NBSIR 74-451

Field Comparisons of Steel Surveyors' Tapes

C. Leon Carroll, Jr.

Institute for Basic Standards
National Bureau of Standards
Washington, D. C. 20234

November 1973

Final

U. S. DEPARTMENT OF COMMERCE

NATIONAL BUREAU OF STANDARDS

NBSIR 74-451

FIELD COMPARISONS OF STEEL
SURVEYORS' TAPES

C. Leon Carroll, Jr.

Institute for Basic Standards
National Bureau of Standards
Washington, D. C. 20234

November 1973

Final

Field Comparisons of Steel Surveyors' Tapes

C. Leon Carroll, Jr.

The accuracy of a surveyor's measurement must often be provable to
100 ppm (sometimes in a court of law) and a significant feature of
such proof is his knowledge of his tape length under specified con-
ditions. This paper describes a technique which will provide such
knowledge. The technique is an easily performed comparison between
his tape and a calibrated standard tape (perhaps borrowed from a
State Weights and Measures Laboratory). This scheme has been tried
out at the National Bureau of Standards under a number of
conditions likely to be encountered in the field, and the results
of these tests did not differ significantly from a comparison in
our tape laboratory conducted under ideal conditions and using
state-of-the-art apparatus. Traceability to NBS is established by
the calibration genealogy of the standard tape.

A calibration activity measures and certifies the actual length of
the standard tape at 68°F under ten pounds tension. Given access
to such a standard tape, the surveyor may determine the actual
length of his own tape. Although his experiment will not
necessarily be conducted at 68°F, his data will reflect length at
68°F to an accuracy appropriate to 100 ppm survey work if his tape
and the standard tape have similar thermal, elastic and geometric
properties. These required conditions exclude a comparison between
a steel and an invar tape because of grossly different thermal pro-
perties. The surface finishes of the tapes should be similar if
the comparison is made in the direct sunlight.

The comparison experiment, shown schematically by the sketch on the
specimen data sheet, figure 1, consists of measuring the difference
in lengths between the standard and test tapes. If the certified
length of the standard tape is S, and A, B, C and D the measure-
ments indicated on the sketch, then the length of the test tape, L,
at 68°F under the tension applied during the comparison is given by

$$L = S + [A - B - C + D]K$$

where K is the coefficient relating the units of the small end
scales to the tape units (1 Foot = 304.8 millimeters).

The details of the experimental setup are shown in figures 3 and 4.
No effort should be made to align the ends of the two tapes to co-
incidence. However, keep the tapes as close to the end scales as
possible to reduce reading errors due to parallax. Graph paper

placed directly under the tapes is superior. Experience has shown that residual errors associated with failure to achieve perfect coincidence are larger than those associated with measurements of lack of coincidence. Millimeter graduations on the small end scales are far more practical than any other commonly used graduation interval (e.g. 64ths or 10ths of an inch). This is because the normal eye can estimate to 1/10 of a millimeter with an assurance of about 0.15 millimeter using a low-power handheld magnifier. The errors injected into the overall comparison experiment by the imperfections in inexpensive millimeter scales are insignificant in this experiment. The end scale requirements are:

(1) That the graduations of the two edges of the small scale start at a common "zero."

(2) That the small end scales will be required to measure a distance of no more than about an inch by insuring that the end point graduations on the two tapes are separated by no more than about an inch along their lengths.

(3) For convenience of observation (estimating 1/10 mm) the thickness of the graduation lines be no more than about 1/10 the graduation interval. Good quality graph paper satisfies this requirement adequately.

Survey measurements to 100 ppm allow for errors of 0.12 inch per hundred feet. Although it is unlikely that errors of as much as one-third of this allowance could occur in the comparison experiment, good practice demands a redundancy of measurements. The specimen data sheet (figure 1) requires three independent measurements of the difference between the two tape lengths. Requirements are satisfied by moving both end scales after a round of observations on A, B, C and D.

If the surveyor customarily makes only one field measurement of a distance (for example, from a bench mark to a fence), then the comparison experiment is adequately performed by filling out and calculating one data sheet (i.e. three determinations). On the other hand, if his customary practice is to make the measurement twice and report the average value, then he should fill out two data sheets and use the average of the two values of L obtained thereby.

As pointed out above, the certified value, S, of the standard tape refers to its length at 68°F and ten pounds tension. The similarity between the thermal properties (that is, the temperature

coefficients of expansion of the two tapes) eliminates the requirement to conduct the experiment at 68°F. The tension applied to the two tapes, however, must be carefully measured. The tension in the standard tape must be ten pounds inasmuch as this is the certification tension. Our experimental setup is shown in figures 3 and 4. It is noted that we also used a spring balance (checked as shown in figure 2) to tension our test tape to the ten pound level, however, this is not required. The comparison experiment is perfectly valid regardless of the tension, Q, applied to the test tape. The surveyor may apply any amount by any tensioning device of his choice. Inasmuch as the value of L (calculated above) is valid only at tension Q, the surveyor will normally stretch his tape to a tension of Q during practical field measurements.

There are times at which the surveyor will prefer to stretch his tape to the "tension of accuracy," Q_A. This is the amount of tension which causes his tape to assume a length of "exactly" 100 feet at the tape temperature during the field measurement. Q_A at tape temperature T may be calculated from an algebraic combination of Q and L (as determined in the comparison test) with α and AE (two of the constants associated with the tape and obtainable from the manufacturer)

$$Q_A = Q + AE[1 - 0.01(L) - \alpha(T-68)]$$

where α is the temperature coefficient of expansion of the tape in feet per foot per degree F, and AE is the effective product in pounds force of Young's modulus of elasticity of the tape by its cross section area.

From years of experience we have found that .00000645 is an adequate value for α of steel tapes. The surveyor may check the manufacturer's estimate of the AE product by a simple extension of the comparison experiment. From the initial experiment he has determined that a value of L exists at a tension of Q. He must now determine, from a second comparison, a second value of L, namely L_1, which exists when the test tape is stretched by a tension of Q_1. The tension of the standard tape remains at ten pounds during both comparisons. Ordinarily, Q_1, should be about ten pounds greater than Q. From Q, Q_1, L and L_1 he may calculate AE.

For example, suppose the surveyor has found that at Q=10 pounds, L=99.998₄ feet. This is illustrated in figure 5 showing an actual NBS comparison experiment conducted on an asphalt driveway. If a second comparison (conducted at Q_1=20 pounds) yielded a value of L_1=100.006, then

$$AE = \frac{(Q_1 - Q)100}{L_1 - L} = 132,000 \text{ pounds (force)}$$

which is in adequate with the manufacturer's estimate.

- 3 -

It should be carefully noted that T in the formula for Q_A is the temperature of the tape. If the tape is shielded from the direct rays of the sun, the ambient air temperature may be used without unacceptable errors in Q_A. If the tape is exposed to the direct sunlight, the actual tape temperature may be thirty or more degrees Fahrenheit above ambient, in which case the tape temperature must be measured by a tape thermometer (obtainable from tape manufacturers). We have found that a mercury thermometer covered by a surface similar to that of the tape will indicate a temperature approximating that of the tape. Thus, black friction tape (for use with a black measuring tape), or white filament type tape (for use with a white measuring tape) will force a mercury thermometer to approximate the measuring tape temperature. In direct sunlight we have found a 15°F difference in the temperature of a black tape (hotter) and a white one (colder) with bare stainless steel and bare brass between these two extremes. Our measurements were made in the summer (75-85°F ambient), and these radiant effects are probably much greater during the winter in a cold ambient.

For tapes longer than 100 feet, each 100 foot interval may be compared as described above. It should be mentioned that each such interval should be subjected to the same test tension, Q.

Figures 5, 6, 7 and 8 show the results of comparisons between the same two tapes under various conditions likely to be encountered in the field. The results are tabulated on the following page, all values referring to a ten pound tension on the test tape.

EXTERNAL CONDITIONS	AMBIENT TEMP	TAPE LENGTH	RAW DATA
Asphalt parking lot and driveway with a 5% grade in bright sunlight.	88°F	99.998_4 ft.	Fig. 5
On grass alongside brick building -- mostly shade, some sun.	82°F	100.000_2 ft.	Fig. 6
On cement platform of truck scale and extending through doors to outside of scale house on cement approach.	78°F	99.998_4 ft.	Fig. 7
On vinyl tile hallway in basement of Metrology Building.	72°F	99.999_{-2} ft.	Fig. 8
Comparison conducted in tape laboratory under ideal controlled conditions.	68°F	99.999 ft.	Not Shown

The spread of field data is $.001_8$ feet, or about 20 ppm, all points being in good agreement with the laboratory experiment.

While the completed data sheet is normally adequate, it may be required to provide further documentation. The following wording is suggested:

"This is to certify that the tape (manufacturer, serial number, type) marked (see below) has been tested in accordance with the procedure outlined in NBSIR Report No. 73-408. These tests were conducted with reference to a standard tape owned by (owner) which was calibrated by the National Bureau of Standards under Test Number _____. The length of the tape tested was found to be _____ feet under _____ pounds tension at 68°F with the tape supported throughout its length."

- 5 -

This report should be dated and signed by the surveyor (or some other designated person in the organization). The supporting data should be retained on file. If it is felt that tested tapes should be marked for identification, suitable marking can be done with etching ink commercially available.

US COMM—NBS—DC

OBSERVED DATA AND CALCULATIONS OF THE LENGTH (L) OF A STEEL SURVEYOR TAPE AT 68°F BASED ON A FIELD COMPARISON TO A CALIBRATED STANDARD TAPE

DATE_____ TIME_____ AIR TEMP_____ SKY/WEATHER_____
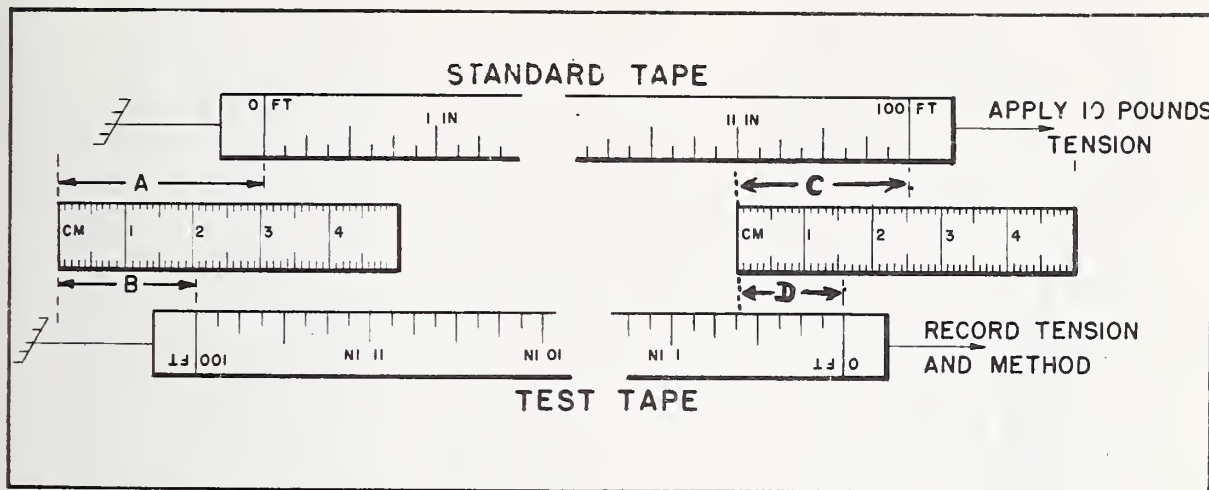
STANDARD TAPE

TEST TAPE

STANDARD TAPE

Manufacturer_____Serial_____

Temp.Coef.Exp.=α=_____FT/FT/°F

WT/FT=W=_____LBS AE=_____LBS

Material/Color/Finish_____

Certified Length at 68°F Under a Tension of

10 pounds (S=)_____feet

TEST TAPE

Manufacturer_____Serial_____

Temp.Coef.Exp.=α=_____FT/FT/°F

WT/FT=W=_____LBS AE=_____LBS

Material/Color/Finish_____

Applied Tension_____POUNDS

Tension Method_____

Observed Data (in cms)

	A	B	C	D	(A - B - C + D)*
First Trial					
Second Trial					
Third Trial					

ΣA=_____ ΣB=_____ ΣC=_____ ΣD=_____
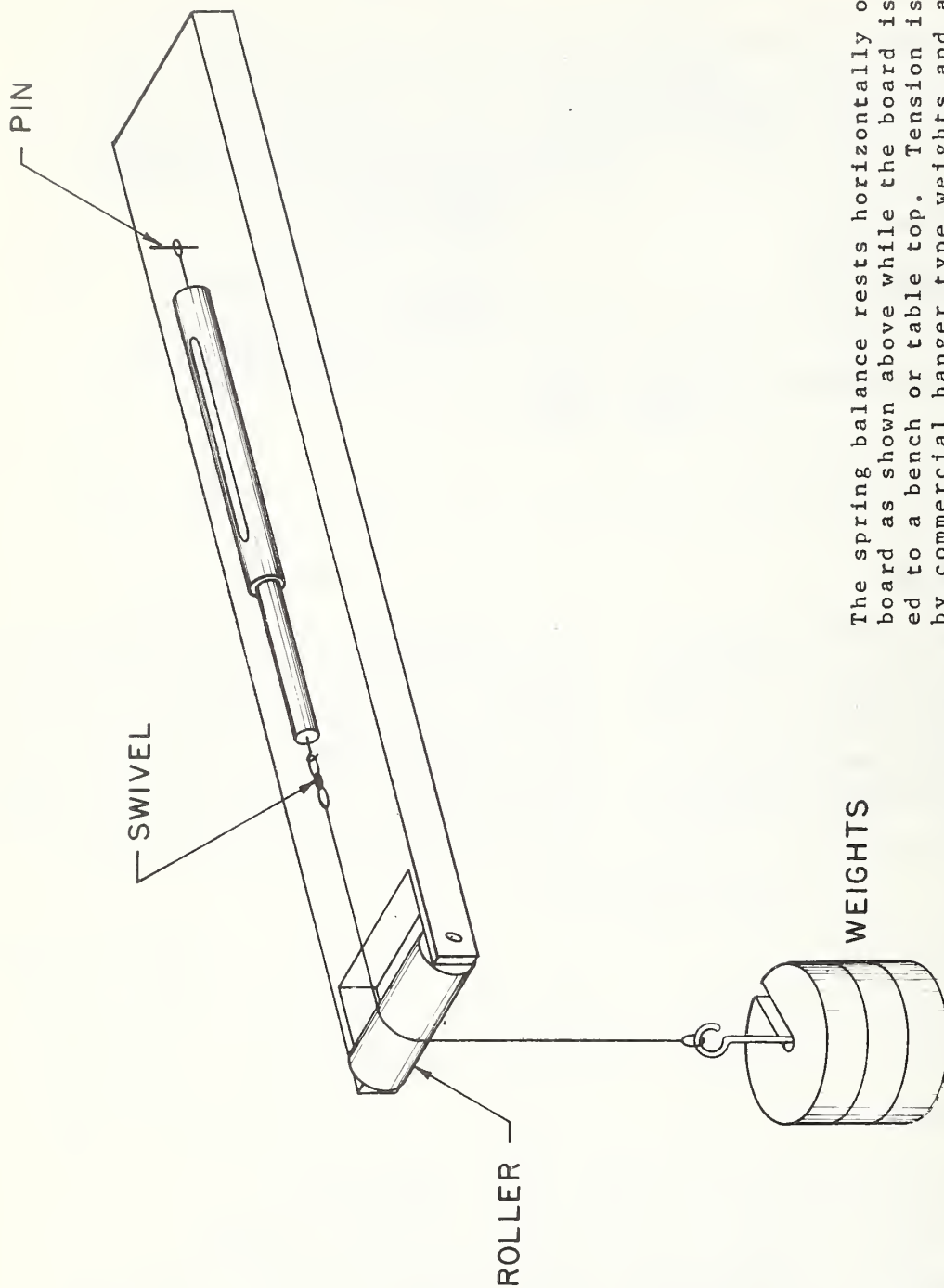
L = S + .010936 [ΣA - ΣB - ΣC + ΣD] = _____feet

*This is a check calculation. In the absence of gross blunders these three values would normally differ by no more than about 0.15.

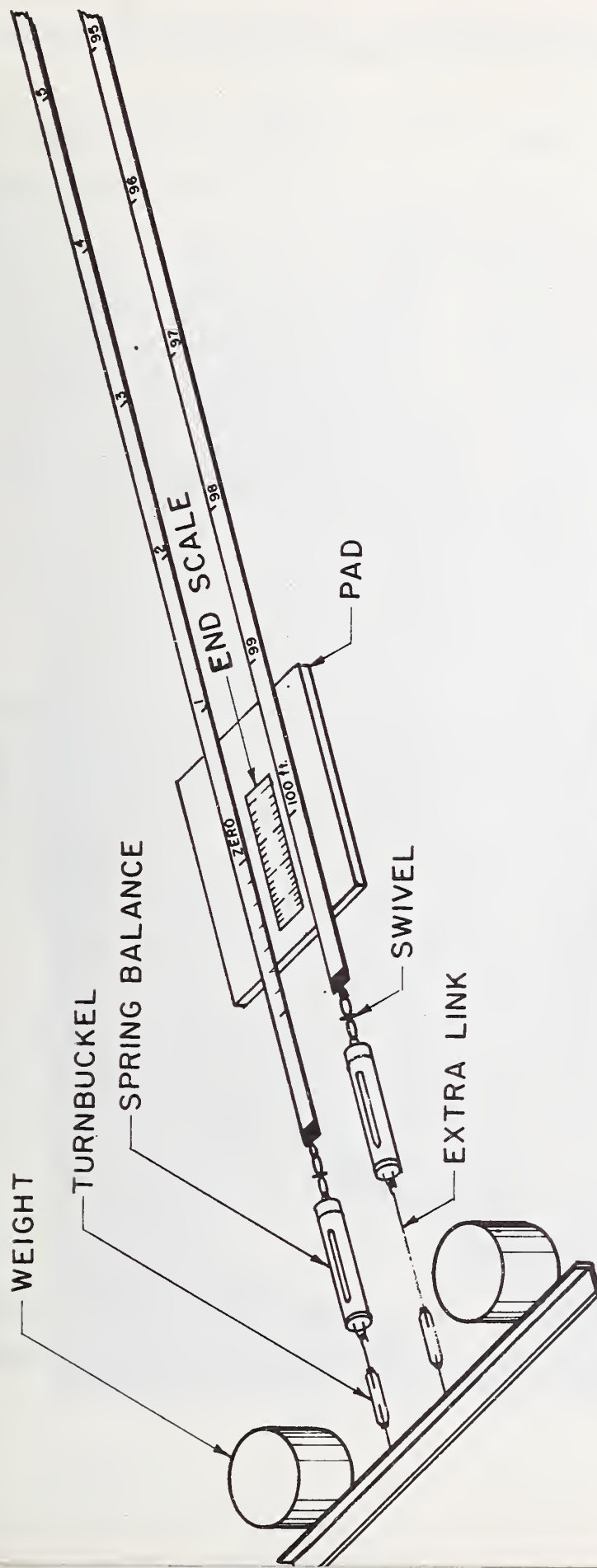REMARKS (Show calibration genealogy of the standard tape and describe conditions surrounding comparison).

FIGURE 1   OBSERVER_____

PIN

SWIVEL

ROLLER

WEIGHTS

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.

FIGURE 2

WEIGHT

TURNBUCKEL

SPRING BALANCE

END SCALE

ZERO

100 ft.

PAD

SWIVEL

EXTRA LINK

95

96

97

98

99

5

4

3

2

1

The test tape and standard tape lie next to each other
with the small end scales between the tapes as shown
above on the same supporting surface. Most comparisons
will have one tape lying in the opposite direction to
bring the tape graduations as close to the end scale as
possible. The short pad brings the thin scales up to
the same elevation as that of the tapes. Weights or
anchor pins are used at each end of the tapes, while
spring balances indicated the tension applied by the
turnbuckles. Note some times extra linkage may be re-
quired to bring the tape graduation within one inch of
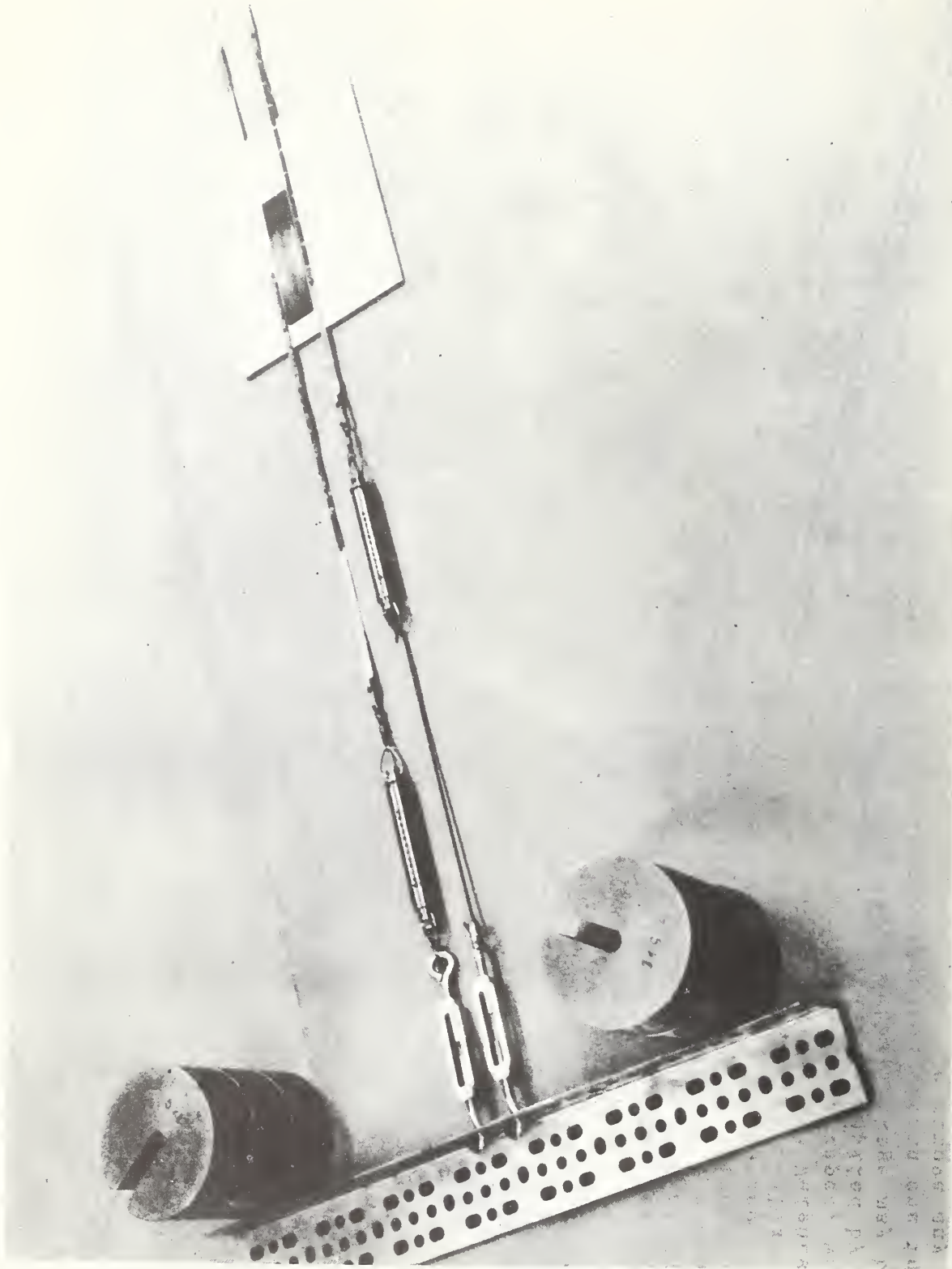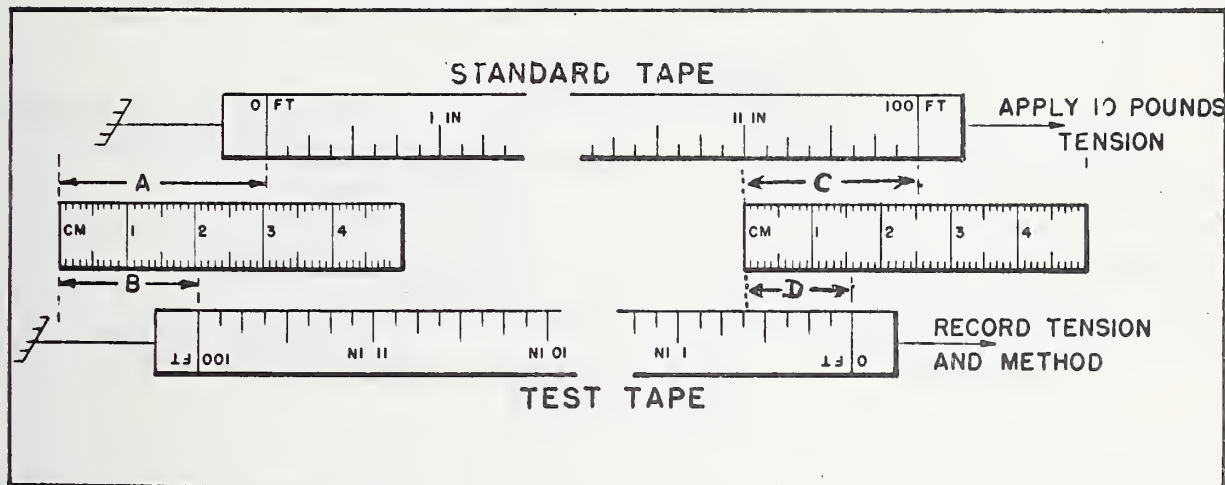each other. Swivels are also used to remove any axial
twisting.

FIGURE 3

FIGURE 4

OBSERVED DATA AND CALCULATIONS OF THE LENGTH (L) OF A STEEL SURVEYOR TAPE AT 68°F BASED ON A FIELD COMPARISON TO A CALIBRATED STANDARD TAPE

DATE _7-18-70_ TIME _10 ^{45}/AM_ AIR TEMP _88_ SKY/WEATHER _CLEAR_

STANDARD TAPE	TEST TAPE
Manufacturer_____Serial_____	Manufacturer_____Serial_____
Temp.Coef.Exp.=α= _0.00000645_ FT/FT/°F	Temp.Coef.Exp.=α= _0.00000645_ FT/FT/°F
WT/FT=W= _0.0147_ LBS AE= _128000_ LBS	WT/FT=W= _0.0142_ LBS AE= _125000_ LBS
Material/Color/Finish _STEEL BLACK GLASS_	Material/Color/Finish _STEEL BLACK GLASS_
Certified Length at 68°F Under a Tension of	Applied Tension _____10_____ POUNDS
10 pounds (S=) _100.001_ feet	Tension Method _SPRING BALANCE_

Observed Data (in cms)

	A	B	C	D	(A − B − C + D)*
First Trial	2.11	1.94	1.72	1.48	− 0.07
Second Trial	2.29	2.13	2.03	1.81	− 0.06
Third Trial	1.97	1.83	1.34	1.09	− 0.11

$\Sigma A=$ _6.37_ $\Sigma B=$ _5.90_ $\Sigma C=$ _5.09_ $\Sigma D=$ _4.38_

$L = S + .010936 [\Sigma A - \Sigma B - \Sigma C + \Sigma D] =$ _99.9984_ feet

*This is a check calculation. In the absence of gross blunders these three values would normally differ by no more than about 0.15.

REMARKS (Show calibration genealogy of the standard tape and describe conditions surrounding comparison).
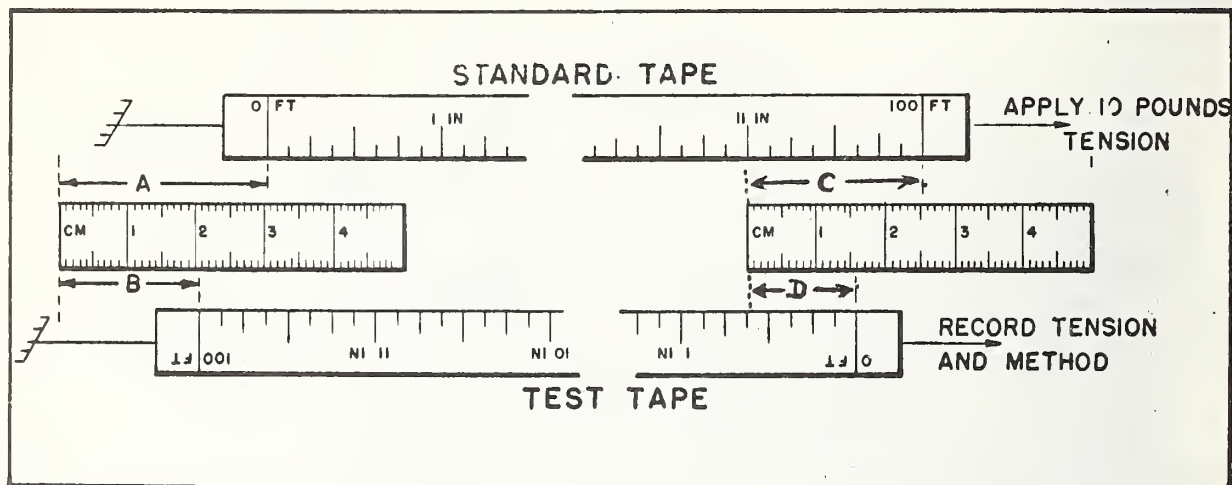
ON ASPHALT PARKING LOT AND DRIVEWAY WITH 5% GRADE

FIGURE 5

OBSERVER _C.L.C. & F.E.S._

OBSERVED DATA AND CALCULATIONS OF THE LENGTH (L) OF A STEEL SURVEYOR TAPE AT 68°F BASED
ON A FIELD COMPARISON TO A CALIBRATED STANDARD TAPE

DATE _7-15-70_ TIME _1 10/PM_ AIR TEMP _82_ SKY/WEATHER _CLEAR (IN SHADE)_

STANDARD TAPE

Manufacturer_____Serial_____

Temp.Coef.Exp.=α= _0.00000645_ FT/FT/°F

WT/FT=W= _0.0147_ LBS AE= _128000_ LBS

Material/Color/Finish _STEEL, BLACK, GLASS_

Certified Length at 68°F Under a Tension of
10 pounds (S=) _100.001_ feet

TEST TAPE

Manufacturer_____Serial_____

Temp.Coef.Exp.=α= _0.00000645_ FT/FT/°F

WT/FT=W= _0.0142_ LBS AE= _125000_ LBS

Material/Color/Finish _STEEL, BLACK, GLASS_

Applied Tension _10_ POUNDS

Tension Method _SPRING BALANCE_

Observed Data (in cms)

	A	B	C	D	(A - B - C + D)*
First Trial	1.72	1.52	1.48	1.26	-0.02
Second Trial	1.37	1.18	1.87	1.63	-0.05
Third Trial	1.87	1.67	1.29	1.07	-0.02

$\Sigma A=$ _4.96_ $\Sigma B=$ _4.37_ $\Sigma C=$ _4.64_ $\Sigma D=$ _3.96_

$L = S + .010936 [\Sigma A - \Sigma B - \Sigma C + \Sigma D] =$ _100.000_2 feet

*This is a check calculation. In the absence of gross blunders these three values would
normally differ by no more than about 0.15.

REMARKS (Show calibration genealogy of the standard tape and describe conditions surrounding
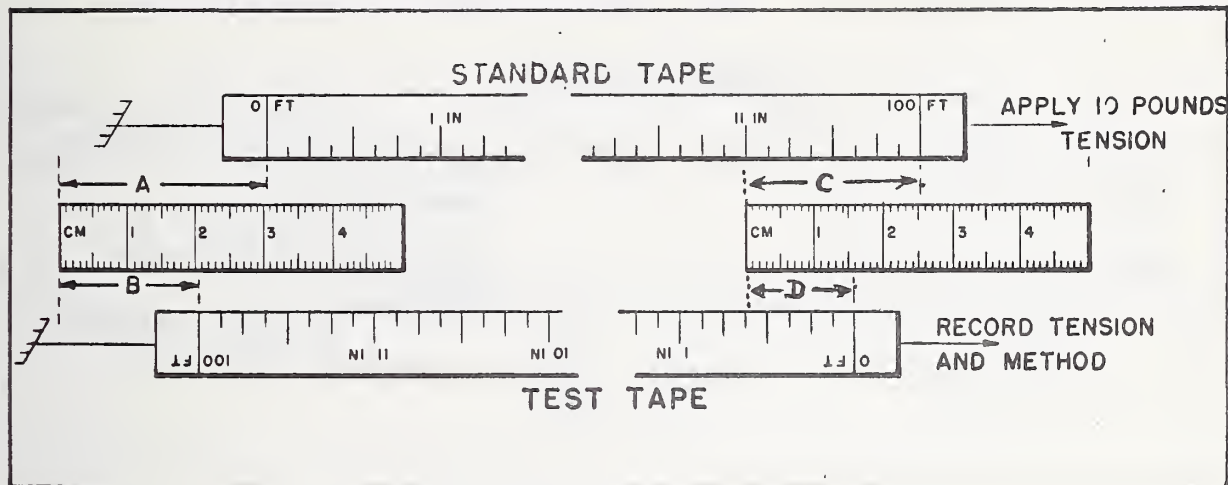comparison).

ON GRASS AT SHADY SIDE OF BUILDING AND ONE END OF
TAPE IN BRIGHT SUNLIGHT

FIGURE 6

OBSERVER _CLC, & FES_

OBSERVED DATA AND CALCULATIONS OF THE LENGTH (L) OF A STEEL SURVEYOR TAPE AT 68°F BASED
ON A FIELD COMPARISON TO A CALIBRATED STANDARD TAPE

DATE _7-15-70_ TIME _9 10/AM_ AIR TEMP _78_ SKY/WEATHER _CLEAR_

STANDARD TAPE   TEST TAPE

Manufacturer_____ Serial_____   Manufacturer_____ Serial_____
Temp.Coef.Exp.=α= _0.00000645_ FT/FT/°F   Temp.Coef.Exp.=α= _0.00000645_ FT/FT/°F
WT/FT=W= _0.0147_ LBS AE= _128000_ LBS   WT/FT=W= _0.0142_ LBS AE= _125000_ LBS
Material/Color/Finish _STEEL, BLACK, Gloss_ Material/Color/Finish _STEEL, BLACK, Gloss_
Certified Length at 68°F Under a Tension of Applied Tension _10_ POUNDS
10 pounds (S=)_ _100.001_ feet   Tension Method _SPRING BALANCE_

Observed Data (in cms)

	A	B	C	D	(A – B – C + D)*
First Trial	1.44	1.22	2.49	2.21	– 0.06
Second Trial	1.91	1.72	2.08	1.79	– 0.10
Third Trial	1.68	1.48	1.83	1.55	– 0.08

ΣA= _5.03_   ΣB= _4.42_   ΣC= _6.40_   ΣD= _5.55_

L = S + .010936 [ΣA – ΣB – ΣC + ΣD] = _99.9984_ feet

*This is a check calculation. In the absence of gross blunders these three values would
normally differ by no more than about 0.15.

REMARKS   (Show calibration genealogy of the standard tape and describe conditions surrounding
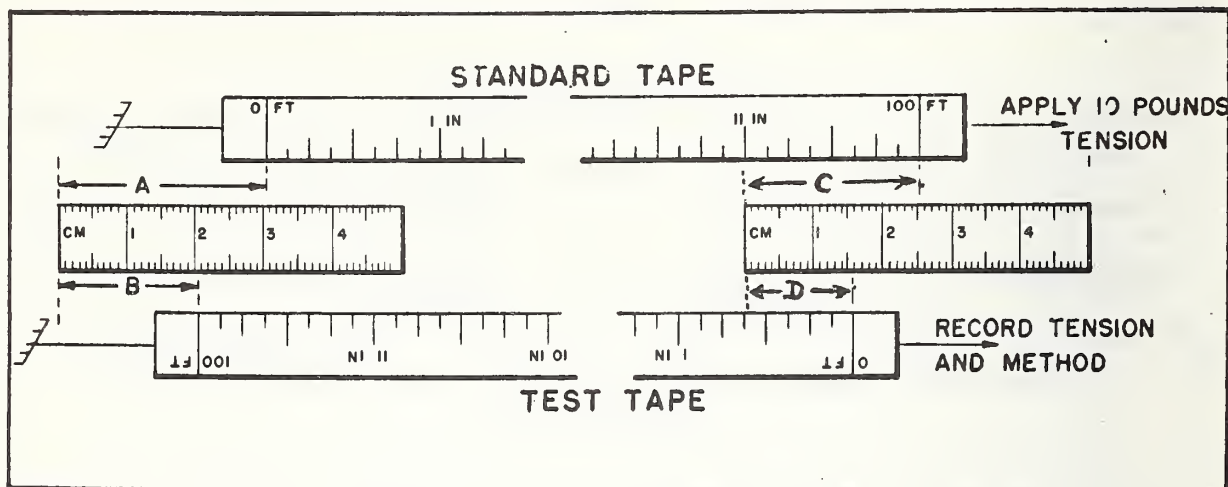   comparison).
    ON CEMENT PLATFORM OF TRUCK SCALE IN SCALE HOUSE AND
TAPES EXTENDING THROUGH DOOR TO OUTSIDE APPROACH RAMP.

        FIGURE 7

                                        OBSERVER _C.L.C. & F.E.S._

OBSERVED DATA AND CALCULATIONS OF THE LENGTH (L) OF A STEEL SURVEYOR TAPE AT 68°F BASED ON A FIELD COMPARISON TO A CALIBRATED STANDARD TAPE

DATE _7-14-70_ TIME _10 05/AM_ AIR TEMP _72_   SKY/WEATHER _INSIDE BLDG_

STANDARD TAPE

APPLY 10 POUNDS TENSION

RECORD TENSION AND METHOD

TEST TAPE

STANDARD TAPE	TEST TAPE
Manufacturer_____Serial_____	Manufacturer_____Serial_____
Temp.Coef.Exp.=α= _0.00000645_ FT/FT/°F	Temp.Coef.Exp.=α= _0.00000645_ FT/FT/°F
WT/FT=W= _0.0147_ LBS AE= _128000_ LBS	WT/FT=W= _0.0142_ LBS AE= _125000_ LBS
Material/Color/Finish _STEEL, BLACK, Gloss_	Material/Color/Finish _STEEL, BLACK, Gloss_
Certified Length at 68°F Under a Tension of	Applied Tension ____10____ POUNDS
10 pounds (S=) _100.001_ feet	Tension Method _SPRING BALANCE_

Observed Data (in cms)

	A	B	C	D	(A − B − C + D)*
First Trial	1.41	1.25	1.89	1.64	−0.09
Second Trial	1.52	1.37	1.51	1.27	−0.09
Third Trial	1.87	1.66	1.80	1.57	−0.02

$$\Sigma A = 4.80 \quad \Sigma B = 4.28 \quad \Sigma C = 5.20 \quad \Sigma D = 4.48$$

$$L = S + .010936 [\Sigma A - \Sigma B - \Sigma C + \Sigma D] = \underline{99.999_{-2}} \text{ feet}$$

*This is a check calculation. In the absence of gross blunders these three values would normally differ by no more than about 0.15.

REMARKS (Show calibration genealogy of the standard tape and describe conditions surrounding comparison).

ON VINYL TILE FLOOR IN BASEMENT

FIGURE 8

OBSERVER _CLC & F.E.S._

U.S. DEPT. OF COMM. BIBLIOGRAPHIC DATA SHEET	1. PUBLICATION OR REPORT NO. NBSIR 73-408	2. Gov't Accession No.	3. Recipient's Accession No.

4. TITLE AND SUBTITLE	5. Publication Date November 1973
Field Comparisons of Steel Surveyors' Tapes	6. Performing Organization Code

7. AUTHOR(S) C. Leon Carroll, Jr.	8. Performing Organ. Report No. NBSIR 73-408

9. PERFORMING ORGANIZATION NAME AND ADDRESS NATIONAL BUREAU OF STANDARDS DEPARTMENT OF COMMERCE WASHINGTON, D.C. 20234	10. Project/Task/Work Unit No.
	11. Contract/Grant No.

12. Sponsoring Organization Name and Complete Address (Street, City, State, ZIP) S A M E	13. Type of Report & Period Covered
	14. Sponsoring Agency Code

15. SUPPLEMENTARY NOTES

This report supercedes NBS Report 10 345

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.)

Report describes a field procedure to compare a steel surveyor's tape to a standard tape that has been calibrated by The National Bureau of Standards. The procedure requires only a hand-held magnifier, two short scales, and two spring balances. Temperature reading device is not required since both tapes are made of steel and have the same temperature during the comparison.

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)

Graduation; length; scale; tape; temperature; tension.

18. AVAILABILITY [x] Unlimited	19. SECURITY CLASS (THIS REPORT)	21. NO. OF PAGES
☐ For Official Distribution. Do Not Release to NTIS	UNCLASSIFIED	14
☐ Order From Sup. of Doc., U.S. Government Printing Office Washington, D.C. 20402, SD Cat. No. C13	20. SECURITY CLASS (THIS PAGE)	22. Price
☐ Order From National Technical Information Service (NTIS) Springfield, Virginia 22151	UNCLASSIFIED	