SOP No. 11

Recommended Standard Operating Procedure for Calibration of Metal Tapes Bench Method

1. Introduction

1.1. Purpose

Metal tapes are used by contractors, surveyors, and others for building layouts, measurement of land areas, establishment of land boundaries, and similar purposes. Inaccuracies in such measurements can cause structural misalignments, boundary controversies, and other problems. The test method described here provides a procedure to calibrate such tapes to four decimal places in the case of measurements in customary units (inches), and to 6 decimal places for measurements expressed in SI units (meters). The calibrated length bench is used as the standard. This procedure may also be used to compare rigid rules having different coefficients of expansion when compared at temperatures other than 20 °C.

1.2. Prerequisites

1.2.1. Valid calibration certificates with appropriate values and uncertainties must be available for all of the standards used in the calibration. All standards must have demonstrated metrological traceability to the international system of units (SI), which may be to the SI through a National Metrology Institute such as NIST.

1.2.2. The ocular microscope used in measuring differences in lengths must be in good operating condition and must be equipped with a calibrated graduated reticle having established traceability.

1.2.3. The operator must be trained and experienced in precision measuring techniques with specific training in GMP 2, GMP 8, GMP 9, SOP 11, and SOP 29.

1.2.4. Laboratory facilities must comply with following minimum conditions to meet the expected uncertainty possible with this procedure. Equilibration of length bench and tapes requires environmental stability of the laboratory within the stated limits for a minimum of 24 hours before a calibration.

Table 1. Environmental conditions.

Temperature Requirements During a Calibration	Relative Humidity (%)
Lower and upper limits: 18 °C to 22 °C Maximum changes: < ± 1 °C / 24 h and ± 0.5 °C / 1 h	40 to 60 ± 10 / 4 h

2. Methodology

2.1. Scope, Precision, Accuracy

The precision and accuracy attainable depend upon the care exercised in aligning the tape on the length bench, and the skill acquired in the use of an optical micrometer to measure scale differences.

2.2. Summary

The tape to be calibrated is laid over the bench scale and sufficient tension is applied to insure that it lies flat on the bench. Differences between the graduation on the tape and that of the bench scale are measured using an ocular micrometer. The temperature of the tape is observed, and corrections applied, to calculate the length at the reference temperature of 20 °C using formulae or tables which are in Appendix B. Tapes longer than the length bench may be calibrated in segments, using the last calibrated graduation as the zero graduation mark for the succeeding segments. Typical lengths to be tested on a 100 foot tape when using the 16 foot length bench are: every foot through 10 feet and then 15, 20, 30, 40, 45, 50, 60, 70, 75, 80, 90, and 100 foot lengths.

2.3. Apparatus/Equipment Required

2.3.1. Calibrated thermometers with sufficiently small resolution, stability, and uncertainty, capable of indicating temperatures in the range of 15 °C to 30 °C, and accurate to ± 0.5 °C.

2.3.2. Calibrated 5 meter (16 foot) length bench.

2.3.3. Microscope with calibrated graduated reticle having graduations spaced at intervals no greater than 0.002 inch.

2.3.4. Clamps, fabric tape in lengths required to connect tension weights to the tape being calibrated, and weights to apply an appropriate tension to the tape under calibration. (See C.3.)

2.4. Symbols

Table 2. Symbols used in this procedure.

Symbol	Description
S	Standard
X	Unknown
d_{0i}	Initial zero difference
d_{0f}	Final zero difference
X_{0L}	Left edge of zero on unknown
X_{0R}	Right edge of zero on unknown
S_{0L}	Left edge of zero on standard
S_{0R}	Right edge of zero on standard
X_m	Center of graduation of unknown
S_m	Center of graduation of standard
d	Difference of interval between X and S
t	Average of initial and final temperatures
t_{corr}	Temperature correction
L_n	Nominal length of tape interval under test in inches
L_X	Calibrated length of tape interval under test in inches
α	Linear coefficient of thermal expansion for the standard bench (0.00001063 / ºC)
β	Linear coefficient of thermal expansion for the tape (0.00001160 / ºC)
AE	Cross-sectional area times Young's modulus of elasticity
Q_0	Lower load (tension) applied to the tape
Q_1	Higher load (tension) applied to the tape
L_0	Length of tape under load Q_0
L_1	Length of tape under load Q_1

2.5. Procedure

2.5.1. Inspect the tape to ensure that no kinks, dents, or other damage are present that will affect the accuracy of the tape

2.5.2. Clean the tape and bench by first wiping with a soft cloth, and then with a soft cloth saturated with alcohol to remove protective oil film. (See Appendix C, Section C.1.)

2.5.3. Place the tape, under the clamp, at the zero end of the bench, and adjust so the starting mark on the tape is near the zero graduation on the length bench. When the ring is part of the measuring tape, a special clamp must be used. See Appendix C.5 for further information on this matter.

2.5.4. Lay the tape flat on the bench. The tape should extend well beyond the end roller of the bench to permit tension to be applied. Slide one end of a fabric strap onto another tape clamp. Fasten this tape clamp to the tape on the portion that extends below the end roller. Hang the tension weight from the bottom of the fabric strap. Check to see that the tape is lying straight on the bench and parallel to the bench scale. Adjust, if necessary. Apply tension using a weight of 10 pounds, unless other tension is required (See Appendix C.3.) When a tape is shorter than the 5 m length bench, a fabric strap is used to effectively lengthen the tape so that the tension weight is properly suspended below the rollers of the length bench.

2.5.5. Lay two thermometers (See 2.3.1.) on the bench and tape at intervals of 1/3 and 2/3 of the length of the bench to determine its initial and final temperatures at the time of the test.

2.5.6. Adjust the tape clamp on the zero end of the bench so that the starting graduation on the tape coincides with the center of the zero graduation of the bench. Note: Some tapes are calibrated using the one foot mark as the reference point, rather than the zero graduation. In this case, align the 1 foot mark of the tape with the zero graduation mark of the bench.

2.5.7. Check all alignments and coincidence of the graduations down the length of the bench before proceeding with calibration. Use the lateral adjustments at the left end of the bench to facilitate alignment. Caution! Take care that tape is not touched or disturbed during the following sequence of measurements. Record all observations on a suitable data sheet.

2.5.8. Record the temperatures indicated by the two thermometers.

2.5.9. Place the microscope on the bench in the vicinity of the zero position and align it so that its reticle scale is parallel to the tape under test. (See GMP No. 2 for instructions on reading graduations with the microscope.)

2.5.9.1. Observe readings of left and right sides of zero graduation of tape and record to the nearest 0.001 inch.

2.5.9.2. Observe readings of left and right sides of zero graduation of bench and record to the nearest 0.001 inch.

2.5.10. Move the microscope successively to each graduation that needs to be calibrated and record readings similarly as in 2.5.9.1 and 2.5.9.2.

2.5.11. Return the microscope to the zero graduation and repeat readings (2.5.9.1. and 2.5.9.2.) to verify that the tape has not moved. Accept all previous data if the zero readings have not changed by more than 0.001 inch; otherwise, discard all previous data and repeat entire sequence of readings until a satisfactory set of zero readings are obtained.

2.5.12. Loosen the tape by removing the tension weights, move the tape, hang the tension weights back on the fabric strap, and realign the zero marks on the tape and the bench to coincidence.

2.5.13. Repeat 2.5.8 thru 2.5.12 for every 15 foot (5 meter) section of the tape requiring calibration. This will require repositioning the tape, aligning the last measured interval graduation on the tape with the zero graduation of the bench.

2.5.14. Make a second set of measurements as directed in 2.5.8 to 2.5.13.
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2.5.15. After the final measurement is taken and accepted, record the temperatures indicated by the two thermometers.

2.5.16. After all measurements are completed; apply a thin film of oil to the tape.

3. Calculations

3.1. Calculate the Initial Zero Difference, d_{0i} (2.5.8.)

$$d_{0i} = \frac{(X_{0L} + X_{0R} - S_{0L} - S_{0R})}{2} \qquad (1)$$

3.2. Calculate the Final Zero Difference, d_{0f} (2.5.10.)

$$d_{0f} = \frac{(X_{0L} + X_{0R} - S_{0L} - S_{0R})}{2} \qquad (2)$$

3.3. Calculate the center of graduation for unknown, X_m, and standard, S_m, for each set of measurements and each scale interval.

$$X_m = \frac{(X_L + X_R)}{2} \qquad (3)$$

$$S_m = \frac{(S_L + S_R)}{2} \qquad (4)$$

3.4. Calculate the difference, d, between X and S for each scale interval.

$$d = X_m - S_m \qquad (5)$$

3.5. Obtain the correction to the standard, C_S, for the measured interval from the calibration certificate for the length bench scale.

3.6. Calculate the temperature correction, t_{corr}.

$$t_{corr} = L_n\left[(t-20)(\alpha-\beta)\right] \quad (6)$$

3.7. Calculate a correction, C_X, for each trial and each scale interval.

$$C_X = d + C_S + t_{corr} \quad (7A)$$

Be sure to include cumulative errors from previous intervals when transfers are made. (For example, corrections for two prior intervals added for the case when a third interval is calibrated.)

$$C_X = d + C_S + t_{corr} + C_{x'} + C_{x''} \quad (7B)$$

3.8. Calculate and report the mean, $\overline{C_X}$ of the two corrections for each interval.

3.9. Calculate the length of tape under the 10 pound load.

$$L_X = L_n + \overline{C_X} \quad (8)$$

4. Measurement Assurance

4.1. Duplicate the process with a suitable check standard or have a suitable range of check standards for the laboratory. See NISTIR 7383 SOP 17, SOP 20 and NISTIR 6969 SOP 30. Plot the check standard length and verify it is within established limits OR a *t*-test may be incorporated to check the observed value against an accepted value. The mean of the check standard observations is used to evaluate bias and drift over time. Check standard observations are used to calculate the standard deviation of the measurement process which contributes to the Type A uncertainty components.

4.2 If a standard deviation chart is used for measurement assurance, the standard deviation of each combination of Trial 1 and Trial 2 is calculated and the pooled (or average) standard deviation is used as the estimate of variability in the measurement process. Note: the pooled or average standard deviation over time will reflect varying conditions of test items that are submitted to the laboratory. A standard deviation chart will be needed for each interval calibrated (at least initially) so that the variability resulting from transfers will be measured.

5. Assignment of Uncertainty

5.1. The limits of expanded uncertainty, U, include estimates of the standard uncertainty of the length standards used, u_s, estimates of the standard deviation of the measurement process, s_p, and estimates of the effect of other components associated with this procedure, u_o. These estimates should be combined using the root-sum-squared method (RSS), and the expanded uncertainty, U, reported with a coverage factor to be determined based on degrees of freedom, which if large enough will be 2, (k = 2), to give an approximate 95 percent level of confidence. See NISTIR 6969, SOP 29 (Standard Operating Procedure for the Assignment of Uncertainty) for the complete standard operating procedure for calculating the uncertainty.

5.1.1 The expanded uncertainty for the standard, U, is obtained from the calibration report. The combined standard uncertainty, u_c, is used and not the expanded uncertainty, U, therefore the reported uncertainty for the standard will usually need to be divided by the coverage factor k. When transfers are used, u_s for values after the transfer are dependent and cumulative. See NISTIR 6969, SOP 29 for handling of dependent uncertainties.

5.1.2. The standard deviation of the measurement process, s_p, is taken from a control chart for a check standard or standard deviation charts. (See SOP 17, SOP 20, and SOP 30)

5.1.3. Uncertainty associated with bias, u_d. Any noted bias that has been determined through analysis of control charts and round robin data must be less than limits provided in SOP 29 and included if corrective action is not taken. See SOP 29 for additional details

5.1.4. Uncertainty associated with temperature correction includes values for the linear coefficients of expansion for the Standard and Unknown, the accuracy of temperature measurements, and factors associated with potential gradients in measuring the temperature on the length bench and tape.

5.1.5. Other standard uncertainties usually included at this calibration level include uncertainties associated with the ability to read the graduated reticle, only part of which is included in the process variability due to parallax and visual capabilities, and uncertainties associated with the graduations of the reticle.

Table 3. Example uncertainty budget table.

Component	Description	Reference
u_s	Standard uncertainty for standards	Calibration report, divide by k
s_p	Standard uncertainty for the process	Measurement assurance process; range charts
u_{gr}	Standard uncertainty for graduated reticle	Must be assessed experimentally or from a calibration certificate
u_{tc}	Standard uncertainty for temperature correction	Calibration certificate
u_t	Standard uncertainty for temperature	HB 143 accuracy guideline, 0.1 °C
$u_{lce\ (\alpha,\beta)}$	Standard uncertainty for linear coefficient of expansion	5 % to 10 % of the coefficient of expansion value
u_{tw}	Standard uncertainty for tension weights	Calibration certificate
u_d	Standard uncertainty for disparity due to drift/bias	Rectangular distribution and reasons, 0.577 d, 0.29 d; SOP 29 (NISTIR 6969)
u_{res}	Standard uncertainty due to resetting of the tape	Must be assessed experimentally; may be included in the control chart standard deviation where present
u_o	Standard uncertainty for other factors	

6. Report

Report results as described in SOP No. 1 Preparation of Calibration Certificates.

Appendix A

Bench Method Data Sheet

Date			Environmental parameters					
Metrologist				Before	After		Unc/ability to measure	
Test No.			Temperature			°C		°C
s_p		in	Pressure			mmHg		mmHg
df			Humidity			%		%
Based on NISTIR 6969, SOP 29, Appendix A at 95.45 % probability distribution: k factor								

		ID	Range		Linear coefficient of thermal expansion		
S	Bench		16 ft (5 m)		α	0.000 010 63	/°C
X	Tape				β	0.000 011 60	/°C
Tension		lb		Support			

Initial temperatures				Final temperatures					
t_1		°C		t_3		°C	Average temperature		°C
t_2		°C		t_4		°C			

Interval, ft		**Trial**	**Initial Zero Graduations**										
Bench	Tape		Tape			Bench							
0	0	1	X_{0L}	X_{0R}		S_{0L}	S_{0R}						
		Initial zero, difference between X and S, d_{0i}								in			
		2	X_{0L}	X_{0R}		S_{0L}	S_{0R}						
		Initial zero, difference between X and S, d_{0i}								in			
			Intervals after zero										
			Tape			Bench							
			X_{1L}	X_{1R}	X_m	S_{1L}	S_{1R}	S_m	d	C_S	t_{corr}	C_X	*Range*
		1											
		2											
											Average C_X		in
			X_{1L}	X_{1R}	X_m	S_{1L}	S_{1R}	S_m	d	C_S	t_{corr}	C_X	*Range*
		1											
		2											
											Average C_X		in
			Final Zero Graduations										
			Tape			Bench							
0	0	1	X_{0L}	X_{0R}		S_{0L}	S_{0R}						
			Final zero, difference between X and S, d_{0f}							in			
		Difference between Initial Zero and Final Zero, d_{0i} - d_{0f}								in			
		$\lvert d_{0i} - d_{0f}\rvert \le 0.001$ in?							If YES, accept previous data.				
		2	X_{0L}	X_{0R}		S_{0L}	S_{0R}						
			Final zero, difference between X and S, d_{0f}							in			
		Difference between Initial Zero and Final Zero, d_{0i} - d_{0f}								in			
		$\lvert d_{0i} - d_{0f}\rvert \le 0.001$ in?							If YES, accept previous data.				

$$t_{corr} = L_n\left[(t-20)(\alpha-\beta)\right] \qquad C_X = d + C_S + t_{corr} \qquad L_X = L_n + \overline{C_X}$$

$$C_X = d + C_S + t_{corr} + C_{x'} + C_{x''}$$

Appendix B

Table B-1. Temperature Correction Factors for Calibration of Steel Tapes graduated in feet when linear coefficient of thermal expansion for the tape is 0.00001160 / ºC. All values in inches x 10^{-4}

L_n Feet	Temperature, °C											
	19	20	21	22	23	24	25	26	27	28	29	30
1	0.1	0.0	-0.1	-0.2	-0.3	-0.5	-0.6	-0.7	-0.8	-0.9	-1.0	-1.2
2	0.2	0.0	-0.2	-0.5	-0.7	-0.9	-1.2	-1.4	-1.6	-1.9	-2.1	-2.3
3	0.3	0.0	-0.3	-0.7	-1.0	-1.4	-1.7	-2.1	-2.4	-2.8	-3.1	-3.5
4	0.5	0.0	-0.5	-0.9	-1.4	-1.9	-2.3	-2.8	-3.3	-3.7	-4.2	-4.7
5	0.6	0.0	-0.6	-1.2	-1.7	-2.3	-2.9	-3.5	-4.1	-4.7	-5.2	-5.8
6	0.7	0.0	-0.7	-1.4	-2.1	-2.8	-3.5	-4.2	-4.9	-5.6	-6.3	-7.0
7	0.8	0.0	-0.8	-1.6	-2.4	-3.3	-4.1	-4.9	-5.7	-6.5	-7.3	-8.1
8	0.9	0.0	-0.9	-1.9	-2.8	-3.7	-4.7	-5.6	-6.5	-7.4	-8.4	-9.3
9	1.0	0.0	-1.0	-2.1	-3.1	-4.2	-5.2	-6.3	-7.3	-8.4	-9.4	-10.5
10	1.2	0.0	-1.2	-2.3	-3.5	-4.7	-5.8	-7.0	-8.1	-9.3	-10.5	-11.6
15	1.7	0.0	-1.7	-3.5	-5.2	-7.0	-8.7	-10.5	-12.2	-14.0	-15.7	-17.5
20	2.3	0.0	-2.3	-4.7	-7.0	-9.3	-11.6	-14.0	-16.3	-18.6	-21.0	-23.3
30	3.5	0.0	-3.5	-7.0	-10.5	-14.0	-17.5	-21.0	-24.4	-27.9	-31.4	-34.9
40	4.7	0.0	-4.7	-9.3	-14.0	-18.6	-23.3	-27.9	-32.6	-37.2	-41.9	-46.6
45	5.2	0.0	-5.2	-10.5	-15.7	-21.0	-26.2	-31.4	-36.7	-41.9	-47.1	-52.4
50	5.8	0.0	-5.8	-11.6	-17.5	-23.3	-29.1	-34.9	-40.7	-46.6	-52.4	-58.2
60	7.0	0.0	-7.0	-14.0	-21.0	-27.9	-34.9	-41.9	-48.9	-55.9	-62.9	-69.8
70	8.1	0.0	-8.1	-16.3	-24.4	-32.6	-40.7	-48.9	-57.0	-65.2	-73.3	-81.5
75	8.7	0.0	-8.7	-17.5	-26.2	-34.9	-43.7	-52.4	-61.1	-69.8	-78.6	-87.3
80	9.3	0.0	-9.3	-18.6	-27.9	-37.2	-46.6	-55.9	-65.2	-74.5	-83.8	-93.1
90	10.5	0.0	-10.5	-21.0	-31.4	-41.9	-52.4	-62.9	-73.3	-83.8	-94.3	-104.8
100	11.6	0.0	-11.6	-23.3	-34.9	-46.6	-58.2	-69.8	-81.5	-93.1	-104.8	-116.4

For example: For L_n = 20 feet at 25 °C, the temperature correction is -0.001 16 inches.

Table B-2. Temperature Correction Factors for Calibration of Steel Tapes graduated in meters when linear coefficient of thermal expansion for the tape is 0.00001160 / ºC. All values in meters x 10^{-6}

L_n Meters	Temperature, °C											
	19	20	21	22	23	24	25	26	27	28	29	30
0.1	0.1	0.0	-0.1	-0.2	-0.3	-0.4	-0.5	-0.6	-0.7	-0.8	-0.9	-1.0
0.2	0.2	0.0	-0.2	-0.4	-0.6	-0.8	-1.0	-1.2	-1.4	-1.6	-1.7	-1.9
0.3	0.3	0.0	-0.3	-0.6	-0.9	-1.2	-1.5	-1.7	-2.0	-2.3	-2.6	-2.9
0.4	0.4	0.0	-0.4	-0.8	-1.2	-1.6	-1.9	-2.3	-2.7	-3.1	-3.5	-3.9
0.5	0.5	0.0	-0.5	-1.0	-1.5	-1.9	-2.4	-2.9	-3.4	-3.9	-4.4	-4.8
0.6	0.6	0.0	-0.6	-1.2	-1.7	-2.3	-2.9	-3.5	-4.1	-4.7	-5.2	-5.8
0.7	0.7	0.0	-0.7	-1.4	-2.0	-2.7	-3.4	-4.1	-4.8	-5.4	-6.1	-6.8
0.8	0.8	0.0	-0.8	-1.6	-2.3	-3.1	-3.9	-4.7	-5.4	-6.2	-7.0	-7.8
0.9	0.9	0.0	-0.9	-1.7	-2.6	-3.5	-4.4	-5.2	-6.1	-7.0	-7.9	-8.7
1	1.0	0.0	-1.0	-1.9	-2.9	-3.9	-4.8	-5.8	-6.8	-7.8	-8.7	-9.7
2	1.9	0.0	-1.9	-3.9	-5.8	-7.8	-9.7	-11.6	-13.6	-15.5	-17.5	-19.4
3	2.9	0.0	-2.9	-5.8	-8.7	-11.6	-14.6	-17.5	-20.4	-23.3	-26.2	-29.1
4	3.9	0.0	-3.9	-7.8	-11.6	-15.5	-19.4	-23.3	-27.2	-31.0	-34.9	-38.8
5	4.8	0.0	-4.8	-9.7	-14.6	-19.4	-24.3	-29.1	-34.0	-38.8	-43.6	-48.5
10	9.7	0.0	-9.7	-19.4	-29.1	-38.8	-48.5	-58.2	-67.9	-77.6	-87.3	-97.0
15	14.6	0.0	-14.6	-29.1	-43.6	-58.2	-72.7	-87.3	-101.9	-116.4	-131.0	-145.5
20	19.4	0.0	-19.4	-38.8	-58.2	-77.6	-97.0	-116.4	-135.8	-155.2	-174.6	-194.0
25	24.3	0.0	-24.3	-48.5	-72.7	-97.0	-121.3	-145.5	-169.8	-194.0	-218.3	-242.5
30	29.1	0.0	-29.1	-58.2	-87.3	-116.4	-145.5	-174.6	-203.7	-232.8	-261.9	-291.0

For example: For L_n = 4 meters at 25 °C, the temperature correction is -0.000 019 4 meters.

Appendix C

Supplemental Information

C.1. Cleaning

To clean a steel tape before calibration, first wipe the tape with a soft cloth; then with a soft cloth saturated with alcohol to remove the film of oil used to protect the tape.

After calibration, a thin film of light oil, such as sewing machine oil, should be applied to the tape for protection.

C.2. Tolerances

The tolerances for measuring tapes are those stated below.

Table C-1. Tolerances for a 30 meter tape.

Length Interval	Tolerances
0 through 15 meters	1.27 mm (0.050 inch)
15 through 22 meters	1.91 mm (0.075 inch)
22 through 30 meters	2.54 mm (0.100 inch)

C.2.1. The inaccuracy in the length of the ribbon, when supported on a horizontal surface with a tension of 10 pounds at a temperature of 20 °C (68 °F) shall not exceed 0.050 inch for the 75 foot length, and 0.100 inch for the 100 foot length.

C.3. Tension Specifications

The length of a tape will be affected by the temperature of the tape, the tension applied to the tape, and the manner in which the tape is supported. The tape will stretch when tension is applied and will return to its normal length when the tension is removed, provided the tape has not been permanently deformed when it was stretched. The tensions, at which steel tapes are to be calibrated, expressed in terms of the load in kilograms (or pounds) to be applied to obtain the tension, are stated below. The loads should be accurate within 45 g (0.01 lb).

Table C-2. Tension to be applied, in terms of load.

Length Interval	Tension
Less than 10 m (25 ft)	2 kg (3.5 lb)
10 m through 30 m (25 ft through 100 ft)	5 kg (10 lb)
Greater than 30 m (100 ft)	10 kg (20 lb)

C.4. Methods of Support and Tension Considerations

Tapes calibrated in a State laboratory are normally supported on a horizontal surface throughout the entire length of the tape. Also, tapes may be calibrated and used when supported in catenary types of suspension. In these cases, the tape is supported at equidistant points because the weight of the tape affects its length. The weight of the tape increases the tension and the “sag” causes the horizontal length to be shorter than when the tape is supported throughout its length. Equations are given in GMP No. 10 to compute the horizontal straight-line distance of a tape supported at N number of equidistant catenary suspensions and for computing the tension of accuracy, defined as the tension that must be applied to the tape interval to produce its designated nominal length at the observed temperature of the tape.

It is sufficient to provide the user of a steel tape with the calibrated length of the tape under standard temperature and tension conditions, the weight per unit-length of the tape, and the AE value for the tape, as might be requested. This information will enable the user to compute the values desired using the equations cited above.

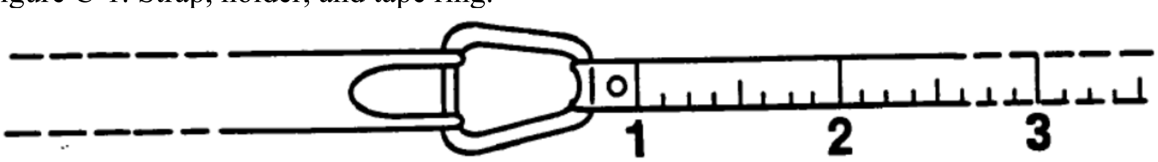
C.5. Zero Reference Point

Metal measuring tapes submitted to a State laboratory for calibration normally will be made of steel. Generally, these tapes will have a ring on the end of the tape. For maximum calibration and measurement accuracy, a tape should have a blank end between the ring and the zero graduation. The zero graduation is then more precisely defined and more easily referenced for calibration and use.

Tapes that have the ring as part of the measuring portion of the tape are more difficult to calibrate than a tape with a blank end. When the ring is part of the measuring portion of the tape, the zero reference point shall be the outside end of the ring unless otherwise specified. It is more difficult to obtain a good zero reference setting on the ring due to its curvature and to parallax in reading the edge of the ring against a reference mark. Additionally, the ring may become permanently deformed in use and change the length of the tape. For these tapes the NIST normally calibrates from the 1-foot mark over the length of the tape, and then calibrates from the ring to the 1-foot mark. These values are reported separately so the user can obtain maximum measurement accuracy by using the 1-foot graduation as the zero reference point.

When the ring is part of the measuring range of the tape, a special holder for the ring is needed to clamp the tape to the length bench. A strap with an open area in the middle is needed to permit the end of the ring to be seen. The strap is slipped through the ring and the strap is clamped to the length bench. See example below.

Figure C-1. Strap, holder, and tape ring.



The edge of the tape to be calibrated (the reading edge) is the edge nearest the observer when the zero graduation is to the observer's left. When viewed through a microscope, some graduations will appear to have irregular edges. The portion of the graduation to be used for calibration is the portion of the graduation at the bottom of the reading edge of the tape. This provides a reference point that can be repeated and referenced by others. Do not attempt to estimate the 'best overall' edge of a graduation because this is not easily repeatable and cannot be accurately reproduced by other. If the graduations to be calibrated do not reach to the edge of the tape, the tape should not be calibrated**.**

C.6. Temperature Considerations

The reference temperature for length calibrations is 20 °C. The length of the tape can be determined at any other temperature T by using the following equation.

$$L_T = L_{20}\left[1 + \alpha(T - 20)\right] \qquad \text{(C-1)}$$

Since α is always positive, it can be seen that for temperatures above 20 °C, the tape is longer than it is at 20 °C. For temperatures below 20 °C, the tape is shorter than it is at 20 °C.

If two length standards have different coefficients of expansion because they are made of different materials, the lengths of the tapes will change at different rates as the temperature changes. If two tapes are being compared at a temperature other than 20 °C, these lengths must be corrected back to 20 °C for calibration.

If two length standards are being compared and they have the same coefficient of expansion, then as the temperature changes the lengths will change by the same amount. Hence, if the standards are compared at a temperature other than 20 °C, the relationship between the two standards will be the same as if they were being compared at 20 °C; thus, no temperature correction is needed.

Table C-3. Coefficient of expansion of various length standards.

Type	**/°C**	**/°F**
Steel tape	11.60×10^{-6}	6.45×10^{-6}
Length bench	10.63×10^{-6}	5.91×10^{-6}
Invar tape	4.0×10^{-7}	2.2×10^{-7}

C.7. Invar tapes

Invar is an alloy of nickel and steel. Invar tapes are used to obtain measurements of greater accuracy than can be made with steel tapes, because invar has a very low coefficient of expansion. It has the added benefit of being very slow to tarnish from exposure to the atmosphere. However, invar tapes require very careful handling to prevent twists and kinks.

The load to be applied to an invar tape to maintain the desired tension is normally 20 lb. A load of 40 lb is used for the higher tension to determine the AE value (see C.8.). For metric tapes, the normal load is 5 kg. A load of 10 kg is used to determine the AE value.

C.8. AE Value

The AE Value (area elongation value) for a tape is determined by first calibrating the tape under its normal tension. The load is then increased by10 lb or 20 lb and one length interval is recalibrated to determine the length of the tape under the increased tension. The AE factor is computed with the following equation.

$$AE = \frac{Q_1 - Q_0}{L_1 - L_0} L_n \qquad \text{(C-2)}$$

For example, a 100 foot tape is calibrated from 0 feet to 100 feet with a load of 10 lb applied to the tape with a resulting length of 99.992 feet. The load is increased to 20 lb and the new length is found to be 100.004 feet. The AE value is:

$$AE = \frac{(20\,lb - 10\,lb)}{(100.004 - 99.992)} 100\ feet = \frac{1000\,lb\ feet}{0.012\ feet} = 83333\,lb$$

It is recommended that the AE value be determined over the longest interval that is convenient to measure. This minimizes the error in the AE value because of the better readability of the change in length

C.9 Weight per Unit Length

The weight per unit length of a tape can be determined as follows:

C.9.1. Weigh the tape and reel (or case).

C.9.2. Remove the tape from the reel or case and weigh the empty reel (or case).

C.9.3. Measure the length of any blank ends on the tape and add this to the measuring length.

C.9.4. Correct for the weight of the loop on the tape. The weight of the loop that is normally used on steel tapes is approximately 2.5 grams.

The weight per unit length is the computed as follows.

$$Weight\ per\ Unit\ Length = \frac{Weight\ of\ loaded\ reel - weight\ of\ empty\ reel - weight\ of\ loop}{length\ of\ tape + length\ of\ blank\ ends}$$