

Recommended Standard Operations Procedure for
Calibration of Metal Tapes
Bench Method

1. Introduction

1.1. Purpose of Calibration

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 inches, and to 6 decimal places for measurements expressed in units of meters. The calibrated length bench is used as the standard.

1.2. Prerequisites

- 1.2.1. Verify that the calibrations for the length bench scale and the thermometers are available and valid at the time of measurement.
- 1.2.2. Verify that the ocular microscope used in measuring differences in lengths is in good working order.
- 1.2.3. Verify that the technician has been trained in the use of this method. Note that 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. Methodology

2.1. 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 the reference temperature of 20 °C, as required, using formulas or tables which are provided. All data are recorded, using the forms contained in Appendix A. 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.

2.2. Apparatus

- 2.2.1. Two thermometers, capable of indicating temperatures in the range of 15 to 30 °C, and accurate to ± 0.5 °C.
- 2.2.2. A 16-foot, (5-meter) bench with attached calibrated length scale.
- 2.2.3. Optical microscope with ocular scale having dimensions spaced at 0.002 inch intervals.
- 2.2.4. Clamps and weights to apply an appropriate tension to the tape under calibration. (See "Tension Specifications", in Appendix C.3.

2.3. Procedure

- 2.3.1. Clean the tape 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.)
- 2.3.2. Lay two thermometers (see 2.2.1) on the bench at intervals of $1/3$ and $2/3$ of the length of the bench to determine its temperature at the time of the test.
- 2.3.3. Place the clamp at the zero end of the bench so that the zero mark on the tape is near the zero graduation on the length bench. Note: When the ring is part of the measuring tape, a special clamp-holder must be used. See Appendix C.5 for further information on this matter.
- 2.3.4. 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 desired. (See Appendix C.3.)
- 2.3.5. Adjust the tape clamp on the zero end of the bench so that the tape zero graduation 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 and interpret all following instructions accordingly.
- 2.3.6. Check all alignments and coincidence of zero graduations 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 such as the one included in the Appendix.

- 2.3.7. Record the temperatures indicated by the two thermometers.
- 2.3.8. Place the ocular microscope on the bench in the vicinity of the zero position and align it so that its scale is parallel to the tape under test. (See GMP No. 2 for instructions on how to make readings.)
 - 2.3.8.1. Observe readings of left and right sides of zero graduation of tape and record to the nearest .001 inch.
 - 2.3.8.2. Observe readings of left and right sides of zero graduation of bench and record to the nearest .001 inch.
- 2.3.9. Move ocular microscope successively to each graduation that needs to be calibrated and record readings similarly as in 2.3.8.1 and 2.3.8.2.
- 2.3.10. Return ocular microscope to the zero graduation and repeat readings to verify that the tape has not moved. Accept all previous data if present zero reading does not disagree with previous reading by more than 0.001 inch; otherwise, discard all previous data and repeat entire sequence of readings until a satisfactory set is obtained.
- 2.3.11. Remove 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.
- 2.3.12. Make a second set of measurements as directed in 2.3.8, 2.3.9, and 2.3.10.
- 2.3.13. Record the temperatures indicated by the two thermometers.
- 2.3.14. After all measurements are completed, apply a thin film of oil to the tape.

2.4. Calculations

- 2.4.1. Calculate X_m and S_m for each series of measurements and for each scale interval, as follows:

$$X_m = \frac{\text{(right edge reading of tape + left edge reading of tape)}}{2}$$

$$S_m = \frac{\text{(right edge reading of bench + left edge reading of bench)}}{2}$$

Record at appropriate places on the data/worksheet.

- 2.4.2. Calculate $d = X_m - S_m$ for each scale interval, and record on the data/worksheet.
- 2.4.3. Obtain the correction to the standard, C_s , from the calibration certificate for the length bench scale and tabulate. Note: If the 1-foot mark or other mark is used as the reference mark, the correction must be made, taking this into account.
- 2.4.4. Calculate the temperature correction, K , from the equation

$$K = L_n [(T-20) (a_s - a_x)]$$

where

a_s = coefficient of linear expansion for the standard bench ($10.63 \times 10^{-6}/^{\circ}\text{C}$)

a_x = coefficient of linear expansion for the tape ($11.60 \times 10^{-6}/^{\circ}\text{C}$)

L_n = nominal length of tape interval under test

In this equation, T is the average of the four temperature readings described in Sections 2.3.7 and 2.3.11. In the case of steel tapes, the value for K may be obtained from the table in Appendix B.

- 2.4.5. Calculate a correction, C_x , for each trial and each scale interval.

$$C_x = d + C_s + K$$

- 2.4.6. Calculate and report the mean, \bar{C}_x , of the two corrections for each interval.
- 2.4.7. Compute the absolute difference between the two corrections for each interval and record as R on the worksheet.
- 2.4.8. Compute the length of the tape under the 10 lb. load as

$$L_o = L + \bar{C}_x$$

3. Determination of AE Value

- 3.1. Replace the tension weight (10 pound) used in 2.3.4 with a 20 pound weight (or with one 10 pounds heavier than that used in the original calibration).
- 3.2. Adjust the coincidence of the zero graduation as was done in 2.3.5.
- 3.3. Adjust the tape so that it lies flat and parallel to the bench scale.
- 3.4. Check the zero graduation coincidence and readjust if necessary.

- 3.5. Record zero readings as instructed in 2.8.
- 3.6. Record readings at the longest scale interval of the bench measured under the original tension, as instructed in 2.3.9.
- 3.7. Take a second series of measurements as described in 3.5 and 3.6.
- 3.8. Repeat appropriate calculations and compute the length of the tape under 20 lb. load as

$$L_1 = L + \bar{C}_x$$

- 3.9. Compute the AE value using the equation

$$AE = \frac{Q_1 - Q_0}{L_1 - L_0} L_n$$

where

- AE - cross sectional area times Young's modulus of elasticity
- Q₀ - the lower load applied to the tape (e.g., 10 lb.)
- Q₁ - the higher load applied to the tape (e.g., 20 lb.)
- L₀ - the length of the tape under load Q₀ (mean of two measurements)
- L₁ - length of the tape under load Q₁ (mean of two measurements)
- L_n - nominal length of the interval under test

4. Determination of Weight-per-Unit Length

- 4.1. Weigh the tape and reel (or case) to ± 0.1 g. (W₁)
- 4.2. Remove the tape from the reel or case and weigh the empty reel or case to ± 0.1 g. (W_c)
- 4.3. Measure the length of any blank ends on the tape to ± 0.01 foot. (L_B)
- 4.4. Use the nominal value 2.5 g for the weight of the loop normally used on steel tapes. (W_L) If a larger or smaller loop is used, its weight should be estimated or the weight of the loop should be obtained from the tape manufacturer.
- 4.5. Compute the weight-per-unit length using the equation

$$\text{Weight/length} = \frac{W_1 - W_C - W_L}{L_T + L_B}$$

where

- W₁ - weight of tape plus reel (or case)
- W_C - weight of reel (or case)
- W_L - weight of loop (2.5 g)
- L_T - graduated length of tape
- L_B - length of blank ends

5. Assignments of Uncertainty

- 5.1. The uncertainty, U_c , of a correction (the mean of two measurements) is given by the expression

$$U_c = \pm U_s + \frac{ts}{\sqrt{2}}$$

Where U_s is the uncertainty assigned for the correction for the standard and s represents the estimate of the standard deviation of a single measurement. The value for t (corresponding to a probability level of 99.73%) and the number of degrees of freedom on which s is based will be found in Table 9.3.

- 5.1.1. If control charts are not maintained, s may be estimated from the average range, \bar{R} , of the ranges, R (absolute differences of the measured corrections) over all n intervals. Thus,

$$\bar{R} = \frac{\sum R}{n}$$

and s is estimated by

$$s = \bar{R}/d_2^*$$

The factor d_2^* is obtained by interpolation of the values in Table 9.1. The degrees of freedom, ν , associated with s should be taken as one-half the degrees of freedom shown below the appropriate d_2^* factor in the same table.‡

- 5.1.2. If control charts are maintained and the measurement system is in a state of statistical control, the value of s on which the control limits are based may be substituted in the equation of 5.1 and the corresponding value for ν is used when selecting the value of t to be used.

- 5.1.2.1. If control charts are maintained, the second trial may be eliminated with a somewhat larger random uncertainty of the measurement. An R control chart (difference of duplicates) is recommended and only the zero and one other scale interval (randomly selected) are measured in duplicate. The difference in the C_x values (R) obtained in these control measurements is plotted on the control chart and indication of measurement process control permits

‡Degrees of freedom are reduced approximately by the factor one-half because the same zero interval measurement, are used for each interval estimated. Values should be rounded to the nearest whole number.

the assignment of the process standard deviation to all measurements made at that time in calibrating the rule. The uncertainty, U_c , becomes

$$U_c = \pm [U_g + ts]$$

Note: See Chapter 7.4 for further information on the maintenance and use of R control charts.

APPENDIX A

CALIBRATION OF METAL TAPES - BENCH METHOD

TEST ITEM _____ TAPE MFGR _____

SUBMITTED BY _____ DATE _____

TEMPERATURE: START: TEMP 1 _____ TEMP 2 _____

FINISH: TEMP 3 _____ TEMP 4 _____ AVERAGE TEMP _____

TENSION _____ SUPPORT _____

OBSERVER _____ SHEET NO. _____

COEFFICIENT OF EXPANSION OF UNKNOWN, a_x - _____

COEFFICIENT OF EXPANSION OF STANDARD, a_s - _____

$C_x = d + C_s + K ; K = L_T [(T - 20)(a_s - a_x)]$

NOTE: Coefficient of expansion for steel tape = $11.60 \times 10^{-6}/^{\circ}C$
 Coefficient of expansion for length bench = $10.63 \times 10^{-6}/^{\circ}C$

Interval x_1 s_1	T r i a l	X			S			d^* $x_m - s_m$	Corr'n to Stand. C_s	K^{**} Temp. Corr'n	Corr'n to X C_x	Range of C_x
		Left Edge	Right Edge	Mean x_m	Left Edge	Right Edge	Mean x_s					
X S	1											
	2											
Average, \bar{C}_x												
X S	1											
	2											
Average, \bar{C}_x												
X S	1											
	2											
Average, \bar{C}_x												
X S	1											
	2											
Average, \bar{C}_x												

*Carry average difference to at least four decimal places if average is in inches, carry to at least six decimal places if average is in meters.
 **Carry to at least four decimal places if in inches; at least six decimal places if in meters.

APPENDIX A

CALIBRATION OF METAL TAPES - BENCH METHOD

TEST ITEM Surveyor's Tape 100 ft TAPE MFR Lufkin

SUBMITTED BY ABC Company DATE 8/29/86

TEMPERATURE: START: TEMP 1 22.3 °C TEMP 2 22.4 °C

FINISH: TEMP 3 22.4 °C TEMP 4 22.5 °C AVERAGE TEMP 22.4 °C

TENSION 10-lb load SUPPORT throughout

OBSERVER HO SHEET NO. 1

COEFFICIENT OF EXPANSION OF UNKNOWN, $a_x = 11.60 \times 10^{-6} / ^\circ C$

COEFFICIENT OF EXPANSION OF STANDARD, $a_s = 10.63 \times 10^{-6} / ^\circ C$

$$C_x = d + C_s + K ; K = L_m [(T - 20)(a_s - a_x)]$$

NOTE: Coefficient of expansion for steel tape = $11.60 \times 10^{-6} / ^\circ C$
 Coefficient of expansion for length bench = $10.63 \times 10^{-6} / ^\circ C$

Interval x_1 s_1	T r 1	X			S			d^* $x_m - s_m$	Corr'n to Stand. C_s	K^{**} Temp. Corr'n	Corr'n to X C_x	Range of C_x	
		Left Edge	Right Edge	Mean x_m	Left Edge	Right Edge	Mean s_m						
X 0-10'	1	.204	.218	.211	.215	.221	.218	-.007	+.002	-.00028	-.00528	.0025"	
S 0-10'	2	.182	.197	.1895	.196	.202	.199	-.0095	+.002	-.00028	-.00778		
Average, C_x											-.00653		
X 0-15'	1	.166	.182	.174	.184	.190	.187	-.013	+.003	-.00042	-.01042	.0020"	
S 0-15'	2	.198	.214	.206	.218	.224	.221	-.015	+.003	-.00042	-.01242		
Average, C_x											-.01142		
X 15-20'	1	.160	.174	.167	.168	.174	.171	-.004	-.001	-.00014	-.00514	.0015"	
S 0-5'	2	.144	.159	.1515	.154	.160	.157	-.0055	-.001	-.00014	-.00654		
From 0-20' $C_x = -.01142 + (-.00589) = -.01731$											Average, C_x	-.00559	
X 15-30'	1	.216	.232	.224	.219	.225	.222	.002	+.003	-.00042	.00458	.0020"	
S 0-15'	2	.140	.156	.148	.145	.151	.148	.000	+.003	-.00042	.00258		
From 0-30' $C_x = -.01142 + .00358 = -.00784$											Average, C_x	.00358	

*Carry average difference to at least four decimal places if average is in inches, carry to at least six decimal places if average is in meters.
 **Carry to at least four decimal places if in inches; at least six decimal places if in meters.

APPENDIX B-1

TEMPERATURE CORRECTION FACTOR FOR CALIBRATION OF STEEL TAPES
(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	-0.1	-0.2	-0.3	-0.5	-0.6	-0.7	-0.8	-0.9	-1.0	-1.2
2	0.2	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	-0.3	-0.7	-1.0	-1.4	-1.7	-2.1	-2.4	-2.8	-3.1	-3.5
4	0.5	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	-0.6	-1.2	-1.7	-2.3	-2.9	-3.5	-4.1	-4.7	-5.2	-5.8
6	0.7	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	-0.8	-1.6	-2.4	-3.3	-4.1	-4.9	-5.7	-6.5	-7.3	-8.1
8	0.9	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	-1.0	-2.1	-3.1	-4.2	-5.2	-6.3	-7.3	-8.4	-9.4	-10.5
10	1.2	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	-1.7	-3.5	-5.2	-7.0	-8.7	-10.5	-12.2	-14.0	-15.7	-17.5
20	2.3	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	-3.5	-7.0	-10.5	-14.0	-17.5	-21.0	-24.4	-27.9	-31.4	-34.9
40	4.7	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	-5.2	-10.5	-15.7	-21.0	-26.2	-31.4	-36.7	-41.9	-47.1	-52.4
50	5.8	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	-7.0	-14.0	-21.0	-27.9	-34.9	-41.9	-48.9	-55.9	-62.9	-69.8
70	8.1	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	-8.7	-17.5	-26.2	-34.9	-43.6	-52.4	-61.1	-69.8	-78.6	-87.3
80	9.3	0	-9.3	-18.6	-28.0	-37.2	-46.6	-55.9	-65.2	-74.5	-83.8	-93.1
90	10.5	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	-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 -0.00116 inches.

APPENDIX B-2

VALUES FOR K
 TEMPERATURE CORRECTION FOR CALIBRATION OF STEEL TAPES
 GRADUATED IN METERS
 (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	-0.1	-0.2	-0.3	-0.4	-0.5	-0.6	-0.7	-0.8	-0.9	-1.0
0.2	0.2	0	-0.2	-0.4	-0.6	-0.8	-1.0	-1.2	-1.4	-1.6	-1.7	-1.9
0.3	0.3	0	-0.3	-0.6	-0.9	-1.2	-1.5	-1.7	-2.0	-2.3	-2.6	-2.9
0.4	0.4	0	-0.4	-0.8	-1.2	-1.6	-1.9	-2.3	-2.7	-3.1	-3.5	-3.9
0.5	0.5	0	-0.5	-1.0	-1.5	-1.9	-2.4	-2.9	-3.4	-3.9	-4.4	-4.9
0.6	0.6	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	-0.7	-1.4	-2.0	-2.7	-3.4	-4.1	-4.8	-5.4	-6.1	-6.8
0.8	0.8	0	-0.8	-1.6	-2.3	-3.1	-3.9	-4.7	-5.4	-6.2	-7.0	-7.8
0.9	0.9	0	-0.9	-1.7	-2.6	-3.5	-4.4	-5.2	-6.1	-7.0	-7.9	-8.7
1.0	1.0	0	-1.0	-1.9	-2.9	-3.9	-4.8	-5.8	-6.8	-7.8	-8.7	-9.7
2.0	1.9	0	-1.9	-3.9	-5.8	-7.8	-9.7	-11.6	-13.6	-15.5	-17.4	-19.4
3.0	2.9	0	-2.9	-5.8	-8.7	-11.6	-14.6	-17.5	-20.4	-23.3	-26.2	-29.1
4.0	3.9	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	-4.8	-9.7	-14.6	-19.4	-24.2	-29.1	-34.0	-38.8	-43.6	-48.5
10	9.7	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	-14.6	-29.1	-43.6	-58.2	-72.8	-87.3	-101.8	-116.4	-131.0	-145.5
20	19.4	0	-19.4	-38.8	-58.2	-77.6	-97.0	-116.4	-135.8	-155.2	-174.6	-194.0
25	24.2	0	-24.2	-48.5	-72.8	-97.0	-121.2	-145.5	-169.8	-194.0	-218.2	-242.5
30	29.1	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 -0.0000194 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 in the Federal Specification, "Tapes, Measuring (General Use)" which is Federal Spec. GGG-T-106D dated November 12, 1969. Steel tapes of lengths 25, 50, 75, and 100 feet fall under Type II class 3. The tolerances are stated in section 3.8.2.6 and given below for reference.

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

Tolerances for a 30-meter tape are given below.

<u>Length Interval</u>	<u>Tolerance</u>
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.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 pounds (or kilograms) to be applied to obtain the tension, are as follows:

lengths less than 25 feet (10 m)	3 1/2 lb (2 kg)
lengths of 25 ft through 100 ft (10 m - 30 m)	10 lb (5 kg)
lengths greater than 100 feet (30 m)	20 lb (10 kg)

The loads should be accurate within 0.1 lb (45 g).

