SOP No. 12

Recommended Standard Operating Procedure
for
Calibration of Metal Tapes[1]
Tape-to-Tape Method

I. 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. The accuracy of the measurement often must be provable to 0.000 1 meter on a 100 meter tape (0.000 1 foot on a 100 foot tape), sometimes in a court of law. A significant feature of such proof is the knowledge of the accurate length of the tape used. 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 by comparison to a calibrated standard tape.

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 operator must be trained and experienced in precision measuring techniques with specific training in GMP 8, GMP 9, SOP 12, and SOP 29.

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

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[1] Many references are provided in in-pound units due to common use in U.S. weights and measures requirements. The International System of Units, SI, is the official system of units for metrological traceability.

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 method is applicable to the calibration of metal tapes such as used by surveyors, builders, and contractors. The overall length and specified intermediate lengths may be checked by the technique. The accuracy is limited by the accuracy of the calibration of the standard tape and by the precision of intercomparison. The latter should be within ± 0.001 foot, corresponding to 10 parts per million in a 100 foot tape. The method is limited to calibration of steel tapes (because the tension is specified as the result of a 10 pound load).

2.2. Summary

This procedure is based upon the method developed by C. Leon Carroll Jr., National Bureau of Standards, NBSIR 74-451, "Field Comparisons of Steel Surveyors' Tapes."

The tape to be calibrated is stretched out parallel to a standard tape on a reasonably flat surface. Paper scales (graph paper), graduated in millimeters are used at the zero and at each specified interval of calibration to measure any difference between the two tapes. The length of the tape undergoing calibration is computed from the known length of the standard tape and the observed differences between the test tape and the standard.

Calibrations are usually made at each 1 foot interval for the first 10 feet, and at each 10 foot interval to the full length of the tape.

2.3. Apparatus/Equipment Required

2.3.1. Standard tape, calibrated to within ± 0.001 foot.

2.3.2. Pieces of graph paper (10 x 10 to the centimeter, i.e., millimeter graduations), approximately 5 cm in width by 15 cm in height. Number the horizontal centimeter graduations, 0, 1, 2, etc.. Evaluate and document the range of use to within 0.1 mm using a calibrated rigid rule or a microscope with calibrated reticles to ensure that the graph paper has sufficient accuracy.

2.3.3. Equipment, see Figure 1, to apply tension to the tapes under test, consisting of the following.

2.3.3.1. Spring scales (two); one capable of indicating a load of 10 pounds and the other capable of indicating a load of 20 pounds. The scales should be calibrated with an accuracy of ± 0.1 lb. This may be done by the arrangement shown in Figure 2 with results internally documented.

2.3.3.2. Turnbuckles, suitable for adjusting tension on the tapes.

2.3.3.3. Swivel connectors to prevent axial twisting of the tapes.

2.3.3.4. Magnifying glass to aid in reading the graph paper values.

2.3.3.5. Small weights (< 5 lb) to hold the tapes down flat to the paper.

Figure 1. Experimental Arrangement.

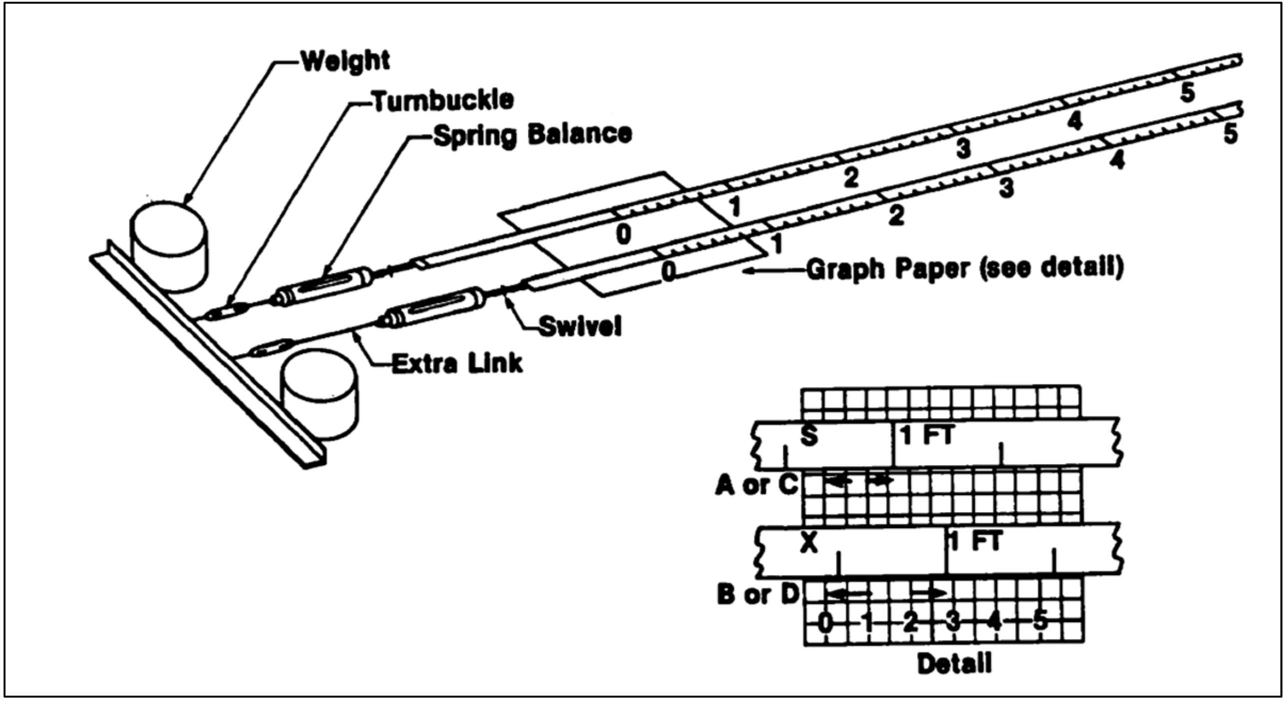
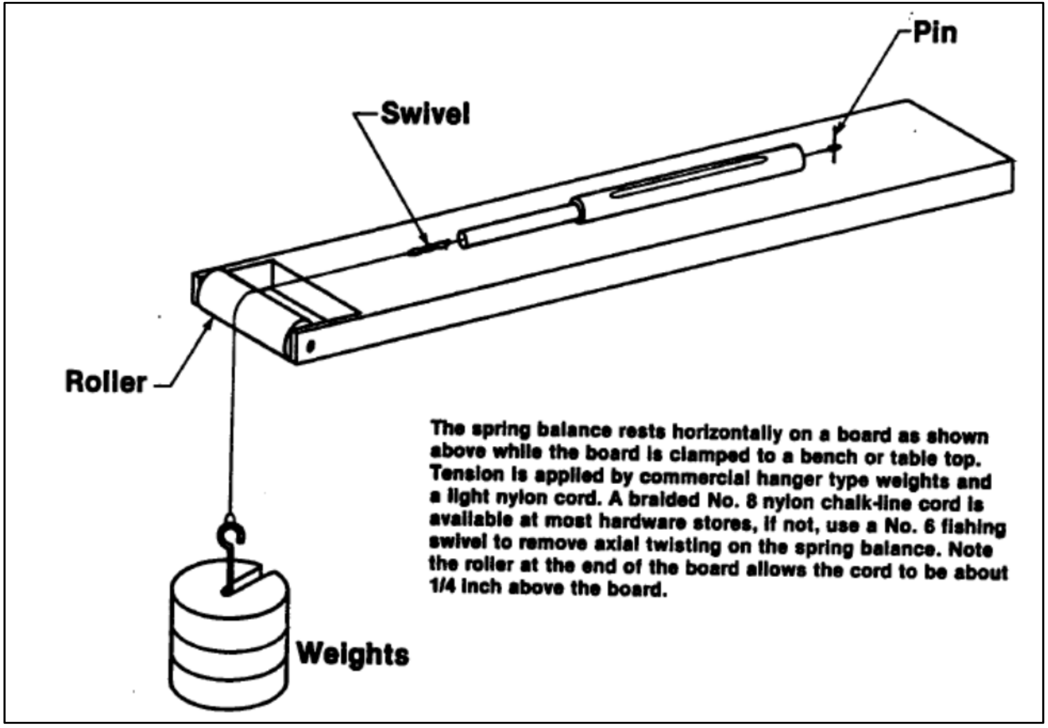


Figure 2. Calibration of Spring Scales.



The spring balance rests horizontally on a board as shown above while the board is clamped to a bench or table top. Tension is applied by commercial hanger type weights and a light nylon cord. A braided No. 8 nylon chalk-line cord is available at most hardware stores, if not, use a No. 6 fishing swivel to remove axial twisting on the spring balance. Note the roller at the end of the board allows the cord to be about 1/4 inch above the board.

2.4. Symbols

Table 2. Symbols used in this procedure.

Symbol	Description
S	Length of the Standard Tape at the calibration interval
L_X	Length of the Test Tape at the calibration interval
cf	Conversion factor, 0.032 808 ft/cm for tapes graduated in feet 0.010 000 m/cm for tapes graduated in meters
L_n	Nominal length of tape interval under test
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 tapes to ensure that no kinks, dents, or other damage are present which will affect the accuracy of the calibration.

2.5.2. Clean the tapes by first wiping with a soft cloth, and then with a soft cloth saturated with alcohol to remove protective oil film.

2.5.3. Stretch the test tape and standard tape parallel to each other on a reasonably flat surface. The evenness of the surface is less important than the parallelism of the tapes. The two tapes should be separated by a constant distance of about 1 to 3 centimeters. The zero and test intervals of the two tapes should not be in coincidence but rather displaced by one or two centimeters, as indicated in the detail of Figure 1.

2.5.4. Use the turnbuckles to apply equal loads of 10 pounds to the two tapes as indicated by the spring scales. (Note the use of swivels to prevent axial twisting.)

2.5.5. Place a piece of graph paper under the zero interval and each interval to be calibrated as shown in the detail in Figure 1. Adjust the tapes and the paper so that the former are precisely aligned with the lateral rulings of the paper. It is convenient but not necessary for these to be the bold centimeter rulings of the paper. Note the amount of separation of the tapes at the zero interval and make corresponding adjustments at each calibration interval of interest. In this way, parallelism of the two tapes is easily verified.

2.5.6. Make final adjustment of tensions on the tapes and recheck for parallelism at all test points before taking the readings described in 2.5.7. Do not disturb during the measurement sequence.

2.5.7 Read the distances A, B, C, and D as indicated in the detail of Figure 1. Note that A and B are for the zero (or first) interval and are the same for all test intervals. C and D have subscripts 1, 2, etc. corresponding to the interval, *i*, calibrated. Make all readings to the center of the graduation mark tested and estimate to the closest 0.1 mm. Record all readings in centimeters.

2.5.8. Record all measurements as Trial 1.

2.5.9. Release the tension to the tapes and reapply it.

2.5.10. Displace each piece of graph paper a few millimeters, then readjust the load, check for parallelism, and record a second series of measurements as Trial 2.

2.5.11. Release the tension to the tapes and reapply it.

2.5.12. Displace each piece of graph paper a few millimeters, then readjust the load, check for parallelism, and record a second series of measurements as Trial 3.

2.5.13. After all measurements are completed; apply a thin film of oil to the tapes.

3. Calculations

3.1. Calculate and record A – B – C + D for each trial, then record the value of R, the range of these values (difference of highest and lowest) for each scale interval. The range should not exceed 0.15 cm. Sum the values for A, B, C, D for the three trials to use when calculating the length, L, of each interval.

3.2. The value obtained from ΣA – ΣB – ΣC + ΣD must equal the sum of the column A – B – C + D, otherwise an error has been made in the calculations.

3.3. Calculate the length of the test tape at each calibration interval according to the following equation.

$$L_X = S + \frac{cf}{3}\Sigma(A - B - C + D) \tag{1}$$

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 3 Trials 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.

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

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_{gp}	Standard uncertainty for graph paper	Must be assessed experimentally
u_{tw}	Standard uncertainty for the spring scales	Must be assessed experimentally or from a 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 tapes	Must be assessed experimentally
u_o	Standard uncertainty for other factors	

6. Report

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

Appendix A

Tape-to-Tape 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	
S				
X				
Tension		lb		

Interval	Trial	A	B	C	D	A-B-C+D			
	1						$\frac{cf}{3}\Sigma(A-B-C+D)$	S	L
	2								
	3								
	Σ								
					Range				
	1						$\frac{cf}{3}\Sigma(A-B-C+D)$	S	L
	2								
	3								
	Σ								
					Range				
	1						$\frac{cf}{3}\Sigma(A-B-C+D)$	S	L
	2								
	3								
	Σ								
					Range				
	1						$\frac{cf}{3}\Sigma(A-B-C+D)$	S	L
	2								
	3								
	Σ								
					Range				
	1						$\frac{cf}{3}\Sigma(A-B-C+D)$	S	L
	2								
	3								
	Σ								
					Range				
	1						$\frac{cf}{3}\Sigma(A-B-C+D)$	S	L
	2								
	3								
	Σ								
					Range				

Appendix B

Supplemental Information

B.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.

B.2. Tolerances

The tolerances for measuring tapes are those stated below.

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

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

B.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.

B.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 B-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)

B.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.

B.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 B-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**.**

B.6. Temperature Considerations

No temperature correction is required, provided the test tape and the standard tape are at the same temperature and of the same material. This will be the case when the measurements are made inside a building. Tapes of the same color would be expected to attain the same temperature, even in sunlight. However, black and white tapes have shown temperature differences of as much as 8 °C when exposed to direct sunlight. In such cases, the temperature differences, even when measured, would be uncertain due to variability of exposure along the length of the tape. Accordingly, calibrations in the laboratory are preferred, when possible.

B.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.

B.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.

$$AE = \frac{Q_1 - Q_0}{L_1 - L_0} L_n \tag{B-1}$$

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:

$$AE = \frac{(20\,lb - 10\,lb)}{(100.004 - 99.992)} 100\ feet = \frac{1\,000\,lb\ feet}{0.012\ feet} = 83\,333\,lb$$

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

B.9 Weight per Unit Length

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

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

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

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

B.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.

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