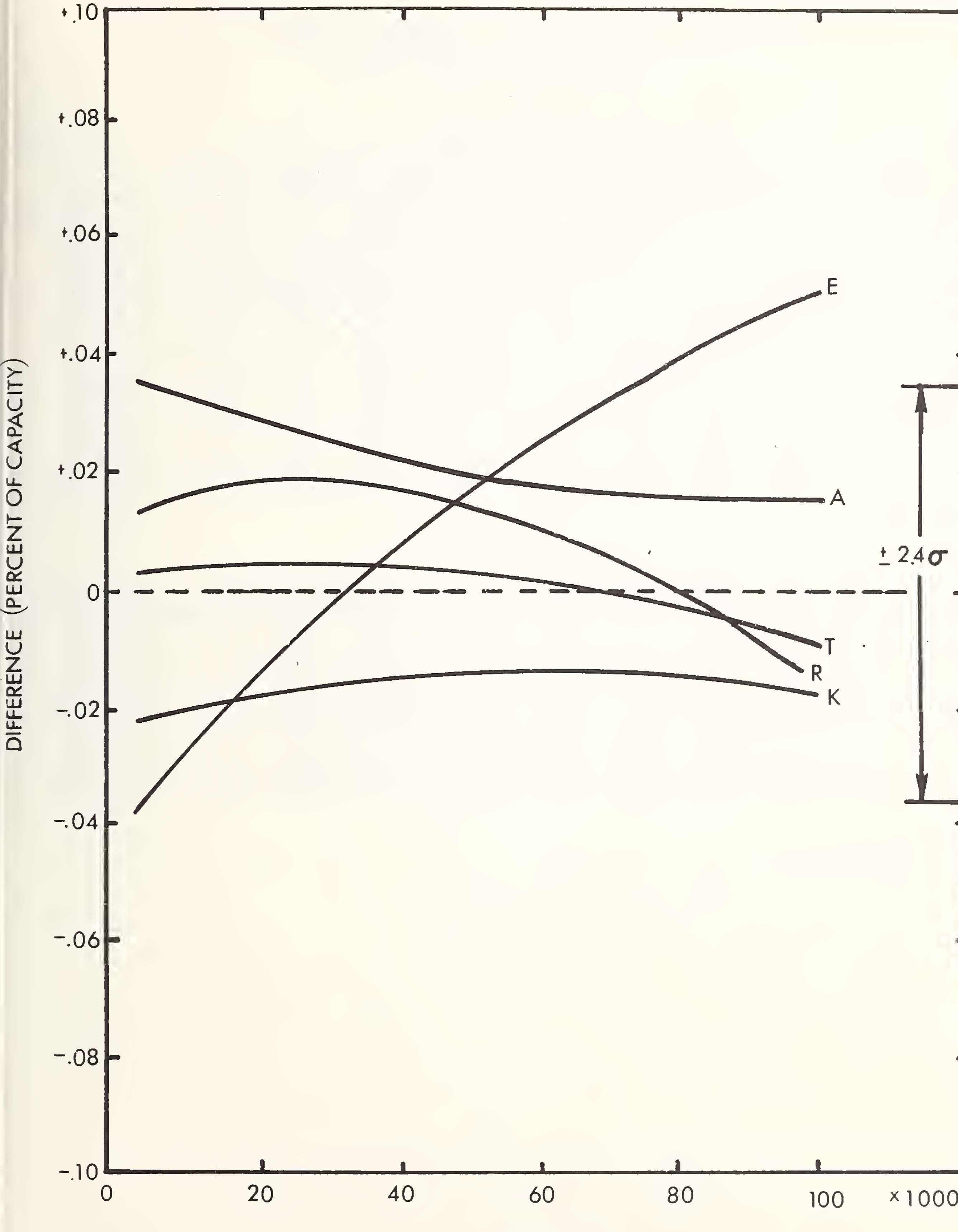

Figure 9. Difference between curve values and NBS base value in tension.

TABLE 1. Comparison of Calibration Data
for 500 lbf Capacity Cells

COMPRESSION

LAB	DIFFERENCE FROM BASE CURVE								UNCERTAINTY		
	25%		50%		75%		100%		LAB	LAB & BASE	
	LBF	% CAP	LBF	% CAP	LBF	% CAP	LBF	% CAP	LBF	LBF	% CAP
A(1.)	-.012	-.002	-.007	-.001	-.003	-.000	.001	.000	.123	.233	.047
E(2.)	.014	.003	.006	.001	-.002	.000	-.009	-.002	.195	.315	.063
H(2.)	-.059	-.012	-.038	-.008	-.018	-.004	.003	.000	.122	.241	.048
K(1.)	-.016	-.003	-.003	.000	.010	.002	.023	.005	.047	.157	.031
R(1.)	.000	.000	.022	.004	.044	.009	.065	.013	.083	.194	.039
T(2.)	-.027	-.005	-.041	-.008	-.055	-.011	-.069	-.014	.163	.163	.033

TENSION

LAB	25% LBF	25% % CAP	50% LBF	50% % CAP	75% LBF	75% % CAP	100% LBF	100% % CAP	LAB LBF	LAB & BASE LBF	LAB & BASE % CAP
A(1.)	.032	.006	-.054	-.011	-.141	-.028	-.227	-.045	.081	.242	.048
E(2.)	-.018	-.004	-.024	-.005	-.029	-.006	-.035	-.007	.093	.211	.042
H(2.)	.094	.019	.208	.042	.323	.065	.437	.087	.136	.255	.051
K(1.)	-.026	-.005	-.023	-.005	-.020	-.004	-.017	-.003	.068	.228	.046
R(1.)	.115	.023	.042	.008	-.032	-.006	-.105	-.021	.375	.535	.107
T(2.)	-.032	-.006	-.028	-.006	-.024	-.005	-.021	-.004	.053	.171	.034

(1.) Original cell
(2.) Replacement cell

TABLE 2. Comparison of Calibration Data for 5000 lbf Capacity Cell

COMPRESSION

LAB	DIFFERENCE FROM BASE CURVE								UNCERTAINTY		
	25%		50%		75%		100%		LAB	LAB & BASE	
	LBF	% CAP	LBF	% CAP	LBF	% CAP	LBF	% CAP	LBF	LBF	% CAP
A	.15	.003	.70	.014	1.25	.025	1.80	.036	.93	2.17	.043
E	-.91	-.018	-1.64	-.033	-2.37	-.047	-3.10	-.062	1.68	2.92	.058
H	1.96	.039	4.95	.099	7.95	.159	10.94	.219	1.93	3.17	.063
K	-.15	-.003	-.56	-.011	-.97	-.019	-1.38	-.028	1.32	2.56	.051
R	-.88	-.018	-.36	-.007	.15	.003	.67	.013	2.11	3.35	.067
T	.25	.005	.81	.016	1.38	.028	1.95	.039	.89	2.14	.043

TENSION

LAB	25% LBF	25% % CAP	50% LBF	50% % CAP	75% LBF	75% % CAP	100% LBF	100% % CAP	LAB LBF	LAB & BASE LBF	LAB & BASE % CAP
A	-1.63	-.033	-2.39	-.048	-3.15	-.063	-3.92	-.078	.94	2.67	.053
E	-.10	-.002	-.39	-.008	-.68	-.014	0.96	-.019	.70	2.42	.049
H	-.41	-.008	-.57	-.011	-.72	-.014	-.87	-.017	1.72	3.45	.069
K	.11	.002	-.90	-.018	-1.92	-.038	-2.93	-.059	1.56	3.28	.066
R	.15	.003	.48	.010	.82	.016	1.16	.023	1.99	3.72	.074
T	-.25	-.005	-.23	-.005	-.21	-.004	-.19	-.004	1.38	3.10	.062

TABLE 3. Comparison of Calibration Data for 20 000 lbf Capacity Cell

COMPRESSION

LAB	DIFFERENCE FROM BASE CURVE								UNCERTAINTY		
	25%		50%		75%		100%		LAB	LAB & BASE	
	LBF	% CAP	LBF	% CAP	LBF	% CAP	LBF	% CAP	LBF	LBF	% CAP
A	4	.020	2.1	.010	.2	.001	-1.7	-.008	6.8	12.1	.061
E	-	-	-	-	-	-	-	-	-	-	-
H	-13.5	-.067	-28.7	-.144	-43.9	-.220	-59.2	-.296	6.1	11.4	.057
K	2.5	.012	4.7	.024	6.9	.034	9.1	.045	1.8	7.1	.036
R	4.3	.022	7.2	.036	10.1	.050	12.9	.065	2.6	7.8	.039
T	2.8	.014	1.9	.009	.9	.005	-.05	-.000	6.6	11.9	.060

TENSION

LAB	25% LBF	25% % CAP	50% LBF	50% % CAP	75% LBF	75% % CAP	100% LBF	100% % CAP	LAB LBF	LAB & BASE LBF	LAB & BASE % CAP
A	-1.8	-.009	-6.9	-.034	-12	-.060	-17.1	-.085	7.5	10.8	.054
E	-	-	-	-	-	-	-	-	-	-	-
H	-.5	-.002	-2.8	-.014	-5	-.025	-7.3	-.037	6.9	10.1	.051
K	-.5	-.002	1	.005	2.5	.013	4.1	.020	1.6	4.9	.024
R	1.2	.006	3	.015	4.9	.024	6.8	.034	2.1	5.4	.027
T	2.7	.013	-3.6	-.018	-9.8	-.049	-16	-.080	9.4	12.7	.063

TABLE 4. Comparison of Calibration Data for 100 000 lbf Capacity Cell

COMPRESSION

LAB	DIFFERENCE FROM BASE CURVE								UNCERTAINTY		
	25%		50%		75%		100%		LAB	LAB & BASE	
	LBF	% CAP	LBF	% CAP	LBF	% CAP	LBF	% CAP	LBF	LBF	% CAP
A	16	.016	41	.041	65	.065	90	.090	34	64	.064
E	38	.038	113	.113	188	.188	263	.263	33	63	.063
H	–	–	–	–	–	–	–	–	–	–	–
K	9	.009	15	.015	21	.021	27	.027	18	48	.048
R	8	.008	23	.023	38	.038	52	.052	28	59	.059
T	9	.009	29	.029	49	.049	69	.069	36	66	.066

TENSION

A	27	.027	16	.016	6	.006	-4	-.004	60	96	.096
E	-4	-.004	30	.030	63	.063	97	.097	42	77	.077
H	–	–	–	–	–	–	–	–	–	–	–
K	-15	-.015	-9	-.009	-3	-.003	3	.003	15	50	.050
R	23	.023	32	.032	40	.040	48	.048	40	76	.076
T	6	.006	7	.007	9	.009	11	.011	44	80	.080

In an attempt to determine if there were predominate systematic differences between the results from the various laboratories, the differences from the average of all results at capacity load were plotted in the form of Youden graphs, with tension and compression data for one load cell being shown on a graph. Systematic differences would be shown by the plotted points tending to fall along a diagonal line, i.e., in the first and third quadrants. These graphs are shown in Figure 10 through 13. Although there is some tendency towards such grouping, it is not conclusive. This process was also used to examine the results of each test package to determine if indicator instability was a significant problem. These graphs, Figures 14 and 15, show no significant trend. It should be noted that the values plotted in Figures 10 through 15 are not of the type usually compared by means of the Youden graphs and that the number of laboratories involved is small for such a comparison. While an indication of a strong systematic difference would have been significant, the results shown are not considered to be conclusive.

5. SUMMARY OF RESULTS

Table 5 is a summary of the results from the participating laboratories. An all cases, the base uncertainty is larger than the smallest uncertainty value of the participating laboratories. This is attributed to long term drift, and other factors affecting system stability during the course of the program. Inspection of all of the data suggests a systematic drift of most of the devices. However, since the largest uncertainty for the NBS base equation is 0.036 percent of capacity, no attempt was made to adjust the data to account for the possible drift. It is also noted that this uncertainty (0.036 percent of capacity) would allow an ASTM E74-74 Class A loading range from 15 to 100 percent of device capacity.

Although a number of the laboratory results did differ from the NBS base equation, the significance can only be evaluated in terms of the individual laboratory requirements. Since information for such an evaluation was not gathered as part of this program, no judgments will be made here. As noted earlier, however, each laboratory was informed of their agreement with NBS values shortly after their data were submitted. In some cases NBS cooperation was sought to reduce the differences.

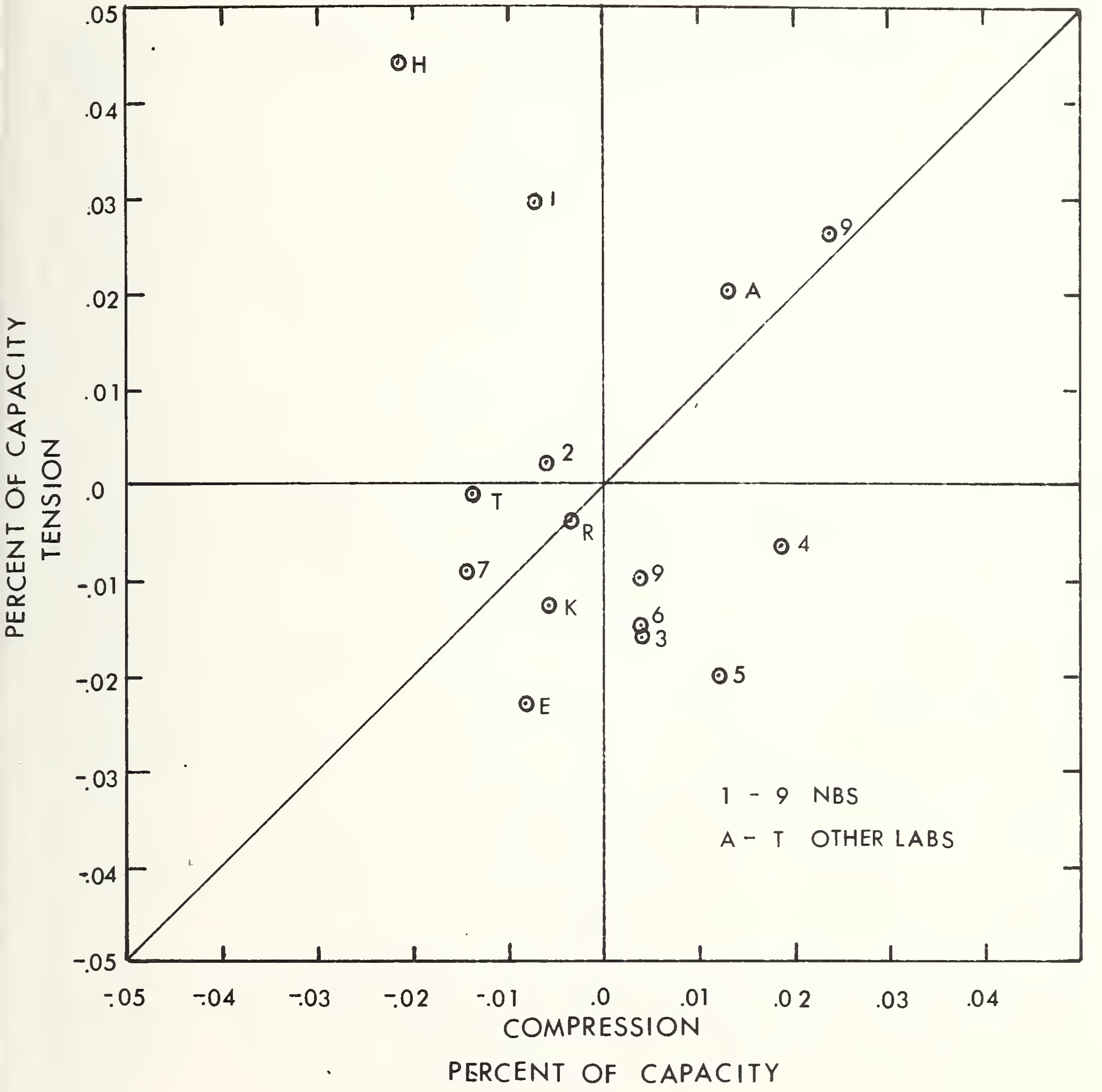

Figure 10. Difference between each calibration and the average value at capacity load for 500 lbf capacity load cells.

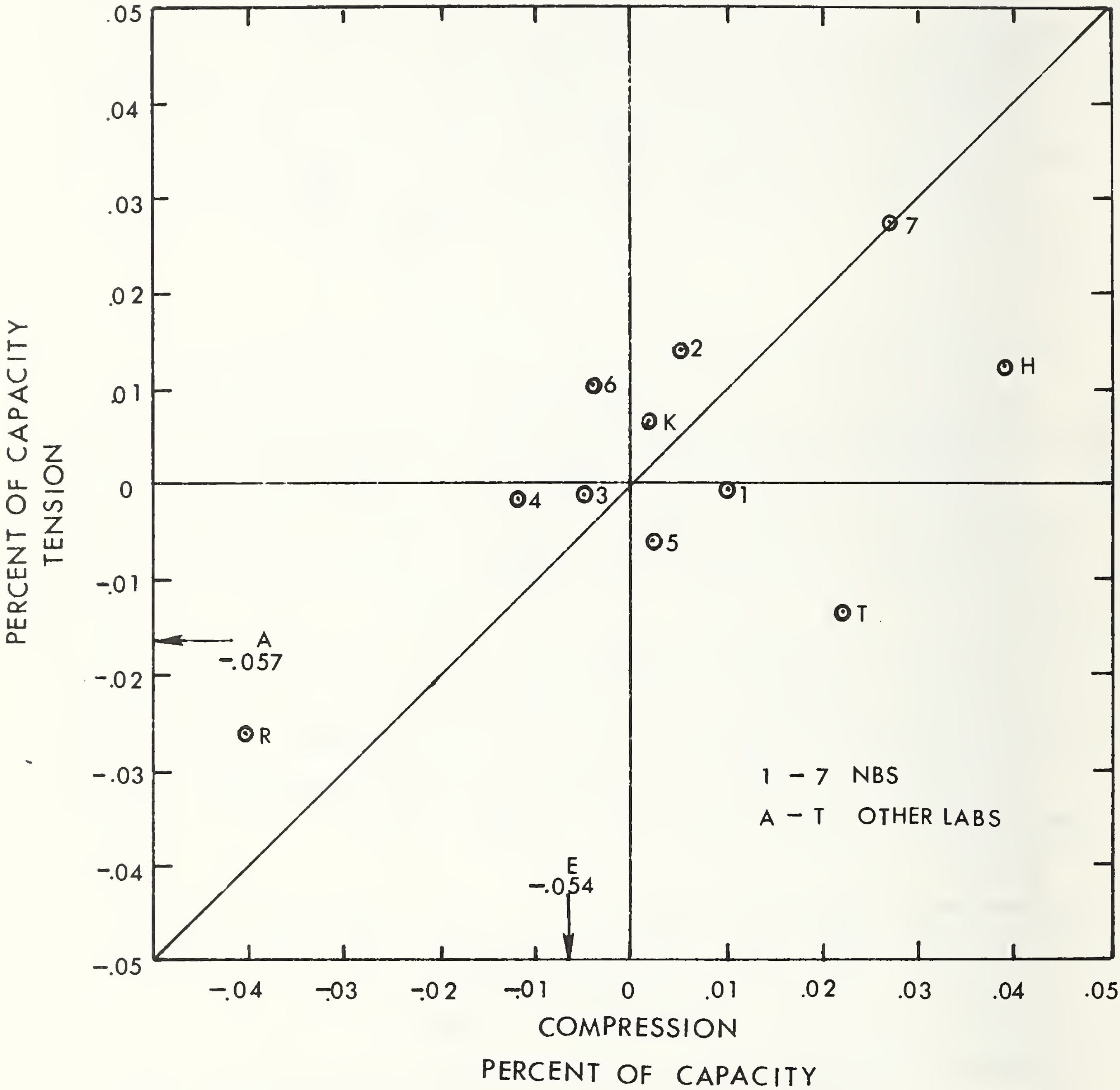

Figure 11. Difference between each calibration and the average value at capacity load for 5000 lbf load cell.

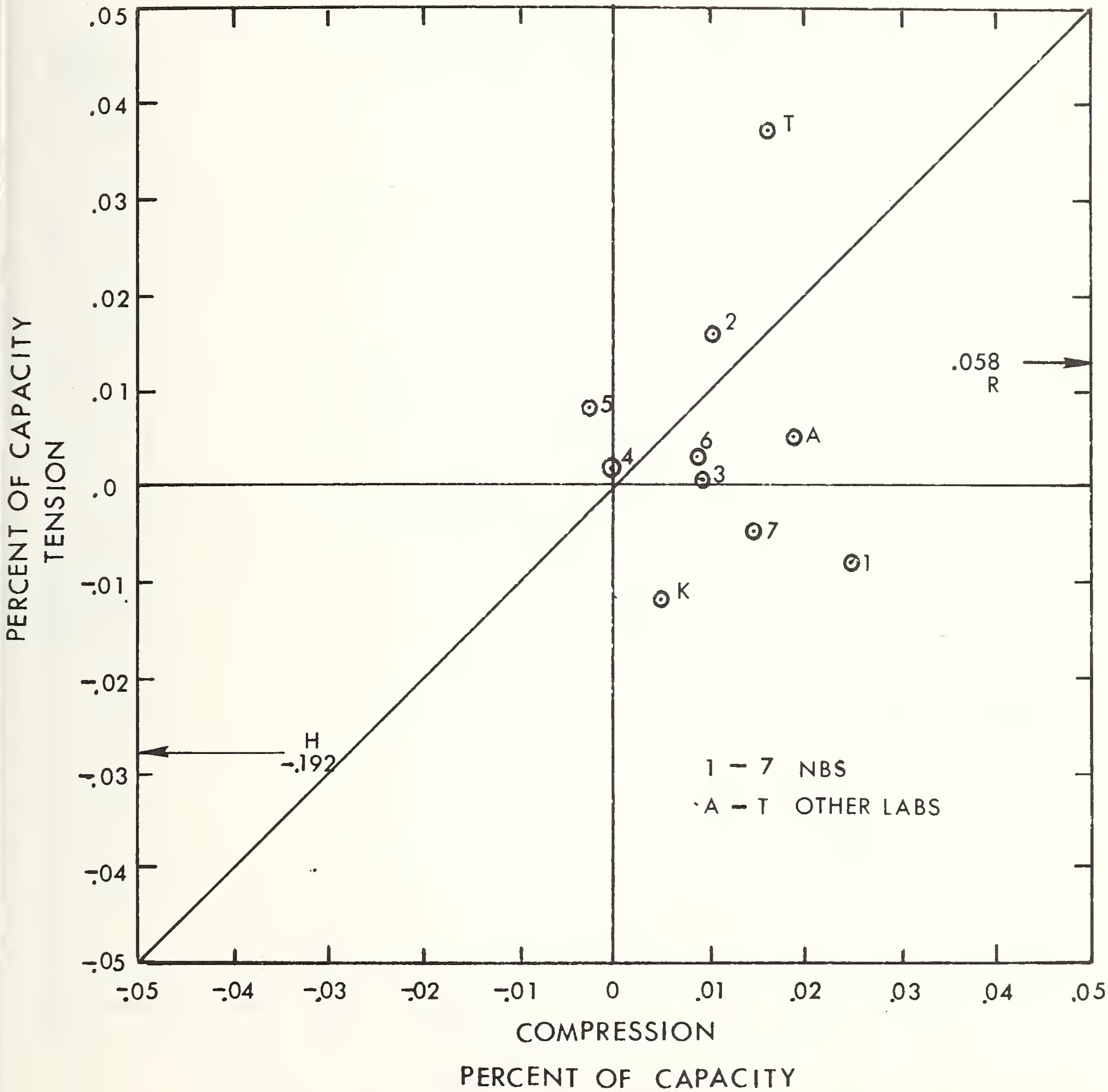

Figure 12. Difference between each calibration and the average value at capacity load for 20 000 lbf load cell.

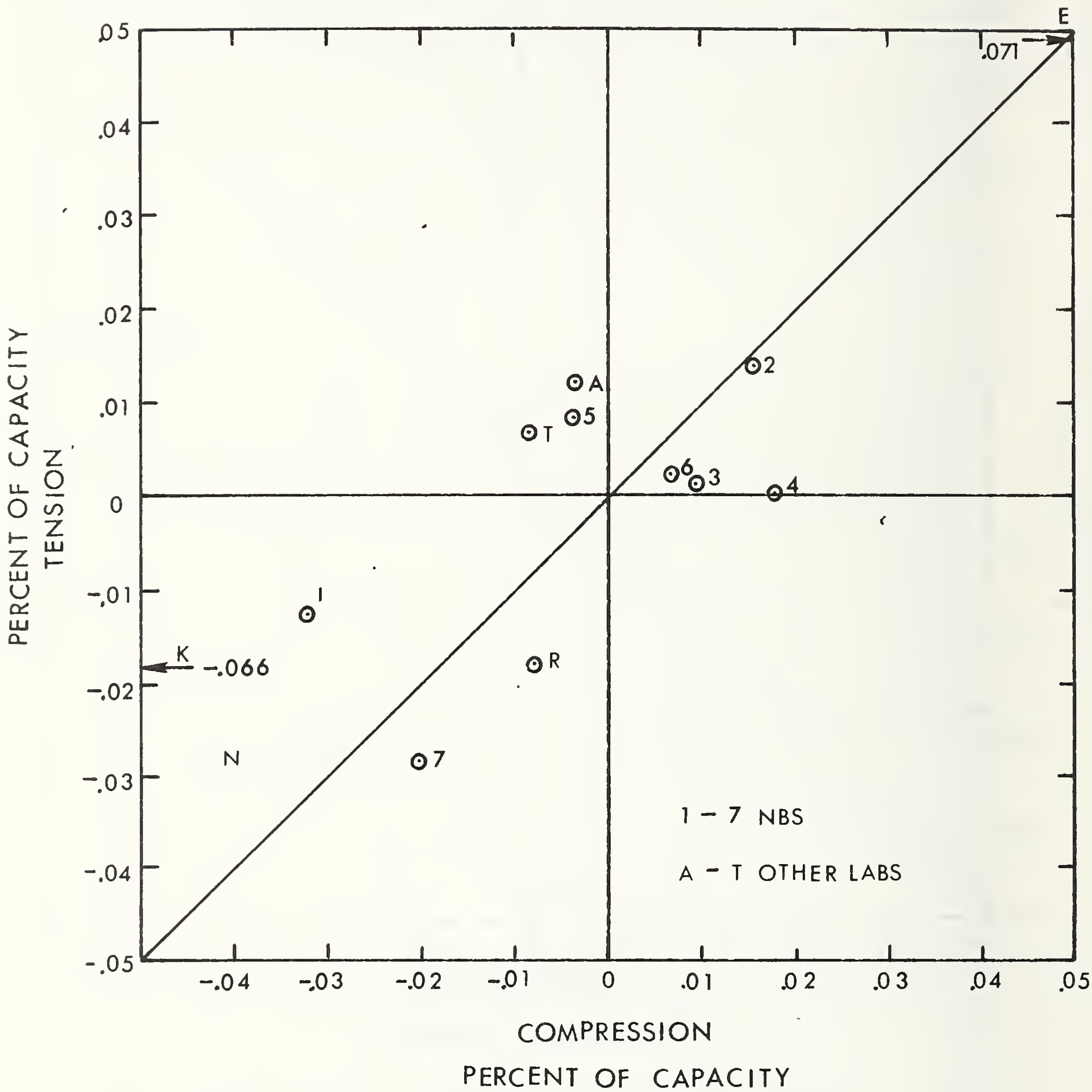

Figure 13. Difference between each calibration and the average value at capacity load for 100 000 lbf capacity load cells.

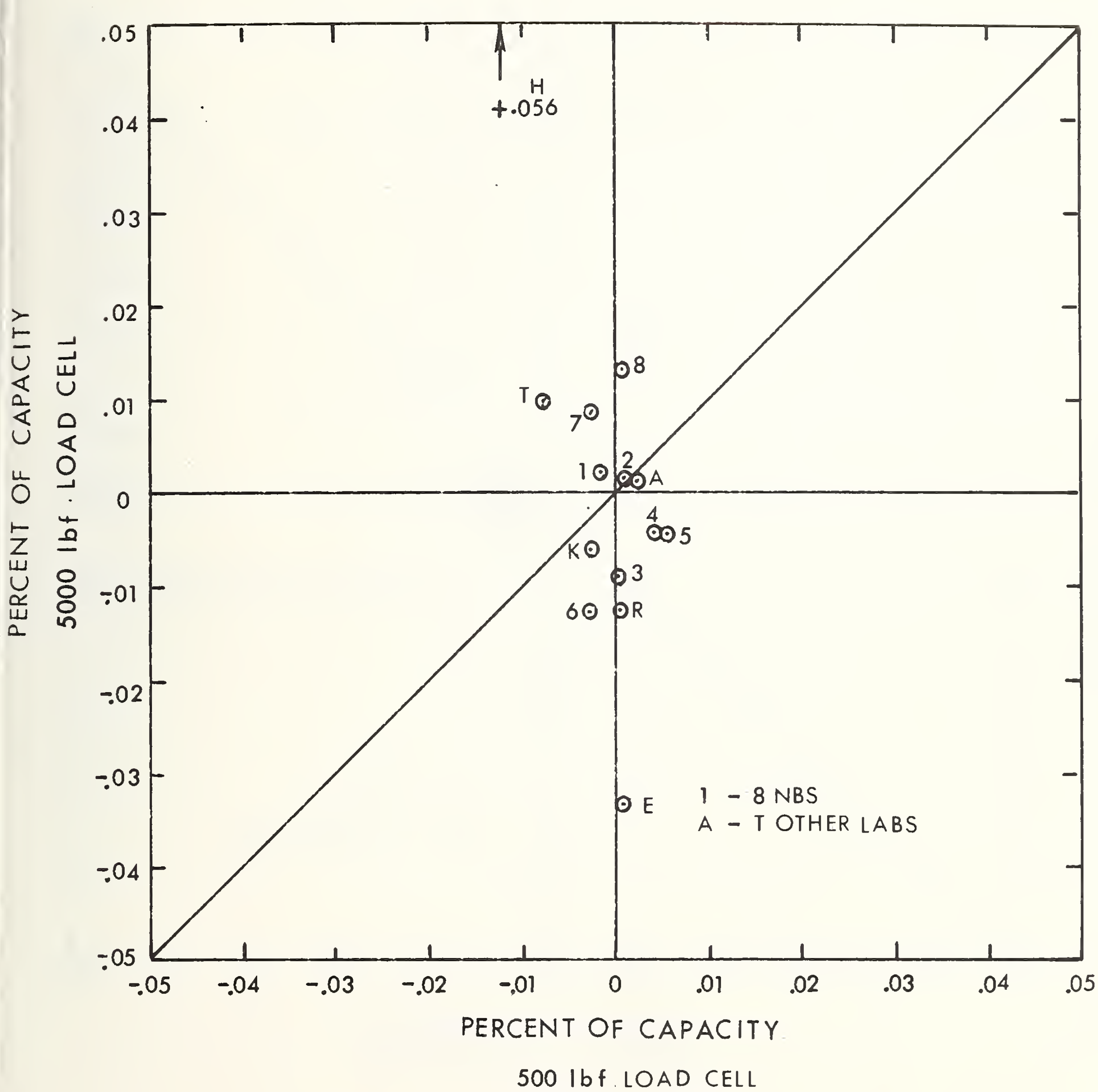

Figure 14. Difference between each calibration and the average value at 50 percent of capacity load for load cells of Package 1 in compression.

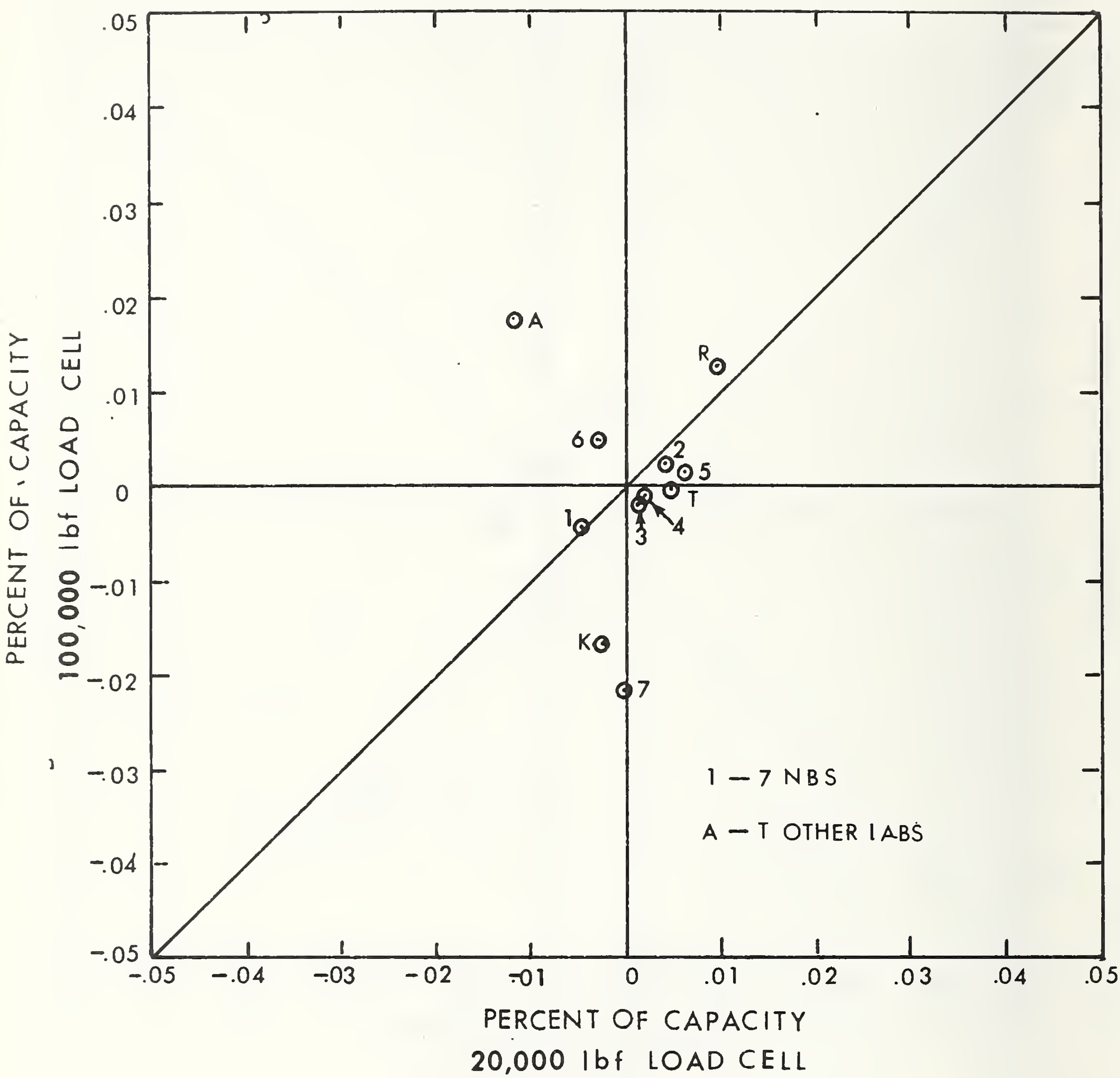

Figure 15. Difference between each calibration and the average value at 50 percent of capacity load for load cells of Package 2 in tension.

TABLE 5. Summary of Calibration Results

Load Cell Cap	Loading Mode	Uncertainty (LBF) Base	Uncertainty (LBF) Labs (min-max)	Calibrations by Participating Laboratories
500 (a)	C	0.110	0.047 - 0.123	3
500 (a)	T	0.161	0.068 - 0.375	3
500 (b)	C	0.120	0.043 - 0.195	3
500 (b)	T	0.119	0.053 - 0.136	3
5000	C	1.24	0.89 - 2.11	6
5000	T	1.73	0.70 - 1.99	6
20,000	C	5.3	1.8 - 6.8	5
20,000	T	3.3	1.6 - 9.4	5
100,000	C	30	18 - 36	5
100,000	T	36	15 - 60	5

(a) Original Load Cell (Destroyed on 2-26-75)
(b) Replacement Load Cell

6. CONCLUSIONS

Results obtained from the first phase of this program show that the provisions of ASTM Method E74-74 can be met by a variety of calibration laboratories since no comments indicating procedural problems were received. In general, uncertainties computed from the data are of the magnitude expected based upon the NBS results. A significant number of the laboratory results were statistically different from the NBS base equation values, but the significance of this cannot be evaluated without more information on the end use of the calibration results. The stability of load cell systems may be a problem for the second phase of the program, although frequent calibration by NBS should permit the data to be adjusted for time effects.

7. RECOMMENDATIONS FOR FUTURE PROGRAM PHASES

The logistical aspects of the first phase seem quite acceptable. Since a substantial data base for the instruments has been developed, the next phase will be conducted without returning the packages to NBS after each laboratory calibration. As many as three laboratories will perform calibrations on each excursion of a package.

A more satisfactory method of comparing the calibration results with the NBS base equation is being sought.

APPENDIX A

ASTM FORCE ROUND ROBIN

Information Sheet for

____

In order to provide a comprehensive evaluation of test results, the following information is requested for each calibration. This information, along with your calibration data will be held in confidence by NBS. However, if there are restrictions on furnishing some information requested, omit that portion and make an appropriate note.

Laboratory ______________________; Date of Calibration________

Person providing this information____________________

Force Standard(s) Employed

Type	MFG	Serial Number	Range	Uncertainty	Last Calibrated Date	By

Notes

1. Types of standards include, deadweight, load cell, proving ring, hydraulic force-multiplying system, mechanical force-multiplying system, etc.

2. When quoting uncertainty, if given in percent, be sure to state whether percent of load or percent of capacity of standard.

If secondary force standards (proving rings, load cells, etc.) were employed, please indicate the type of apparatus used to apply the loads.

_____ Hydraulic Loading Frame, capacity _____

_____ Mechanical Loading Frame, capacity _____

_____ Testing Machine, capacity _____

_____ Other ____________ capacity_____

If applicable, please give the force-deflection equation for each force standard.

____; serial no. ______________________

____; serial no. ______________________

____; serial no. ______________________

If hydraulic or mechanical force-multiplying systems were employed, please give the nominal multiplying ratio.

____; serial no. ______________________

____; serial no. ______________________

____; serial no. ______________________

If ambient temperature during calibration is not shown on your data sheet, please indicate here (average value) __________________________________.

If deadweights are used, either directly or in force-multiplying systems, has your data been compensated for the effects of local gravity and air-bouyancy?

_____ No

_____ Yes; _____mathematically, or _____ weight adjustment (refer to Section 5.1.1 of E74-74).

Please describe describe briefly your efforts to randomize loading conditions as specified in Section 6.4 of ASTM E74-74.

____

____

____

____

____

____

Will you furnish a formal calibration report (in the near future) as specified by section 11. of E74-74?

_____ Yes _____ No

We would appreciate any comments on E74-74; it's usefulness, problems, good points or bad.

____

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NBS-114A (REV. 7-73)

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16. ABSTRACT (*A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.*)

This report covers the first phase of an intercomparison of force calibrations coordinated by the National Bureau of Standards in conjunction with Committee E28.01 of the American Society for Testing and Materials. Results obtained show that the provisions of ASTM Method E74-74, "Standard Methods of Calibration of Force-Measuring Instruments for Verifying the Load Indication of Testing Machines" can be met by a variety of calibration laboratories. In general, uncertainties computed from the data are of the magnitude expected based upon the NBS results. An important by-product of the program is the mechanism for self-evaluation by each laboratory of its own force calibration capability.

17. KEY WORDS (*six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons*)

Force; force calibration; interlaboratory comparison; load cell; static force.

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