SOP No. 12

Recommended Standard Operations Procedure for

Calibration of Steel Tapes

Tape-to-Tape Method

1. Introduction

1.1. Purpose of Test

The accuracy of a surveyor's measurement often must be provable to 100 ppm (sometimes in a court of law). A significant feature of such proof is the knowledge of the accurate length of the tape used. This procedure describes a technique which will provide such information, by comparison of a tape with a calibrated standard tape.

1.2. Prerequisites

1.2.1. Verify that a valid calibration certificate is available for the standard tape used.

1.2.2. Verify the availability of all equipment necessary to make the test.

1.2.3. Verify that the person performing the calibration is capable of making basic measurements of length, using steel tapes and has been trained in the use of this procedure.

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 intervals 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 end and at each specified interval of calibration to measure any differences 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. Equipment

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

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.

2.3.3. Equipment, such as shown in Figure 1, to apply a load to the tapes under test, consisting of:

2.3.3.1. Spring scales (two) one capable of indicating a load of 10 pounds and the other to 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.

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.

2.4. Procedure

2.4.1. Set up an experimental arrangement similar to that shown in Figure 1. The ends of the tapes (not shown) are held in place by suitable anchor pins.

2.4.2. Stretch the test tape and standard tape <u>parallel</u> to each other on a reasonably flat surface such as the corridor of a building or the surface of a parking lot. 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.

2.4.3. 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.)

2.4.4. Place a piece of the 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.

2.4.5. Make final adjustment of tensions on the tapes and recheck for parallelism at all test points before taking the readings described in 2.4.6. Do not disturb during the measurement sequence.

2.4.6. 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.

2.4.7. Record all measurements on an observation sheet such as that provided in the Appendix of this SOP as First Trial.

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

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

2.4.10. Readjust as in 2.4.8 and record a third series of measurements as Third Trial.

2.5. Calculations

2.5.1. 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.

2.5.2. The value obtained from $\Sigma A - \Sigma B - \Sigma C + \Sigma D$ must equal the sum of the column A - B - C + D, otherwise an error has been made in the calculations.

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

$$L = S + \frac{k}{3} \Sigma (A - B - C + D)$$

where L = length of test tape at the calibration interval

S = length of standard tape at the calibration interval

k = Conversion factor, tape interval/scale interval, i.e.,

k = 0.032808 ft/cm for tapes graduated in feet

and k = 0.010000 m/cm for tapes graduated in meters

2.6. Temperature Correction

No temperature correction is required, provided the test tape and the standard tape are at the same temperature. 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 difference, even if measured, would be uncertain due to variability of exposure along the length of the tape. Accordingly, calibrations in the laboratory are preferred, when possible.

2.7. Measurement of the AE Value

2.7.1. Apply a load of 20 pounds to the test tape while maintaining a load of 10 pounds on the standard tape.

2.7.2. Measure the difference of length over a relatively large interval as described in 2.4. (ordinarily, the maximum interval is chosen).

2.7.3. Calculate the AE value using the equation

$$AE = \frac{10\ L_n}{\frac{k}{3}\left[\Sigma(A-B-C+D)_{20} - \Sigma(A-B-C+D)_{10}\right]}$$

where L_n is the nominal value for the interval and all other symbols are the same as those used earlier. The subscripts 10 and 20 signify the readings observed for the respective tensions applied to the test tape.

2.8. Determination of Weight-per-Unit Length

2.8.1. Weigh the tape and reel (or case) to ± 0.1 g. (W_1)

2.8.2. Remove the tape from the reel or case and weigh the empty reel or case to ± 0.1 g. (W_c)

2.8.3. Measure the length of any blank ends on the tape to ± 0.01 foot. (L_B)

2.8.4. 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.

2.8.5. Compute the weight-per-unit length using the equation

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

where

W_1 = 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

2.9. Assignment of Uncertainty

Calculate the uncertainty, U_c of the calibration, using the following equation

$$U_c = U_s + U_I$$

where U_s = uncertainty of the standard

U_I = uncertainty of the intercomparison measurement.

The uncertainty of intercomparison can be estimated from the average range, R, of the three replicate measurements at each calibration point, as follows:

$$\bar{R} = \frac{(R_1 + R_2 + R_3 + \cdots + R_k)}{k}$$

where k = number of points calibrated. The estimate of the standard deviation, s, is calculated as follows

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

The value for d_2^* to be used can be found in Table 9.1. The degrees of freedom ν associated with s_R should be taken as one-half the degrees of freedom shown below the appropriate d_2^* factor in the same Table.[§]

The uncertainty of intercomparison, U_I, is calculated as follows:

$$U_I = \frac{t\,\bar{R}}{\sqrt{3}\,d_2^*}$$

The value for t which can be found in Table 9.3 depends on the number of degrees of freedom, ν, associated with s and the confidence level desired. For example, for 19 calibration points, $\nu \approx 18$ and $t = 3.475$ for a 99.73% confidence level.

Accordingly, in this case,

$$U_I = \frac{3.475\bar{R}}{\sqrt{3}\,d_2^*}$$

This uncertainty would be applicable to each of the intervals calibrated.

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

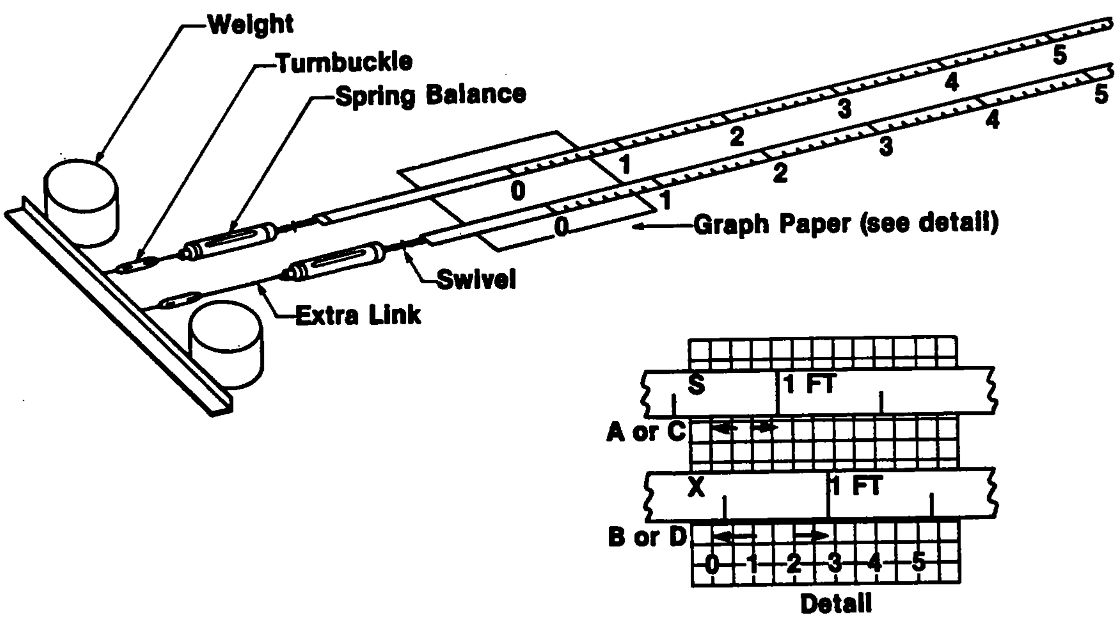

Figure 1. Experimental Arrangement

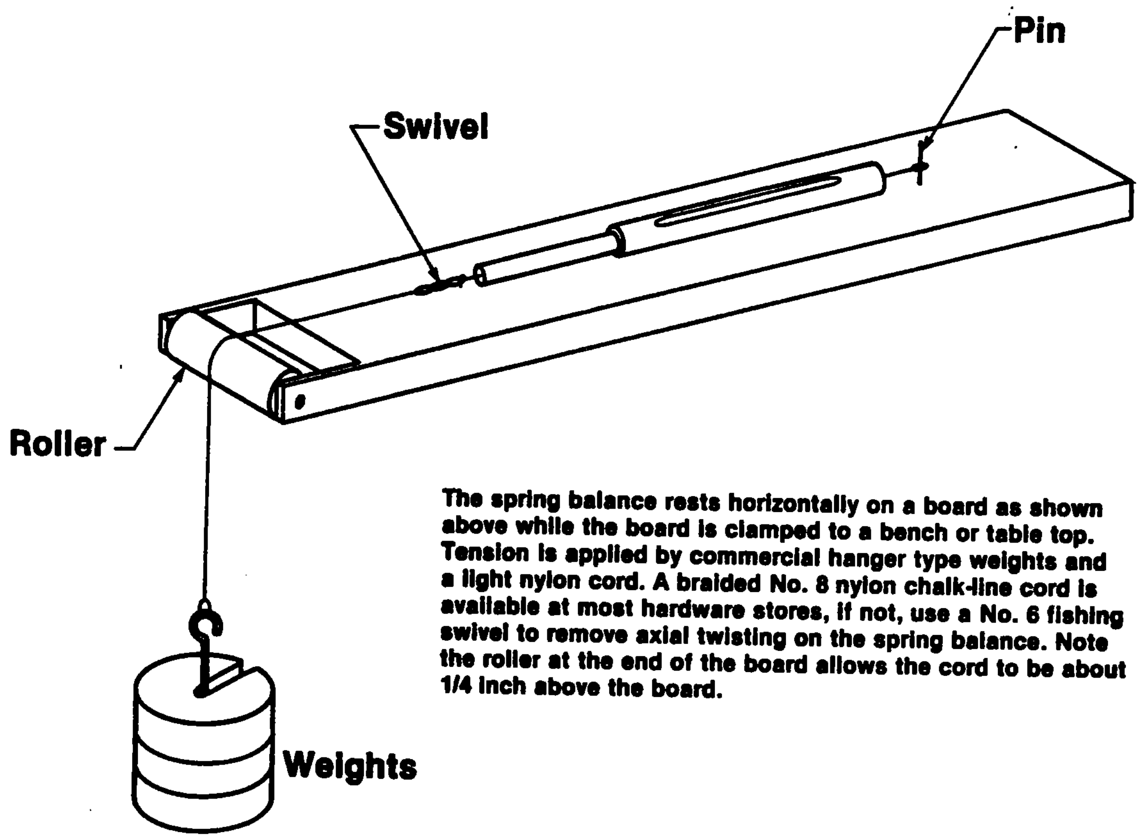

Figure 2. Calibration of Spring Scales.

Appendix

OBSERVED DATA AND CALCULATIONS OF THE LENGTH (L) OF A STEEL SURVEYOR TAPE BASED ON A COMPARISON TO A CALIBRATED STANDARD TAPE

Standard Tape

Manufacuturer ______________________
Serial No. ______________________
Temp. Coef. Exp., α= ______________
Weight/Length __________ AE= ______LB
Material/Color/Finish ______________

Test Tape

Manufacturer ______________________
Serial No. ______________________
Temp. Coef. Exp., α= ______________
Weight/Length __________ AE= ______LB
Material/Color/Finish ______________
Applied Load For Tension ______LB

Observed Data (in cm)

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

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

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

Interval	Trial	A	B	C	D	A-B-C+D
	1					
	2					
	3					
	Σ					
					Range, R	

$\frac{k}{3}\Sigma(A-B-C+D)$	S	L

Interval	Trial	A	B	C	D	A-B-C+D
	1					
	2					
	3					
	Σ					
					Range, R	

$\frac{k}{3}\Sigma(A-B-C+D)$	S	L

Interval	Trial	A	B	C	D	A-B-C+D
	1					
	2					
	3					
	Σ					
					Range, R	

$\frac{k}{3}\Sigma(A-B-C+D)$	S	L

Interval	Trial	A	B	C	D	A-B-C+D
	1					
	2					
	3					
	Σ					
					Range, R	

$\frac{k}{3}\Sigma(A-B-C+D)$	S	L

Appendix

OBSERVED DATA AND CALCULATIONS OF THE LENGTH (L) OF A STEEL SURVEYOR TAPE BASED ON A COMPARISON TO A CALIBRATED STANDARD TAPE

Standard Tape

Manufacuturer Lufkin
Serial No. #5678
Temp. Coef. Exp., α = 11.60 x 10^{-6}/°C

Weight/Length 0.0147lb/ft AE = 128000LB
Material/Color/Finish steel/black/gloss

Test Tape

Manufacturer Lufkin
Serial No. #1234
Temp. Coef. Exp., α = 11.60 x 10^{-6}/°C

Weight/Length 0.0147/lb/ft AE = ______ LB
Material/Color/Finish steel/white/gloss
Applied Load For Tension 10 LB

Observed Data (in cm)

Interval	Trial	A	B	C	D	A-B-C+D	$\frac{k}{3}\Sigma$(A-B-C+D)	S	L
0-30′	1	0.83	3.08	2.43	4.65	-0.03			
	2	0.22	2.44	3.37	5.55	-0.04			
	3	0.69	2.93	2.03	4.23	-0.04			
	Σ	1.74	8.45	7.83	14.43	-0.11	-.00120 ft	30.0012	30.0000 ft
					Range, R	0.01			

Interval	Trial	A	B	C	D	A-B-C+D	$\frac{k}{3}\Sigma$(A-B-C+D)	S	L
0-50′	1	0.83	3.08	5.12	7.28	-0.09			
	2	0.22	2.44	5.99	8.12	-0.09			
	3	0.69	2.93	5.84	8.03	-0.05			
	Σ	1.74	8.45	16.95	23.43	-0.23	-.00252 ft	50.00167	49.99915 ft
					Range, R	0.04			

AE test

Load on unknown = 20 lb

Interval	Trial	A	B	C	D	A-B-C+D	$\frac{k}{3}\Sigma$(A-B-C+D)	S	L
0-50′	1	1.80	2.54	4.82	5.62	0.06			
	2	1.25	1.98	5.34	6.17	0.10			
	3	0.60	1.38	4.39	5.17	0.00			
	Σ	3.65	5.90	14.55	16.96	0.16	0.00175 ft	50.00167	50.00342 ft
					Range, R	0.10			

$$AE = \left(\frac{10}{50.00342 - 49.99915}\right) 50$$

AE ≈ 117000 lb